Therapeutic and nutritional uses of marine algae: a pharmacy in the ocean

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Background

Oceans and seas constitute more than 70% of planet Earth, representing the largest habitat on Earth and a prolific resource for organisms with high biological and chemical diversity. Of this huge area, less than 5% of the seafloor has been explored in any way and less than 0.01% has been studied in detail. This exploitation, due to technical limitations, began with the collection of organisms such as algae (micro and macro), sponges, corals, which have been shown to possess a wide variety of compounds with unique chemical structures [1, 2].

Many species of marine macroalgae are of great economic importance to humans, since they are used as food, forming part of the diet of some peoples, or as raw material by industry, namely food, pharmaceuticals, cosmetics, paints, among others [2]. Marine macroalgae, or seaweeds, are a source of natural compounds, highlighting their antioxidant and anticancer activity. They are rich in vitamins, namely, A, B₃, B₅, B₆, C and E, niacin, as well as some minerals, such as calcium, potassium, magnesium, iron and iodine. They contain proteins with essential amino acids and low-fat content in their constitution [1]. In this way, algae has been a growing interest in their benefits from the food and pharmaceutical industries.

In the Western world, it seems that only Iceland and Hawaii preserved this tradition, perhaps, due to the scarcity of food resources. In addition, reminiscences of seaweed use can be found in some Western locations and countries such as Finno-Scandinavia, Ireland, Scotland and Wales, Brittany (France), Galicia (Spain), Azores (Portugal), Peru, Chile, Caribbean and Alaska (USA). Ole G. Mourišen [1], in his work “Seaweeds: edible, available & sustainable”, discusses some theories about the role of seaweed in the evolution of the human brain. One of them points to the consumption of “ω-3 fatty acids, present in fish and crustaceans – however, not synthesized by their organisms – which feed on phytoplankton. Another theory would indicate that early man was actually a vegetarian and, in turn, those who lived in coastal regions could have used algae as a staple food. However, there is no universal truth, and it is most likely that the first human beings, due to the omnivorous characteristic of our species, adopted different diets, and could even oscillate between a vegetarian diet based on algae, a pisco vegetarian diet, and a carnivorous diet, depending on available resources. As seen earlier, seaweeds are common foods in countries like Japan, Korea and China. With the migratory movements from East Asia to the rest of the world, there was an influx of foods and people who carried with them the tradition of using algae in food, contributing significantly to its dissemination in other cultures. On the other hand, there are studies that prove that algae are pharmacologically active, presenting anti-inflammatory, antidiabetic, anticoagulant, antiviral, antifungal and anticancer activities, among others, so they can have many applications in the pharmaceutical industry [1, 3]. Two substances found in several species of marine algae have antioxidant and photoprotective characteristics. These are carotenoids (organic pigments) and mycosporins (a type of amino acid). [1, 4]. In addition, there are currently several cosmetics on the market, aimed at skin care and sun protection, which contain algae extracts in their composition.

Here, the author summarized the therapeutic and nutritional uses of marine algae, including their antibacterial, antitumor and antiviral activities, as well as their current application in the food, pharmaceutical and cosmetic industry, to propose a big therapeutic potential of algae and their components and extracts.

Algae and their diversity

The name Algae appears for the first time, in 1753, to designate a systematic category of plants. This category included algae, as well as some lichens and bryophytes. Algae are ubiquitous and occur in diverse habitats, from aquatic to terrestrial, virtually across the globe [2]. Algae do not have roots, leaves, stems or vascular systems. Algae reproduction can be sexual or asexual. Algae appear in different cellular forms (a single microscopic cell, macroscopic multicellular clusters, branched colonies or more complex leaf or blade forms), which contrasts with the homogeneity of vascular plants [2]. Algae constitute a set of organisms with a wide diversity of forms, functions and survival strategies, not having a monophyletic origin. Therefore, algae can be characterized as photosynthetic organisms, ranging from unicellular (microalgae) to multicellular [2].

Macroalgae are unicellular and photosynthetic organisms, located mainly in marine environments, fresh waters and moist soils, which can only be observed under a microscope. Planktonic microalgae or phytoplankton are the base of the marine food chain and produce more than 50% of the molecular oxygen available on the planet [2]. It is thought that algae were the first organisms to carry out photosynthesis and one of the agents responsible for creating the current Earth’s atmosphere. These are essential to planetary balance, since the dynamics of carbon dioxide on Earth is largely determined by these organisms that are responsible for more than 50% of the planet’s photosynthetic activity. On the other hand, microalgae play an important role in energy transfer along the trophic chain, as they are primary producers and, therefore, responsible for the food base of other aquatic organisms [2].

