

Research Perspective

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Nutritional and Antioxidant Properties of *Porphyra* spp.: Implications for Human Health

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Abstract *Porphyra* spp. is a widely edible marine red algae that has attracted much attention for its rich nutritional value and significant antioxidant activity. This study systematically analyzes the nutritional composition, functional compounds and their antioxidant properties of seaweed, and explores the potential benefits of seaweed intake for human health. Seaweed has high protein content, complete types of essential amino acids and appropriate proportions; it is rich in carbohydrates and dietary fiber, and has significant vitamins and minerals. Seaweed is rich in functional ingredients such as polyphenols, carotenoids, phycobilidins and sulfate polysaccharides, making it have significant antioxidant activity and a variety of biological functions. Studies have shown that seaweed extract has the ability to scavenge free radicals and may play an active role in anti-inflammatory, immune regulation, cardiovascular health protection, as well as anti-tumor and anti-aging. This study sorts out the results of research on nutrition and function of seaweed in recent years and discusses future research and application directions.

Keywords Seaweed; Nutritional components; Antioxidant; Functional compounds; Human health

1 Introduction

Seaweed is a edible red algae that plays an important role in the food culture of coastal East Asia and is widely used in traditional cuisines in Japan, South Korea and China. In modern society, with people paying attention to healthy diets, seaweed has attracted global attention due to its high nutritional value and potential health benefits. Processed products of seaweed (such as roasted seaweed, ready-to-eat seaweed snacks, etc.) have gradually entered the markets of Western countries and are popular among consumers (Pandey et al., 2020). Global seaweed production has increased significantly in recent years, reflecting the importance of seaweed in the food supply and health industries (Silva-Obando et al., 2025).

The genus *Porphyra* spp. belongs to the genus *Porphyra* spp., which includes *Porphyra* and *Pyropia*. Nori is a typical leaf-like red algae. Common edible species include *Porphyra yezoensis* and *Pyropia haitanensis*. These seaweed species are widely distributed in the intertidal zone. Traditional *Porphyra* genus is divided into several new genera, but people are usually still accustomed to collectively referring to it as "nori" or "nori" in English. Seaweed is shaped like a thin sheet, consisting of monolayers of cells, rich in a variety of nutrients and secondary metabolites, which lays the foundation for its nutritional and medicinal value (Geng et al., 2019).

In order to explore the mechanism of action of seaweed on human health, this study will systematically discuss the nutritional components, functional compounds, antioxidant properties and potential health benefits of seaweed, and compare the intake of seaweed in different regions through case analysis, and finally make a prospect for future research and application prospects.

2 Nutritional Components of Seaweed

2.1 Protein and essential amino acid content

Seaweed is known for its high protein. The crude protein content of dried seaweed can usually reach 20%~30%, and the protein content of certain varieties even exceeds 35% during a specific growth period. Such protein levels

rank among the top in seaweed, making seaweed an important source of high-quality protein for vegetarians (Arakaki et al., 2023). The amino acid composition of seaweed protein is balanced, and the essential amino acids are complete and the proportions are appropriate. A study and comparison of the protein composition of seaweed in different harvest periods was found that the ratio of total amino acids and essential amino acids of seaweed was the highest during the peak growth period (Mohammed et al., 2021). In addition, seaweed is rich in amino acid derivatives such as taurine, which helps to improve nutritional value and has health effects such as regulating metabolism.

2.2 Carbohydrates and dietary fiber

Carbohydrates are another major component of the dry weight of seaweed, and the content is usually between 30% and 50%, of which a considerable proportion exists in the form of dietary fiber (Gonçalves et al., 2021). Among them, water-soluble dietary fiber (such as seaweed polysaccharide) is rich in content, which helps maintain intestinal health and reduces cholesterol absorption. Seaweed polysaccharide is the most distinctive carbohydrate in seaweed. Its main chain consists of alternating galactose and 3,6-dehydrated galactose, and has a sulfate group attached to some galactose residues. It is a typical sulfate polysaccharide (Mei et al., 2024). As dietary fiber, seaweed polysaccharides have the effects of absorbing water and promoting intestinal peristalsis, and also exhibit a variety of biological activities. In addition, seaweed also contains a small amount of soluble sugars, but the overall fat content is extremely low, and energy mainly comes from carbohydrates and proteins. This high-fiber, low-fat ingredient feature makes seaweed a healthy food choice.

