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Review

Antimicrobial potential of macro and microalgae against pathogenic and spoilage microorganisms in food

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ABSTRACT

Algae are a valuable and never-failing source of bioactive compounds. The increasing efforts to use ingredients that are as natural as possible in the formulation of innovative products has given rise to the introduction of macro and microalgae in food industry. To date, scarce information has been published about algae ingredients as antimicrobials in food. The antimicrobial potential of algae is highly dependent on: (i) type, brown algae being the most effective against foodborne bacteria; (ii) the solvent used in the extraction of bioactive compounds, ethanolic and methanolic extracts being highly effective against Gram-positive and Gram-negative bacteria; and (iii) the concentration of the extract. The present paper reviews the main antimicrobial potential of algal species and their bioactive compounds in reference and real food matrices. The validation of the algae antimicrobial potential in real food matrices is still a research niche, being meat and bakery products the most studied substrates.

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1. Introduction

Research on the production of algae under controlled conditions started after the Second World War, with the United States, Japan

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and Germany as pioneers in research and investment in this area (Guedes, Barbosa, Amaro, Pereira, & Malcata, 2011). Furthermore, the study of natural bioactive compounds obtained from marine organisms is a relatively new field of research (since the '90s), with enormous scientific potential (Cakmak, Kaya, & Asan-Ozusaglam, 2014; Mehadi et al., 2015). Given that oceans cover three quarters of the Earth's surface, these marine organisms are of potential interest not only as ingredients for the production of food but also as practical and necessary metabolites with medical and technological properties, such as lipids, enzymes, biomass, polymers, toxins, pigments, and clean fuel, which can be produced, concentrated, and successfully isolated from these small but efficient "marine bioreactors". These organisms are a viable and economical source for the production of these substances, and are in great demand in the nutraceutical, pharmaceutical, chemical, food, and cosmetic industries because of their moisturizing, antioxidant, and regenerative properties (Batista, Gouveia, Bandarra, Franco, & Raymundo, 2013; Devi, Suganthy, Kesika, & Pandian, 2008; Rani, Singh, & Maheshwari, 2013). The possibility of an efficient and sustainable use of marine resources offers an important way of providing staple food, animal feed, pharmacological products, functional ingredients, and medical solutions for a global population that is rapidly increasing.

The term "algae" comprises a complex and heterogeneous group of photosynthetic organisms characterized by their photosynthetic nature and their simple reproductive structures. The algae group is divided into multicellular organisms, MACROALGAE or seaweed, and unicellular organisms, known as MICROALGAE (measuring from 1 μm to several cm). Macroalgae are often fast-growing, reaching sizes of up to 60 m in length. A standard classification has been established, dividing seaweed organisms into three groups on the basis of their pigmentation: i) brown seaweed (*Phaeophyceae*); ii) red seaweed (*Rhodophyceae*) and iii) green seaweed (*Chlorophyceae*). Seaweeds are mainly used for the production of food and the extraction of hydrocolloids. On the other hand, microalgae are microscopic bodies that normally grow in suspension, some with features characteristic of bacteria. These algae grow in seawater, in the region where light penetrates (photic zone), basically up to a depth of 200 meters. Diatoms (*Bacillariophyceae*), green algae (*Chlorophyceae*), and golden algae (*Chrysophyceae*) are the most important microalgae in terms of abundance, but blue-green algae (*Cyanophyceae*) are also classified as microalgae (e.g. *Spirulina*) (Guedes et al., 2011).

More than ten million algal species are estimated to exist nowadays, most of them microalgae, representing a virtually unexplored plant material. So far, only about 50 species have been studied in detail from a physiological and biochemical point of view, in the discipline of "phycology".

The remarkable biodiversity of algae, ranging from species found in the coldest regions of Antarctica to those that grow in the hottest deserts, opens up a new research niche, mainly in the baseline of the "functionality of these marine vegetables".