Macroalgae are macroscopic algae that are easily seen with the naked eye and consist of three major phyla: Chlorophyta (green algae), Rhodophyta (red algae) and Ochrophyta, class Phaeophyceae (brown algae) (Figure 1). Macroalgae are photoautotrophic multicellular organisms that play an important role in the structure and support of habitats, in addition to primary production [2]. Macroalgae or seaweeds are macroscopic marine algae that can reach several meters in length (some thallii of these algae can reach 65 m in length, if not subject to intense herbivory). As primary producers, macroalgae are at the base of the marine food chain supporting several communities of herbivorous animals (invertebrates, such as some sea urchins and/or gastropods, and vertebrates, such as herbivorous fish) where they end up finding refuge from their predators, the carnivores. In order to escape this herbivory, which is sometimes intense (in natural reefs or rocky walls of the continental shelf), many macroalgae have been improving defense strategies, with calcification (common in red algae, such as the Corallinaceae family) being one of the most common, although they can also produce secondary metabolites (terpenes, aromatic substances, polyphenols, etc.) that act as demotivators of their ingestion [2].
Use of algae

The commercial cultivation of algae started only a few decades ago, namely in Germany, during the Second World War, where they were used as a source of protein, since animal meat was a scarce commodity. However, the consumption of these organisms stood out in Asian countries, where for many centuries they have been used as a nutritional and medicinal product [1, 3]. In the post-war period, Germany had a serious shortage of raw materials and, as a result, companies went bankrupt, inflation was high and there were not enough US dollars in reserves for imports. Europe was experiencing an energy crisis, and the situation became particularly difficult in the winter months. In this sense, algae were also used as a source of biomass for methane production [3].

The first commercial products from algae were polysaccharides extracted from macroalgae and used as a source of phycocolloids (agar, carrageenan and alginate). Until now, several species of algae considered an important natural source of secondary metabolites, such as functional nutrients and bioactive compounds, have been studied, and their biological activities and their beneficial effects on health have aroused the interest of many scientists. The bioactive compounds existing in these organisms, with antioxidant and antibacterial activity, raised the attention of the pharmaceutical industry, and the food industry used them essentially as nutritional supplements for human consumption, due to their high levels of proteins, polysaccharides and their vitamin content. There are many interesting applications of algae in the food, pharmaceutical and cosmetic industries [1].

The photosynthetic efficiency of algae is very high, with a positive impact on minimizing the greenhouse effect and on the planet’s climate change with their production. Algae promote bioremediation and the removal of carbon dioxide from gases emitted from fossil fuels from thermolectric plants and other sources, contributing to the reduction of gas emissions [2].

Algae in the food industry

The introduction of microalgae in human food dates back to ancient times, when they were used as a source of protein by the ancient African tribes of Chad and by the Aztec Indians. However, it was only in the 20th century that the commercialization of microalgae as a nutritional source began. Shortly thereafter, the recognition of the high protein content (> 60%) of the species Arthrospira/Spirulina spp. (Cyanobacteria) led to its introduction in the American market. Despite the exponential increase in microalgae production, only more recently, with the evaluation of their biological, biotechnological and nutritional potential, these algae were considered functional foods [3]. This type of products has registered a high expansion, so that countries such as Israel, Brazil, France, Mexico and Thailand have become major producers of microalgae biomass, with Japan being the country where the consumption of this type of food is greater.

The recognized nutritional value of algal biomass has promoted its use as a protein supplement and as a nutraceutical. Due to its nutritional value, algae biomass is commercialized, usually in the form of capsules, as a supplement for human or animal food. Studies carried out in Buarcoes Bay on the west coast of Portugal with several species of edible algae (Figure 1), Gracilaria gracilis, Osmundea pinnatifida, Grateloupia turuturu (Rhodophyta), Sargassum muticum, Saccorhiza polyschides (Phaeophyceae), and Codium tomentosum (Chlorophyta) showed that these algae have a nutritional potential, either as direct food or for applications. The proximate and elemental composition varied significantly between brown, red and green algae, as well as within each main species. Red algae had a higher protein content, but lower fat and sugar. On the other hand, green and brown algae had a higher fat and sugar content, respectively. The low-fat content (0.6–3.6%) is associated with the profile of specific fatty acids, namely palmitic acid, arachidonic acid and eicosapentaenoic acid. The content of total phenolic compounds is higher in green algae (C. tomentosum), followed by brown algae (S. muticum) and red macroalgae (Rhodophyta) [1, 3].