2.3 Vitamin and mineral distribution

Seaweed is rich in a variety of vitamins and minerals and is a natural "nutrition treasure house". Seaweed is a few plant sources that contain vitamin B12, and intake is moderate to help prevent anemia caused by deficiency of this vitamin. In addition, seaweed provides rich antioxidant vitamins such as vitamins A, C, E, etc., which helps improve the body's immunity and antioxidant defense (Kaur and Kaushik, 2025). In terms of minerals, the content of iodine, iron, calcium, magnesium, potassium and other elements in seaweed is outstanding (Alda et al., 2023). Among them, iodine is an essential element for the synthesis of thyroid hormones, and eating seaweed can prevent iodine deficiency (such as goiter). Iron in seaweed is beneficial to improve iron deficiency anemia, and calcium and magnesium help maintain bone and nerve health. However, it is necessary to note that the iodine and sodium content in seaweed is high, and it is necessary to eat it in moderation.

3 Functional Compounds of Nori

3.1 Polyphenol compounds

Polyphenols are one of the important active ingredients in seaweed, giving seaweed strong antioxidant ability and various biological activities. Seaweed contains a variety of polyphenol compounds such as phenolic acids, flavonoids and brominated polyphenols unique to marine algae. Among them, bromine polyphenols have higher antioxidant activity due to their presence of bromine atoms and are considered to be a key ingredient for the health care effects of seaweed (Goya and Mateos, 2024). In vitro experiments showed that the seaweed polyphenol extract showed significant effects in free radical scavenging such as DPPH and ABTS and inhibiting cellular lipid peroxidation. Xu et al. (2022) extracted the saphi polyphenol and found that it had a significant inhibitory effect on the proliferation of human liver cancer HepG2 cells (Xu et al., 2022). It can be seen that seaweed polyphenols are one of the main contributors to seaweed's antioxidant and other biological activities.

3.2 Carotenoids and phycobilide proteins

Nori contains carotenoids such as beta-carotene and lutein. It not only gives nori a unique color, but also an important source of antioxidants and vitamin A, which helps protect vision and improve immunity. Seaweed is also rich in phycobilidin (especially R-phycoerythrin), and the photosynthetic pigment protein unique to this type of red algae is also biologically active. Some studies have pointed out that phycoerythrin has antioxidant, antitumor and immune regulation activities. Phycoerythrin can not only be used as a natural food coloring, but also has application value in the field of biotechnology. Carotenoids and phycobilidin in seaweed together improve their nutritional and functional value (Chen et al., 2017).

3.3 Sulfate polysaccharide and other secondary metabolites

Sulfate polysaccharide is the core of the functional ingredients of seaweed, among which seaweed polysaccharide (Porphyrin) is the most popular. Seaweed polysaccharides have significant antioxidant, immunomodulatory and other biological activities, which can enhance the body's anti-infection and anti-tumor ability (Pradhan et al., 2022). Studies have found that the oligomers obtained by degradation of seaweed polysaccharides are more active in antitumor and antioxidant aspects (Figure 1). In addition, seaweed also contains secondary metabolites such as betaine and phytosterol, which have the effects of protecting the liver and regulating lipids (Kim et al., 2024). Overall, the sulfate polysaccharides and a variety of secondary metabolites rich in seaweed provide them with diverse biological functions, making seaweed not only a food, but also a marine resource with multiple health benefits (Huang and Li, 2024).

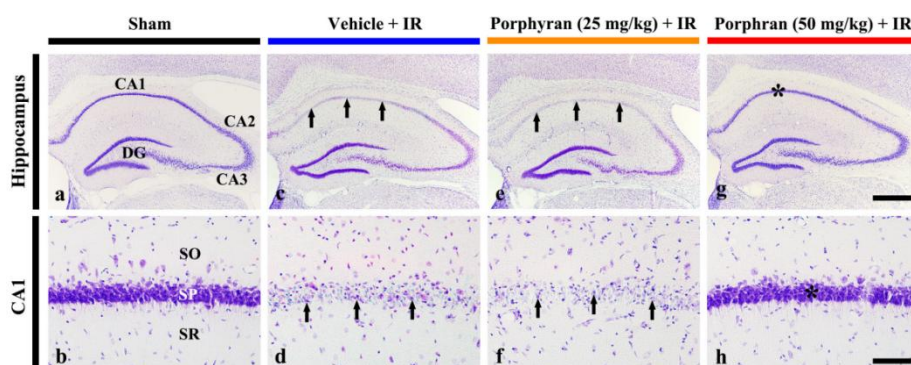


Figure 1 Representative images of CV staining in the hippocampus (upper panels) and its CA1 subregion (lower panels) of the sham (a, b), vehicle-IR (c,d), 25 mg/kg (e, f), and 50 mg/kg Porphyrin-IR (g,h) groups at 4 days after IR. Strong CV stainability is observed in the stratum pyramidale (SP, asterisks) consisting of pyramidal cells in the CA1 subregion of the 50 mg/kg Porphyrin-IR group in comparison with that in the vehicle-IR and 25 mg/kg Porphyrin-IR groups, showing damaged pyramidal cells (arrows). CA, cornu ammonis; DG, dentate gyrus; SO, stratum oriens; SR, stratum radiatum. Scale bar = 400 μ m (a, c, e, g) and 50 μ m (b, d, f, h) (Adopted from Kim et al., 2024)