Among the various research fields in which macro- and microalgae are appearing, gastronomy and food technology are two of the most important areas. New trends in cooking are emphasizing the use of algae as healthy, tasty, colorful ingredients to accompany the most innovative dishes. France, Ireland, Canada, and the United States are particularly active in introducing seaweed into local cuisine, and the movement is spreading to cookery books that include recipes with algae as the main ingredient (FAO, 2012). Consumers have a good perception of algae as "natural products", like lettuce, chard, or broccoli, with well-known, accepted health benefits (Honkanen, 2009). Humans have certainly been consuming algae for years: pet foods, baby foods, dairy products, instant soups, meat coatings (cooked ham), and many others commodities are clear examples of the presence of seaweed in our daily diet. Nowadays, most of these algae ingredients correspond to EU labeled additives E-406, E-401, E-402, E-403, and E-404 (Regulation (EC) No 1333/2008).

Exciting organoleptic properties (color, flavor, aroma, and taste) are being developed by introducing algae into the formulation of novel products with additional technological functions, including preservative functions (antibacterial, antifungal, antiviral, bacteriostatic) (El Shoubaky & El Rahman-Salem, 2014; Sanmukh et al., 2014; Tüney, Çadirci, Ünal, & Sukatar, 2006), structural functions (emulsifying, gelling, and thickening properties attributed to algae) (Ursu et al., 2014), and nutritional properties (vitamins, proteins, polyunsaturated fatty acids) (Bishop & Zubeck, 2012; El-Baky, El Baz, & El-Baroty, 2008). *Spirulina maxima*, C*hlorella vulgaris*, *Haematococcus pluvialis*, *Diacronema vlkianum*, and *Isochrysis galbana* are some of the most interesting algae with potential bioactive properties (Batista et al., 2013). All of them are able to accumulate high amounts of bioactive compounds with functional and technological properties. Several products, such as pasta, bread, and snacks, are being developed with the incorporation of algae extracts in their formulation, and expectations about this practice are promising for the food industry.

In view of the development of antibiotic resistance in bacteria and international trade pressure to achieve a high level of consumer protection, new alternatives to traditional preservatives should be developed and introduced by the food industry, even in products with limited shelf life. The new line of preservatives should also accomplish two further objectives, (i) to preserve the quality and organoleptic value of the product, and (ii) to satisfy consumer demand for natural, functional, ready-to-eat meals. In this connection, marine algae are emerging as a new generation of potential preservatives, macro- and microalgae extracts, or pure ingredients with health benefits and demonstrated antibacterial, antifungal, and antiviral activities (Dai & Mumper, 2010; Devi et al., 2008).

Although intensive study of the antimicrobial potential of algae has begun [2005–2016], most of the studies that have been published are about therapeutic and antibacterial/antiviral capabilities of algae compounds, their ability to inhibit or kill clinical bacteria (Mehadi et al., 2015; Rajeshkumar et al., 2014; Rhimou, Hassane, José, & Nathalie, 2010), but not about the effect of these bioactive molecules against foodborne pathogens and spoilage microorganisms commonly found in food matrices.

2. General view of algae compounds with antimicrobial potential

Among the major bioactive constituents of algae with demonstrated antimicrobial potential, proteins, polysaccharides, polyunsaturated fatty acids (PUFAs), especially EPA and DHA, amino acids, and antioxidants (polyphenols, flavonoids, and carotenoids) are the most important ones (Al-Saif, Abdel-Raouf, El-Wazanani, & Ibrahim, 2014; Senthilkumar & Sudha, 2012). However, the identification of compounds directly responsible for the antimicrobial potential of algae is still a relatively incipient field of research, mainly owing to the new kinds of compounds found in recent years (Amaro, Guedes, & Malcata, 2011).

2.1. Protein and peptides

The recent year 2014 was designated as "Protein Year", underlining the importance of finding alternative sources of these valuable molecules, proteins of animal and vegetable origin. In this field, algae take a high position among the raw materials proposed as alternative protein sources, together with soy, beans, grains,