

Exploring the Emerging Potential of Nutraceuticals from Marine Sources: A Comprehensive Review of Current Trends and Future Prospects

Rima Kundu¹, Moumita Das^{2*}

¹M.Sc., Student, Department of Food & Nutrition, Swami Vivekananda, University, Barrackpore, W.B., India.

²Assistant Professor, Department of Food and Nutrition, Swami Vivekananda University, Barrackpore, W.B., India

***Corresponding E-mail:** moumitadas@svu.ac.in

Abstract

Marine resources represent a rich and underutilized source of bioactive compounds with substantial potential for the development of nutraceuticals. Marine organisms, including algae, fish, mollusks, and marine bacteria, produce unique bioactive molecules that exhibit diverse health benefits, such as antioxidant, anti-inflammatory, immunomodulatory, and antimicrobial properties. Compounds such as omega-3 fatty acids, carotenoids, polyphenols, and peptides are increasingly recognized for their role in supporting human health and preventing chronic diseases, including cardiovascular conditions, neurodegenerative disorders, and metabolic syndromes. With the rising demand for natural, functional foods and dietary supplements, marine-derived nutraceuticals offer a promising alternative to traditional plant-based sources. Various types of fish, such as salmon, tuna, and mackerel, which are rich in omega-3 fatty acids, serve as remedies for different types of diseases. On the other hand, cod liver oil, which is extracted from the liver of codfish, is rich in protein, essential fatty acids, vitamins, and other nutrients. These components are crucial for reducing the risks of heart attacks, strokes, and brain diseases. This review aims to explore various marine derived bioactive compounds and their therapeutic applications for human health. Furthermore,

the study also underscores the importance of sustainable harvesting and biotechnological innovation to ensure the ethical and environmentally responsible exploitation of marine resources for nutraceutical development.

Keywords: *Marine sources; Nutraceuticals; Sustainability; Public health.*

Introduction

Marine bioresources are emerging as prosperous gold mines that can potentially contribute to the marvelous growth of various sectors. Also, the investigation of marine resources is a fertile ground for novel drug discovery. This is because novel compounds can be obtained through chemical transformation and bacterial activities from fish waste. Nutraceutical is a term that represents compounds with medicinal value for the regulation of body functions and the prevention of abnormalities. Pharmacologically, nutraceuticals are key players in important health solutions. The term “nutraceuticals” indicates natural compounds, including nutrient-based supplements, herbal products, and herbomineral products, which provide the necessary nourishment for physiological functions and can therefore be used in a therapeutic context for treating deficiencies of certain vital compounds and disorders. Plant bioresources are classified as nutraceuticals. Dietary supplements and thermogenic agents produce fewer side effects and act equally (Ghosh et al.2022; Rotter et al.2021; Daniotti & Re, 2021).

The present comprehensive review focuses on elaborating the current trends and future perspectives of marine nutraceuticals. Nutraceuticals play a major role in maintaining sound physical health and mental fitness. A combination of nutrition and pharmaceuticals is vital for a good way of living. Cancer, diabetes mellitus, cardiovascular diseases, and neurodegenerative diseases can be regulated by marine nutraceuticals. There are three types of marine nutraceuticals: Marine Food Nutraceuticals, Marine Medicine Nutraceuticals, and Marine Nutri-Phyto-Orthomolecular Nutraceuticals. Researchers are very attentive in finding new

sources of bioactive compounds like fish, shellfish, marine algae, sea cucumber, chitosan, and marine nutraceuticals. These three classes of bioactives have been mentioned as having several physiological benefits in animals and humans. The exoskeleton and scales of marine fish are rich sources of chondroitin 4-sulphate, chondroitin 6-sulphate, dermatan sulphate, heparan sulphate, and heparin. In the exoskeletons of vertebrate animals, chitosan is antisclerotic, antitumor, antiseptic, and it has blood lipid-reducing ability. It has bone healing properties and also provides squid and prawn with calcium coats. Carotenoids are pigments found in salmon and shrimp. Cured and stored fish benefit from marine concentrate nutrients, mainly for the nourishment of minerals. Different marine nutraceuticals include keratin, gelatin, chitosan, collagen, squalene, starch, and others (Kumari et al., 2023; Dama et al.2024).