4 Antioxidant Properties of Seaweed

4.1 Study on the in vitro free radical scavenging activity

A large number of in vitro antioxidant experiments have proved that seaweed extract (including proteolytic products, polyphenols, etc.) can effectively eliminate free radicals such as DPPH and ABTS, and its scavenging rate increases significantly with the increase of concentration. The antioxidant peptide obtained by proteolysis of nori showed a good dose-effect relationship in DPPH free radical scavenging experiments; the nori polyphenol extract also showed excellent antioxidant ability in ABTS free radical and reducing force tests (Yang et al., 2024). These results demonstrate the free radical removal potential of seaweed from an experimental level, providing a scientific basis for its antioxidant and health care effects.

4.2 Antioxidant mechanism: enzymatic and non-enzymatic pathways

The antioxidant mechanisms of seaweed include non-enzymatic pathways (its active substances directly eliminate free radicals, chelate metal ions, etc.) and enzymatic pathways (intake of seaweed can improve the activity of antioxidant enzymes in the body and reduce peroxidative damage indicators) (Zhong, 2024). Non-enzymatic effects mainly rely on the polyphenols in the seaweed to eliminate excess free radicals through hydrogen supply and chelation, while enzymatic effects indirectly reduce oxidative damage by upregulating the expression of endogenous antioxidant enzymes such as superoxide dismutase (SOD) and catalase (CAT) through the active ingredients of seaweed to indirectly reduce oxidative damage (Wu et al., 2020). The two pathways complement each other, allowing seaweed to play an antioxidant protective role at the cellular level and overall body level.

4.3 Comparison with other seaweed antioxidant capacity

Compared with green algae and brown algae, red algae, seaweed, is rich in substances such as bromine polyphenols, and its antioxidant activity has been outstanding in many tests. The study compared the antioxidant

indicators of different seaweeds, and the results showed that seaweed was superior to brown and green algae in certain free radical scavenging and anti-lipid peroxidation abilities (Urrea-Victoria et al., 2022). This may be attributed to the effect of the active ingredients in seaweed. The sort of antioxidant activity of seaweed may vary slightly under different assay methods, but the overall status of seaweed as an "antioxidant star" is generally recognized. This suggests that seaweed has considerable advantages in antioxidant health care (Nova et al., 2023).

5 Potential Benefits for Human Health

5.1 Anti-inflammatory and immune regulation effects

The various active ingredients of seaweed give it anti-inflammatory and immune-regulating potential. In vitro cell model studies have shown that seaweed polysaccharides can reduce the inflammatory mediators (such as NO, cytokines) produced by macrophages, thereby exerting anti-inflammatory effects (Wang et al., 2020). Clinical trials have confirmed that supplementing seaweed extract can significantly improve the activity of peripheral blood NK cells, suggesting that seaweed is beneficial to enhancing the body's resistance. Animal experiments also prove that seaweed polysaccharide can promote lymphocyte proliferation and macrophage activation, and enhance humoral immunity and cellular immune function (Park et al., 2023). Therefore, as a functional food, seaweed has application prospects in preventing chronic inflammation and improving immunity.

5.2 Cardiovascular health protection (anti-lipid, anti-atherosclerosis)

Regular consumption of seaweed is considered to help cardiovascular health. The dietary fiber and polysaccharides contained in seaweed can reduce cholesterol absorption in the intestine and thus reduce blood lipids. Preliminary clinical trials have shown that after eating dried seaweed products for several weeks, the subjects' serum total cholesterol and LDL cholesterol decreased. In addition, seaweed is rich in active ingredients such as taurine and phytosterol, which can promote cholesterol metabolism and inhibit cholesterol absorption, thus helping to lower blood cholesterol (Cao et al., 2016). These effects mean that seaweed has potential value in anti-hyperlipidemia and preventing atherosclerosis, and has positive implications for maintaining cardiovascular health.

5.3 Anti-tumor and anti-aging potential

A large number of experiments have proved that seaweed polysaccharides can inhibit the proliferation of cancer cells and induce their apoptosis, while enhancing the anti-tumor ability of the body's immune system (Pradhan et al., 2022). A Japanese study of patients with digestive tract cancer showed that patients with colorectal cancer who regularly consume seaweed had significantly lower risk of death. In terms of anti-aging, the antioxidant effect of seaweed helps to reduce cellular oxidative damage, thereby delaying the aging process of the body to a certain extent (Zhang et al., 2019). In short, nori has shown considerable potential for its role in preventing tumor development and delaying aging, which laid the foundation for its development to become a functional food or auxiliary treatment method.