The demand for functional foods has suffered, in recent times, a growing interest from consumers. These seek beneficial foods, motivated by the increase in life expectancy and the improvement of its quality, as well as the increase in health care costs. In this sense, the food industry has been developing the production of appealing, low-cost and increasingly healthy foods. The term “functional food”

![Figure 1: Seaweed species images](https://www.tmrjournals.com/tmr)
was created and introduced in the early 1980s in Japan. According to the Food and Nutrition Board, “functional food” is “any food or food constituent with potential health-promoting benefits and disease prevention, independent of essential nutrient function”. This concept encompasses foods made up of nutrients potentially beneficial to human health, such as carotenoids, polyphenols, flavonoids, fibers, long-chain polyunsaturated fatty acids, antioxidant pigments, among others. The term “nutraceutical” is based on the combination of the terms “nutrition” and “pharmaceutical” as it encompasses nutrients with proven ability to provide health benefits as if it were a pharmaceutical product.

In 1990, the International Life Science Institute was created in Europe with the aim of establishing a scientific basis for a diet rich in certain nutrients and disease prevention. In turn, in the United States of America, the regulation on functional foods is administered by the Food and Drug Administration, created in 1966. As a rule, high levels of minerals were found in all algae. Therefore, algae such as S. muticum, S. polydiscus and C. tomentosum can be included in the human diet to solve problems associated with mineral deficiency, in particular, Ca, K, Mg and Fe, since these species proved to be good sources of these elements and may contribute to satisfying their daily needs [3]. The algae G. gracilis and O. pinnatifida are producers of agar, the G. turuturu of carrageenans. In brown algae, S. muticum and S. polydiscus, alginates and fucoids were the main polysaccharides found, while C. tomentosum contain (1->4)-β-D-mannans and sulfated and non-sulfated galactose residues. The presence of these polysaccharides further supports the interest in the study of this type of algae for applications in the health area, namely, as nutraceuticals.

Seaweeds are indispensable ingredients in Japanese cuisine. In addition to being used in various recipes, they bring numerous health benefits. Today, we’re going to explore the varieties of edible seaweed used in Japanese cuisine, their health benefits, and how you can incorporate these sea vegetables into your meals [1, 3]. Seaweed and its derivatives have been central ingredients of Japanese cuisine for thousands of years. There are several different types of kelp, with different tastes and textures. Here are some varieties of edible seaweed that are most commonly used in Japanese cuisine.

Nori is a thin, greenish leaf species made from seaweed. It is made by crushing and drying edible red macroalgae of the Porphyra/Pyrøspia/Neoporphyra/Neotrypred sp. (red algae) that are pressed into a thin sheet – a method adopted in the papemaking process. This ingredient is widely used to wrap sushi and onigiri.

Other forms of nori include kizami nori (nori cut into thin strips), used to garnish dishes like donburi (rice bowls) and “sornori” (powdered nori), used as a condiment on foods such as okonomiyaki and yakisoba. There is also a flavored version (“ajinori”) that is consumed as a snack [1, 3]. In Japan, nori no “tsukudani” is another classic way to enjoy seaweed, where it is mixed with soy sauce, dashi, sake and mirin and made into a pasta side dish usually eaten with white rice. Nori seaweed is rich in calcium, iron, vitamin A, B and C. In addition, it contains twice as much protein as some meats.

Kombu is a variety of seaweed that has a dark green color and a tough texture and must be rehydrated before use. It is made with the edible brown algae Laminaria and Saccharina spp. Composed of umami (fifth essential flavor), it is one of the main ingredients of dashi broth. Other ways to consume kombu are in salads, in stews, in the “tsukudani” style or in the preparation of “kombu-cha”. Japanese kombu is grown mainly in Hokkaido. There are more than ten species of kombu algae, and each has its own flavor characteristics. The highest quality is Ma-Kombu, with the widest leaves [3].

 Wakame has a smooth texture and a mild, sweet taste. Fresh wakame is the brown seaweed species Undaria pinnatifida, which is originally harvested from the Sea of Japan from February to June, but dried wakame is available year-round and can be easily reconstituted by immersion in water or other liquid. It is commonly added to “misoshiro” (miso soup) and salads. Wakame is low in calories and is known for its ability to aid in weight loss and boost energy levels.

A brown seaweed Hijiki or Hiziki is the Sargassum fusiforme species collected from the rocky shores of Japan, Korea and China. Purchased in the form of dried sprigs, this ingredient must be rehydrated before being used in recipes. This deep black seaweed with a soft texture when hydrated can be incorporated into “ochazuke”, salads and rice.

