Food Research International 56 (2014) 115–125

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Review

# Marine microorganisms: An emerging avenue in modern nutraceuticals and functional foods

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ARTICLE INFO

*Article history:*
Received 9 September 2013
Accepted 13 December 2013

*Keywords:*
Marine microorganism
Bioactive compound
Nutraceutical
Functional food
Marine natural product

ABSTRACT

Marine microorganisms have received mounting attention in biodiscoveries due to their exclusive physicochemical characteristics which have been acquired as an adaptation to prevailing extreme conditions in the marine environment. It has been noticed that those unique marine microbes and their biologically active metabolites are potential sources to be used as sustainable food and pharmaceutical ingredients. Even though dozens of research articles demonstrate the immense potentials of marine microbial metabolites as lead compounds in drugs and pharmaceutical developments, their role as food ingredients is poorly addressed. However, recent advances in food technology have opened up a number of novel avenues to develop natural substances as food or food ingredients. In this context, this review aims at revealing and discussing prospective applications of marine microorganisms and their metabolites in modern nutraceuticals and functional foods.



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## 1. Introduction

Natural products have been used as a promising source to prevent and cure various diseases for centuries. Earlier, many of them were consumed more often as a complete or a part of diet with the aim of earning additional health benefits beyond their basic nutritional value. Even though exact biological consequences of such diets were not clearly identified, evolutionary experiences have brought sufficient knowledge regarding the medicinal properties of natural products (Cavender, 2006; Dias, Urban, & Roessner, 2012). The inspiration from ancient diet and its promising health effect resulted in the development of a number of natural product based commercial products. Among them, functional food and nutraceutical, the most dynamic natural product based segments in the food industry, create a revolution in food industries and made them more research oriented similarly to pharmaceutical industries (Ahamad, Ashraf, Ahmad, Ansari, & Siddiquee, 2011; DeFelice, 1995; Schieber, 2012). Both concepts industrially emerged few decades ago, nevertheless consumer demand and the market

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http://dx.doi.org/10.1016/j.foodres.2013.12.022

share are tremendously increasing while it has been estimated that global nutraceutical market will exceed US$243 billion by 2015 (Schieber, 2012).

The classical definition of nutraceutical and functional food clearly states that both are derived from food or part of food (Kalra, 2003; Shahidi, 2009; Siró, Kápolna, Kápolna, & Lugasi, 2008). However, it seems no longer applicable for modern nutraceuticals; a number of non-food derived ingredients that are recognized as safe have been used in nutraceutical formulations aiming to prevent chronic diseases such as cancer and neurodegenerative diseases (Aruoma, 2010; Carrasco-Gallardo, Farías, Fuentes, Crespo, & Maccioni, 2012; Shahidi, 2004). Various kinds of natural plants (Harbourne, Marete, Jacquier, & O'Riordan, 2013; Johanningsmeier & Harris, 2011; Lattanzio, Kroon, Linsalata, & Cardinali, 2009) and animals (Galanakis, 2013), including marine sources (Freitas, Rodrigues, Rocha-Santos, Gomes, & Duarte, 2012), have been explored for biologically active metabolites that can be used as novel sources for developing modern nutraceuticals and functional foods. Among those sources, use of microorganisms for production of nutraceutical and functional food is emerging as an interesting and economically viable concept (Gobbetti, Di Cagno, & De Angelis, 2010; Hugenholtz & Smid, 2002). In addition to conventional ingredients, many novel metabolites with advanced functional and health benefits have been identified from microorganisms (Ghorai et al., 2009), and such metabolites from food-grade microorganisms are ideal lead compounds for developing modern nutraceuticals, because microbial fermentation generally offers many advantages such as low energy requirements, lower $CO_2$ emissions, low toxic waste and simpler purification scheme (Lin, Jain, & Yan, 2014).

As an ecological group, marine microorganisms also possess the above mentioned characteristics together with additional unique properties. For instance, the diversity of marine microbes is substantially high and they exhibit diverse physiological adaptations for marine environment (Waters, Hill, Place, & Hamann, 2010). The adaptation for such extreme environments has made marine microorganisms capable of producing unique microbial metabolites (Egan, Thomas, & Kjelleberg, 2008; Imhoff, Labes, & Wiese, 2011). Further, marine microorganisms are metabolically efficient and have evolved with effective strategies to use limited dissolved organic matters to produce more metabolites than the energy consumed (Moran & Miller, 2007). Energy-yielding carbon-monoxide-oxidation pathways and broadly distributed bacteriochlorophyll- and proteorhodopsin-based light energy harvesting systems are typical examples of oceanic microbial energy saving pathways (Azam & Malfatti, 2007). Moreover, during past few decades, marine microbiology has gained a remarkable progress in terms of biodiversity and ecological role of marine microbes. The genome sequences of some of the most abundant inhabitants in the marine microbial world have been completely revealed (Delong, 2007). Thus, marine microbes would be an ideal source to explore novel metabolites and biotechnological potentials that could be used in the food industry. Here, we discuss marine microorganism-derived ingredients and their biotechnological potentials in the development of modern nutraceuticals and functional foods.