Nutraceuticals: Definition and Importance

Nutraceutical is a portmanteau of 'nutrition' and 'pharmaceutical', linking together nutrition and medicine, indicating a category of products that can be considered food sources providing health benefits over treating a particular ailment. Thus, the term 'nutraceutical' comprises two words: 'nutrition' and 'pharmaceuticals'. The responsible adverse effects of pharmaceuticals are also remedied with the consumption of nutraceuticals. Nutraceuticals are products, usually natural, with bioactive phyto compounds, and are available in several formulations. They are used in a wide range of role combinations as food supplements or functional foods and beverages. Traced back to the word 'nutra', which is a combination of nutrition and pharmaceutical, the word 'pharmaceutical' simply means drug or medicine. While the word 'nutraceutical' portrays the additive character of these products, nutraceuticals are food or food products that provide health and medical benefits, including the prevention and treatment of diseases. They are 'functional' food components, but also some pharmacological agents used for disease treatment, control, and prevention. Nutraceutical ingredients and foods have gained widespread acceptance and importance as a flavor, pigment, and preservative in

food materials because they impart added health benefits. Nutraceuticals include health-imparting ingredients used in food processing and augment human health and well-being by lowering the risk of chronic diseases. The term nutraceutical is used to describe these medicinally equivalent entities that provide an added barrier against chronic diseases. Nutraceuticals as dietary supplements include examples of nutraceuticals performed in a variety of vitamin settings, such as vitamins and minerals. Nutraceuticals provide medical or health benefits and contribute to chronic disease therapy or prevention. Nutraceuticals may be used to enhance the quality of life, regulate health, retard the aging process, and reduce the risk of specific conditions and illnesses. The nutritional or dietary part of the respective nutraceutical is intended to enhance or streamline the diet and assist in holistic health management. In the present time, in the food sector, nutraceuticals stand as an attractive product category that has proved particularly appealing to consumers and manufacturers. It has shown recent developing trends that illustrate the growth in the nutraceutical market, and the focus of consumers has also been highlighted (Chopra et al.2022; AlAli et al.2021; Puri et al.2022; Maurya et al.2021).

Nutraceuticals are products derived from various food sources that not only meet the nutritional demands of the human body but also contain biological agents that help manage various metabolic disorders. Many regulatory agencies define nutraceuticals in different ways and accordingly frame policies to control or regulate these products. However, nutraceuticals are mainly referred to as products that have physiological benefits or protect human beings from various health problems. In contrast to conventional nutritional supplements, nutraceuticals possess therapeutic, prophylactic, or palliative properties. Furthermore, nutraceuticals are not only essential nutrients or diets but can also be part of drugs, as some drugs contain an edible component in which nutraceuticals can also be included. Nutraceuticals are considered either dietary supplements or functional foods, where dietary supplements are only taken in oral form, while functional foods can be used orally as well as collectively through fortified foods (Damián et al.2022; AlAli et al.2021)

Nutraceuticals have become a part of the fast-moving pioneer concept in the wellness industry, designed to combat lifestyle-related maladies and various disorders by serving as human biological stabilizers. However, to ascertain the efficacy of these products, the selection of proper nutraceutical systems according to their standardized dosages, bioavailability, or pharmacokinetic behavior is important. Additionally, proper isolation and extraction from prospective microalgae or cyanobacterial species of marine sources, as well as their processing, are basic concerns for these potential nutraceuticals. Due to various governing agencies and their stipulations to define the term “nutraceuticals” categorically, researchers have proposed numerous classifications for nutraceuticals. As a result, for many years, it has remained difficult to provide a general consensus explanation of the term “nutraceuticals.” The term “nutraceuticals” was coined from “nutrition” and “pharmaceutical.” It is used loosely and generally to describe nutritious or beneficial foods and supplements that support diet and contribute to the treatment or prevention of various types of diseases. Such therapeutic substances are found in isolated and purified forms in medicinal doses (Adetuyi et al.2022; Visen et al.2022).

Importance of Nutraceuticals in Health and Wellness

Nutraceuticals are now considered an important part of maintaining the health and wellness of an individual. They serve as a preventive aid and keep the person healthier for a long period. Several surveys conducted worldwide all pointed to the vital role of nutraceuticals in the prevention of chronic diseases and in extending wellness for longer time periods. In the past, there were doubts about the real effects of nutraceuticals on our bodies. With the accumulation of new research studies, several compounds have been isolated that are responsible for the marketed nutraceutical effects. The scientific claims targeting therapeutics of any human diseases must be supported by adequate clinical trials on isolated single compounds or mixtures of them. All these concerted efforts, using a biomedical approach to substantiate health benefits, are validating the use of these products, and hence, their utilization is becoming pertinent (Kour & Nayik, 2021;

Chopra et al.2022; AlAli et al.2021).