6 Case Analysis: Research on Seaweed Intake and Population Health

6.1 Nori eating habits and health indicators for Japanese and Korean people

Japanese and Korean residents have long-term diets containing seaweed foods such as seaweed, which are believed to contribute to their lower incidence of certain chronic diseases and higher life expectancy. Koreans also generally consume seaweed daily, such as seaweed rice and seaweed soup. Dietary surveys show that seaweed intake provides them with considerable dietary fiber and trace elements, which helps explain the lower obesity rate and cardiovascular disease incidence (Park et al., 2022). It can be seen that the traditional dietary model of high seaweed intake may have a positive impact on the health indicators of these populations, providing reference for the promotion of seaweed food in other regions (Yang et al., 2009).

6.2 Research results of seaweed-related intervention trials

Several interventional studies further confirm the health benefits of seaweed. For example, intake of seaweed products can reduce serum total cholesterol in patients with hyperlipidemia; supplementation of seaweed extract can enhance human immune function (Pradhan et al., 2022). Animal experiments have also proved that seaweed

polysaccharide can slow down the formation of atherosclerotic plaques and improve pathological states such as abnormal glycolipid metabolism (Figure 2) (Liu et al., 2019). These findings support the positive impact of seaweed on cardiovascular and immune health from different perspectives.

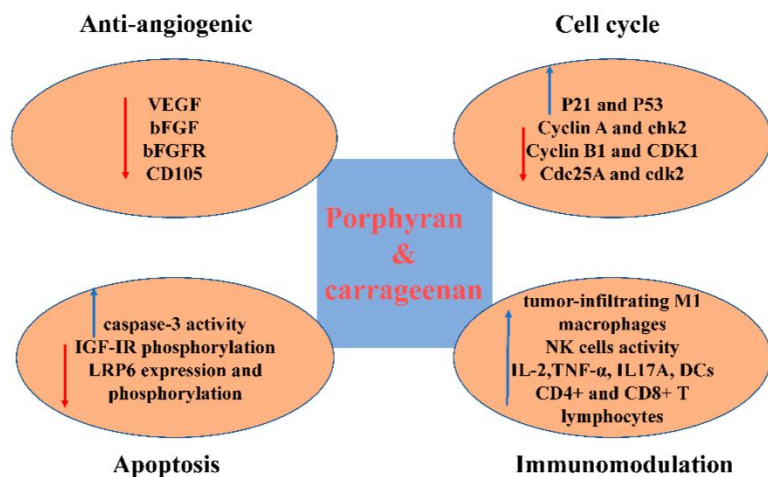


Figure 2 Possible mechanism in the anti-cancer activity of porphyran and carrageenan (Adopted from Liu et al., 2019)

6.3 Cross-cultural comparison: differences in seaweed consumption in East Asia and Western countries

East Asian countries have traditionally had high intake of seaweed, while Western countries have not started to accept seaweed foods such as seaweed until recent years. This difference makes East Asian population more accessible to the unique nutritional and health benefits that seaweed provides. The study also found that Asian immigrants who maintain high intake of seaweed have better health indicators than pure Western dieters (Bouga and Combet, 2015). The consumption differences of seaweed in different cultural contexts provide an interesting perspective for nutrition and health research. With the popularization of global health concepts and the development of marine food, seaweed is expected to benefit more people in different regions from their nutritional and health care value.

7 Conclusions and Prospects

Nagano has excellent nutritional value and extensive health benefits. Its rich in protein, dietary fiber, vitamins and minerals provide important nutritional supplements for humans; unique functional ingredients such as polyphenols, phycobili protein and seaweed polysaccharides give seaweed significant antioxidant, anti-inflammatory, immune regulation and other biological activities, reflecting its comprehensive value as a natural functional food (Kumari et al., 2022).

The study of seaweed highlights the great potential of marine resources in improving human nutrition and health. In the future, scientific interpretation of the nutritional effects of traditional foods should be strengthened and incorporated into public nutrition strategies. For example, moderate intake of seaweed is recommended in dietary guidelines to improve the nutritional and healthy level of the population.

There is still broad room for in-depth research on seaweed. It is recommended to focus on the mechanism of action of active ingredients of seaweed (such as molecular-level antioxidant and immune regulation pathways), evaluate the impact of long-term consumption of seaweed on the risk of chronic diseases, and develop innovative applications of seaweed in the fields of functional food and biomedicine. Through continuous research and development, seaweed, a traditional marine ingredient, is expected to play a greater role in human health protection in the new era.

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Conflict of Interest Disclosure

The authors confirm that the study was conducted without any commercial or financial relationships and could be interpreted as a potential conflict of interest.

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