Mozuku (Cladosiphon okamuranus) is one of the secret ingredients of longevity for Okinawans, along with other superfoods like tofu, turmeric, local vegetables, and goya (nigaoi). Surrounded by clean, shallow water and a temperate climate, Okinawa is Japan’s largest producer of Mozuku [3]. This seaweed has a unique slimy texture. While the most common way to eat it is with a vineger-based dressing, it can also be prepared as a tempura, gyozo, chilled soup, and omelet [1].

**Application of algae in the pharmaceutical and cosmetic industry**

Since the beginning of humanity, natural products have been used by man in the treatment of diseases. With the discovery of Neanderthal fossils, the first traces of the use of medicinal plants were found. The first records discovered about herbal therapies were found in Mesopotamia and date back to 2600 B.C.E. Today, many of these plants continue to be used in the treatment of inflammation, flu, colds and parasite contamination.

Despite the high development of molecular biology and the better understanding of biosynthesis and the functions of bioactive molecules, it was not until the 1970s that great progress was made regarding the use of algae cultures in the production of pigments, food supplements and vitamins for the pharmaceutical industry [4].

Algae are a potential source of various food supplements and biomaterials used in the industry. For example, chlorophyll is an important product for the pharmaceutical industry, which results from its chelating capacity, useful in the treatment of ulcers in the liver. Published studies also attribute antioxidant, anti-mutagenic and antitumor activities of the chlorophyll and their derivatives [4].

Agar, for example, is used in the manufacture of tablets and capsules, surgical lubricants and in various types of emulsions. It is also used as a disintegrating agent and as an excipient in medicinal dragées. In the cosmetics industry, it is used in the production of creams, lotions, lip balms and deodorants.

The application of seaweed extracts in the cosmetics industry is not recent and there are several products derived from these organisms on the market, namely for skin treatment (anti-aging creams, regenerating or refreshing products). There are other cosmetic applications based on microalgae, in the form of hair and sun protection products. An example of these products, commercially available, is an extract of Chlorella vulgaris that stimulates collagen synthesis in the skin and tissue regeneration, contributing to the reduction of signs of aging [4].

On the other hand, alginate extracted from brown macroalgae (Ochrophyta, Phaeophyceae), are effective as laxatives because, by absorbing large amounts of water as it passes through the intestine, they increase in volume and facilitate intestinal transit. In dentistry, these same compounds are used in the preparation of dental molds. Alginate-impregnated bandages are used to treat burns, as this phycocollloid facilitates healing and contributes to less painful healing. Alginites can also be used as neutralizing agents for certain heavy or radioactive metals in cases of intoxication by ingestion [4].

**Antitumor activity of algae.** The alginate produced by brown algae, of which Sargassum vulgare is an example, has demonstrated its antitumor activity by inhibiting the in vivo growth of cancer cells. Undaria pinnatifida, Ecklonia maxima, Fucus vesiculosus, Laminaria ochroleuca, Cladophiona okamuranus (Phaeophyceae) demonstrated antitumor and antiproliferative capacity, being possible candidates for future antineoplastic agents [4].

In addition to applications in the food industry, alginic acid has also shown some antitumor activity, which may represent a great interest on the part of the pharmaceutical industry. Red macroalgae polysaccharides, such as carrageenans, have been suggested as important sources of bioactive compounds with diverse physiological and biological activities, namely, immunomodulation, anti-inflammatory, antioxidant, anticoagulant and antitumor action.
Also, brown macroalgae, rich in iodine and mucilage, act as an anti-cellulite, have laxative effects and decrease the feeling of hunger, which is why they are used in slimming diets. Brown algae, since they are rich in mineral salts and trace elements, in addition to being useful in slimming diets, are used as anti-inflammatory and anti-rheumatic [4].

**Antibacterial activity of algae.** Antibiotics have been considered drugs of great interest since their discovery in 1928 by the microbiologist Alexander Fleming. However, their popularity quickly led to their overuse. During the last decade, antibiotics have lost their effectiveness and the treatment of bacterial infections is increasingly difficult due to the resistance to antimicrobial agents developed by bacteria. Drug resistance is a serious problem today and the discovery of new antibacterial compounds to fight infections is urgent [4].