Wellness is a general term that is highly advocated all over the world because many chronic diseases have been prevented by simply employing the principles of wellness. Experts have claimed that people feel well due to two possible influences: the first is the good physical condition of a subject and the second is the good psychological perception of a person about his or her health. Nutraceuticals, however, in general, represent the physical status of people. Nutraceuticals are gaining momentum due to an increase in consumers' willingness to consume natural products for enjoying better health. They are becoming very popular because they have yielded good results with a positive impact on people's lives. Government establishments worldwide are also looking for food supplements and nutraceuticals that are increasingly attracting the attention of pharmaceutical companies due to the commercial interests behind them. It is natural that companies with a vision of good commercial turnover will get involved in the promotion of nutraceuticals. The nutraceuticals market is growing because of increasing consumer interest. However, scientists' interest in discovering and utilizing these nutraceuticals is already in vogue (Jadhav et al.2023; Shafi et al.2024).

Marine sources of Nutraceuticals

Marine resources have unequivocally demonstrated their immense potential as a valuable source of nutraceuticals, which are essential for health benefits beyond basic nutrition. In our detailed examination, we focused specifically on the most well-studied nutraceutical classes that can be extracted from various matrices of fishery and aquaculture resources. These classes include marine proteins and peptides, polysaccharides, fatty acids, and polyphenols, all of which offer unique health-promoting properties. Moreover, we highlight several prominent examples of the latest research findings in this exciting field. Additionally, we provide crucial background information to underscore the current research trends, while also identifying specific areas that require further investigation to uncover new opportunities for exploration and discovery (Ahmed et al.2022; Ghosh et

al.2022).

Marine fishery and aquaculture resources have increasingly been recognized as highly beneficial sources of nutraceuticals and functional foods over the past few decades. The ability to enhance human diets through the thoughtful inclusion of functional and specialty foods has gained considerable attention. These foods are not only tasteful and appealing to the palate but also particularly abundant in high levels of bioactive components that hold the potential to both prevent and cure various dietary-related diseases. The consumption of seafood has consistently been shown to provide a wide array of health benefits, which has led to its description as 'healthy for life,' as it delivers a multitude of advantages that extend well beyond basic nutrition. In light of these findings, the number of studies dedicated to seafood-derived nutraceuticals has expanded rapidly and significantly. Notably, in 2015, a comprehensive list was published featuring at least 82 distinct commercial bioactive peptides that are derived from marine protein sources, highlighting the diverse potential of these aquatic resources. Among these compounds, fatty acids, particularly eicosapentaenoic acid and docosahexaenoic acid, have emerged as the most popular and sought-after marine nutraceutical monomers. Their importance in dietary formulations cannot be understated, as they contribute crucial health benefits that support overall well-being (Mutalipassi et al.2021; Nag et al.2022; Choudhary et al., 2021).

Bioactive compounds in Marine Nutraceuticals

The wide range of value compounds of marine species could be used directly or after suitable formulations to maintain our health and prevent diseases such as obesity, diabetes, hypercholesterolemia, hypertriglyceridemia, inflammation, and cardiovascular diseases. In the last few years, marine species have become an extremely important source of these nutraceutical compounds used for healthy functional food manufacturing. Especially, the functional ingredients belong to marine-origin active peptides, polysaccharides, pigments, unsaturated fatty acids, polyphenols, taurine, and vitamins with anti-thrombotic, anti-inflammatory, and anti-

tumor activities. The scientific survey indicated that marine-derived nutraceutical ingredients could help in managing hypertension, hypertriglyceridemia, obesity, atherosclerosis, some thrombus-related diseases, diabetes, and other associated metabolic syndromes (Ghosh et al.2022; Nieri et al., 2023; Menea et al.2021; Mutalipassi et al.2021).

Nutraceuticals are foods whose molecular constituents demonstrate potential benefits to human health, known to reduce the risk of some chronic and degenerative diseases with a positive impact on health. Fortunately, a number of compounds from marine sources as nutraceutical products can be applied as a rich omega-3 food supplement to partially correct these deficiencies. Currently, humans have understood more and more about the complexity of human health and diseases, and people begin to think deeply about their own health management, paying more attention to the method to prevent diseases, known as daily healthcare. Therefore, the equipment of nutraceutical ingredients used is the keystone of nutraceutical manufacturing. Although the nutritive demands are the same, the nutraceutical ingredients derived from animal, plant, and microorganism resources have been used for over 12,000, 9,000, and only 1,000 years, respectively. Besides, the ingredient sources have suffered serious overharvesting, pollution, and distinct cost-effective strategies (Fumia et al.2022; AlAli et al.2021).