## 2. Marine microbiology

### 2.1. Marine microorganisms

Oceanic microflora remained largely unexplored until recently because marine science has focused only on either large charismatic creatures or economically important food species in marine environment. Nevertheless, it is a well known fact that marine microorganisms make up more than 90% of the marine biomass (Delong, 2007). These tiny microscopic organisms are the front line of the marine food chains and act as living lung for the planet by producing more than half of the world's oxygen. All microscopic organisms in salt water are referred as marine microorganisms. However, they are basically an ecological group; not a taxonomic classification. Current estimations show that global oceanic microflora is composed of $3.6 \times 10^{29}$ bacterial cells, $1.3 \times 10^{28}$ archaeal cells and $4 \times 10^{30}$ viruses (Bowler, Karl, & Colwell, 2009; Karl, 2007). Further, it has been noticed that marine microbes inhabit all kinds of different environments of the ocean such as polar ice, hydrothermal vent, deep sea, coral reef, mangroves, etc., and their presence and ecological role vary according to the environmental conditions (Webster & Hill, 2007). Because some conventional culturing techniques are not applicable for isolation and identification of marine microorganism, the extent of the diversity is not well-known. Table 1 provides information about some typical marine microorganisms.

Marine environment is considered as a treasurer for scientists to explore unique chemical entities. However, many constraints are associated with marine natural products, particularly the supply of adequate quantity of metabolites (Montaser & Luesch, 2011; Waters et al., 2010). With the identification of those constrains associated with marine animal and plant-derived biologically active metabolites, marine microbes received growing attention as an alternative source of marine natural products. Tremendously diverse marine microbial community produces compounds with unique structural properties and these compounds possess broad spectrum of pharmaceutical properties such as antimicrobial, anti-tuberculosis, antiviral, antiparasitic, anthelmintic, antimalarial, antiprotozoal, anticoagulant, antiplatelet, anti-inflammatory, antidiabetic, and antitumor effects (Imhoff et al., 2011). Hundreds of research articles are being published every year to reveal the potentials of marine microbial metabolites in pharmaceutical applications. Waters et al. (2010) has highlighted that more than half of the molecules currently in the marine drug development pipeline are highly likely to be produced by microorganisms. In addition, a number of food grade metabolites which possess promising pharmaceutical properties have been isolated from marine microbes and there would be a clear potential to develop those active ingredients as modern nutraceuticals and functional food.

### 2.2. Are marine microorganisms food-grade?

When talking about the applications of marine microbes in food industry, the first question that comes to our mind is; are marine microbes food grade? Although marine microbes produce a wide variety of compounds with promising health promoting abilities, all microbes and their metabolites may not be used in food product development as they are required to comply with food regulatory requirements. This is one of the major challenges of marine microbiology due to lack of knowledge and development in the field. However, it is remarkable that there is no legal definition for food-grade microorganisms, and generally, microorganisms that have history of safe use are considered as food-grade microorganisms. Significant human consumption of food over several generations and in a large genetically diverse population for which there exist adequate toxicological and allergenicity data to provide reasonable certainty that no harm will result from the consumption of the food is defined as history of safe use (Bourdichon et al., 2012). For the first time, an inventory of the microorganisms with history of safe use was compiled in 2002 as a joint project of the International Dairy Federation (IDF) and the European Food and Feed Cultures Association (EFFCA). The list consists of 32 genera that are specifically related to dairy products (Mogensen et al., 2002). Recently, the IDF inventory was rearranged considering the other food matrices and 62 new genera with historical evidences of food use have been included. Meanwhile, scientific approaches to determine the potentially safe microorganisms for food processing have also been reported. The taxonomy, undesirable properties, opportunistic infections, toxic metabolites and virulence factors and antibiotic resistance are major criteria which determine the safe use of microorganisms (Bourdichon, Casaregola, et al., 2012). In 2002, a joint committee of FAO and WHO drafted some guidelines for evaluating microbial strains to be used as