Studies made with extracts of *Turbinaria conoides*, *Padina gymnoспорa* and *Sargassum tenerrimum* (Ochrophyta, Phaeophyceae) in bacteria have shown that these macroalgae can inhibit bacterial growth. Other studies have shown that the extracts of *Gracilaria dendroides* (Rhodophyta), *Uva reticulata* (Chlorophyta) and *Dictyota ciliolata* (Ochrophyta, Phaeophyceae), from the Red Sea, showed antibacterial activity against *Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus* and *Enterococcus faecalis*, and the red algae *G. dendroides* shows superior activity to the green and brown macroalgae tested. These and other studies not mentioned here suggest that the next generation of antibiotics could emerge from algae [4].

**Antifungal activity of algae.** In addition to diseases caused by bacteria, pathologies caused by fungi have always been problematic in terms of their therapy. The main characteristic of fungi that makes them pathogenic is their dimorphism, that is, they exist in the form of mycelia in the environment but, convert into fungi with the increase in temperature of the human host. A variety of macroalgae extracts showed interesting results, while antifungal, namely the macroalgae of the Phaeophyceae class which showed antifungal capacity against the fungi *Candida albicans*, *Penicillium sp.*, *Asgergillus flavus*, *Asgergillus terreus*, *Candida glabrata* and *Cryptoccus albidos*. Sesquiterpenes isolated from the red macroalgae *Laurencea okamurana* showed in vitro antifungal activity against four fungi species (Cryptoccus albidos, Candida glabrata, Trichophyton rubrum, and Aspergillus fumigatus) [4].

**Antiviral activity of algae.** Many species of marine algae contain significant quantities of complex structural sulphated polysaccharides that have been shown to inhibit the replication of enveloped viruses [4]. Other compounds, both of red algae (e.g., the lectin griffithsin and the phycococloid carrageenan), and other sulphated polysaccharides extracted from green algae (i.e., ulvans) and brown algae (i.e., fucoids) could be potential antiviral therapeutic agents against severe acute respiratory syndrome coronavirus-2 [5].

The phlorotannins of the Phaeophyceae class show activity against the human immunodeficiency virus (HIV), and lecithins and polysaccharides are obtained from algae, which have shown a moderate effect against the ability of the virus to infect. Sulphated polysaccharides have been shown to inhibit the replication of enveloped viruses, including members of the flavivirus family, togavirus, arena virus, rhadovirus, orthopoxivirus, herpesvirus, and HIV virus. The sulphated polysaccharides obtained with extracts of the Rhodophyta class also showed some anti-HIV activity [5].

According to some studies, extracts of the microalgae *Porphyridium purpureum* (Rhodophyta), *Chlorella vulgaris* var. *autotrophica* (Chlorophyta), *Dictyota galbana* (Haplophyta) and *Dunaliella tertiolecta* (Chlorophyta) have antiviral activity against the viral hemorrhagic septicemia virus. Extracts obtained from *P. purpureum* and *C. vulgaris* var. *autotrophic* also inhibited African swine fever virus. The exocellular extracts of all these microalgae also have inhibitory properties, except the extracts of *L. galbana* against viral hemorrhagic septicemia virus and African swine fever virus and those of *C. vulgaris* var. *autotrophic* and *D. tertiolecta* against the African swine fever virus [5].

Other pharmacological actions of algae. The sulfated fucans present in species of the class Phaeophyceae have anticoagulant and antithrombotic activity, having been observed anti-inflammatory and tissue protection activity with fucans of *Ascosphylum nodosum*, *Lobophora variegata*, *Laminaria digita*, as well as immunomodulation with fucans of *Fucus vesiculosus*.

There are some studies that refer to the protective action of tissues with neuroprotective effects from algae, whereas, for example, the carrageenan from Rhodophyta algae (red algae) has a neuroprotective action, since it reduced the accumulation of α-synuclein, a neuronal toxin, protecting the body against dopaminergic neurodegeneration [4].

**Conclusion**

Marine life is extremely diverse in form and physiology for adaptations in diverse environments, in prey capture strategies or in defense against predators. In these thousands of years of evolution, several molecules emerged and also evolved. And only more recently, in the last three decades, in parallel with technological advances, are we experiencing more and more the isolation and characterization of bioactive compounds. With the growing demand for molecules with antibacterial and antitumor activity, it is not impertinent to say that the marine environment is perhaps the most important environment in the bioprospecting of new pharmacologically active compounds. There are several examples of algae with antibacterial, antitumor and antiviral activities, being that the algae extracts have a big therapeutic potential.

**References**


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**Competing interests**

The authors declare no conflicts of interest.

**Abbreviations**

HIV, human immunodeficiency virus.

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