Current trends in marine nutraceutical research

Marine nutraceuticals are bioactive compounds or molecules that can be isolated from marine sources. In the current literature, most of the research is focused on the extraction and identification of bioactive compounds from several types of marine sources, including fish, crustaceans, algae, and microbes. Simultaneously, an increasing number of articles are addressing global climate change, its impact on the marine environment, and the synergy between global climate change and the nutraceutical potential of marine populations. These papers suggest that environmental factors play an important role in modulating the nutraceutical content of marine organisms. Others are showing significant advances in extraction and chemical and biological characterization

techniques related to nutraceutical properties and, more importantly, methods that apply the principles of green chemistry and green analytical techniques to characterize marine nutraceuticals (Nieri et al., 2023; Ghosh et al.2022).

The exploration of marine bioactive compounds is an attractive topic for the food and pharmaceutical industries given the almost infinite biodiversity of the marine environment. Alongside laboratory developments for commercial production, scientific advances are significantly focusing on the bioactivity of potential commercial compounds. Research is based primarily on independent laboratory experiments that integrate cellular, animal, and clinical trials. Meanwhile, collaborations between universities and the industry are increasing, investigating interdisciplinary research related to nutrition, chemistry, and biology. Some scientific research includes the regulatory landscape of existing dietary supplements, including those related to contaminants or the label claims of marine nutraceuticals. In summary, the development of marine nutraceutical research is a multidisciplinary approach to understanding the potential for commercial exploitation (Ghosh et al.2022; Ahmed et al.2024).

Innovation in marine nutraceuticals

One of the major pushes for innovation in marine nutraceuticals will come from advances in novel extraction and purification procedures, which will enable the isolation of unique nutraceuticals and provide a greater understanding of the properties and constituents of marine products. Once distinctive bioactives have been identified, there is also the possibility to create unique formulations, resulting in combinations of pharmaceutical and food ingredients with enhanced properties not possible to achieve with the individual components (Gamberi et al.2024; Augusto et al., 2024).

Personalized Nutrition

Innovative and emerging areas that are destined to grow and develop over the next few decades include the aquaculture of marine microalgae and biotechnological techniques to produce designer nutraceuticals, such as in livestock waste,

and biopharming and marine nutraceuticals employed in the field of personalized nutrition as well. In addition to this, personalized nutrition is expected to be a growing field with people around the world becoming more conscious of the benefits of products that are formulated to their specific requirements and genetics. The term “nutrigenomics” refers to the dietary recommendations that take into account the influence of genetic variation on the individual’s response to nutrients. This makes it possible to optimize the diet for an individual, basing food consumption on their particular needs, thus preventing and treating specific conditions and boosting overall health by consuming food with beneficial components, such as marine nutraceuticals (Franzago et al.2022; Matusheski et al.2021).

Conclusion and future prospects

This review outlines the growing potential of marine sources to fuel the nutraceutical market. Advances in scientific and research methodologies have provided a foundation to investigate and understand the promising potential of marine nutraceuticals. The focus of this review was to assemble an exhaustive and comprehensive review of the active ingredients present in marine sources. General perceptions and future prospects have also been highlighted. The final aim of this review is to resonate with a broad spectrum of food industry researchers to explore the promising applications of marine sources.

The review can be very helpful in developing a future strategy on marine bioactive potential, as it provides the material and direction for future research. New research should be conducted incorporating different physiological, clinical, and toxicological assessments. Sustainability should also be considered, and efficacy and bioavailability tests should supplement extensive studies on the source. Moreover, collaborative efforts and awareness programs should be devised involving different regulatory bodies and industries to make consumers aware of the associated health benefits. The usage of aquatic species is expanding considerably due to a surge in customer awareness of health and safety improvements. Moreover, aquatic resources provide several

essential components suitable for producing significant dietary supplements and health products. Researchers are advocating the exploitation of marine sources for dietary fiber, antimicrobial peptides, proteins, lipids, and bioactive compounds, which may be derived from seaweeds, fish, and shellfish.

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