Korean seaweeds as a food of future: an update on use and risk factors

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Seaweeds are significant sources of biological importance with an ability to produce a wide variety of marine-based compounds having various biological properties. Recently, there is an urgent need on consistent use of marine-based seaweeds as a source of food and bioactive compounds. This review discusses the risk of hazards due to heavy metals and iodine contents, beneficial effects for human, children and pregnant women's consumption. High iodine content is also a burning problem of seaweed consumption in daily food, therefore here we discussed various view for using seaweed in our daily food. Although plethora of research in aspects of drug development has been done on seaweeds which possess molecules of potent pharmaceutical significance, there is a lot to do with aspects of developing seaweeds as functional food supplements. In this way, it is possible to promote sustainable awareness for seaweed based drug development to assert the economic development of marine industries.

[Keywords: Seaweeds, Marine drug discovery, Risk hazard, Functional food supplement]

Introduction

Biologically, seaweeds are classified as macroalgae, with sub-classification as brown (Phaeophyta), red (Rhodophyta) or green algae (Chlorophyta). Marine algae are rich in dietary fiber, vitamins, and minerals, as well as long-chain polyunsaturated fatty acids. Because seaweeds are low in calories and full of nutrients, adequate consumption of seaweeds is beneficial to health. Marine algae nori (Porphyra), wakame (Undaria), and Kombu (Laminaria) are popular food ingredients in Asian countries such as Taiwan, China, Japan, and Korea. Seaweeds are well-known food sources with rich iodine content. In Korea, there are 780 seaweed species of brown algae, green algae, and red algae including 50 edible species.

Historically, seaweeds are a readily available food sources that have been consumed by the coastal community since ancient time. Seaweeds are consumed habitually in many countries in South-East Asia. However, as a whole food it is not considered a habitual component of the Western diet. In the West, seaweed isolates (e.g. alginate from brown algae and agar or carrageenan from red algae) are typically used industrially. Seaweed consumption has gained a measure of acceptance in some Westernized cultures such as Hawaii, California and Brazil, where there are large Japanese communities who have had a tangible influence on the local dietary practices. Low consumer awareness regarding potential health benefits and a lack of previous experience of seaweed challenges its use in the daily diet.

Although edible seaweeds possess a significant amount of dietary fibers, proteins and vitamins along with low amount of lipid profile, they may interfere with the bioavailability of other dietary. Since complete digestion of seaweed polysaccharide is limited through intestinal digestive enzymes, thus reflecting the ability of potential dietary fibers. These dietary fibers differ in composition, chemical structure, physico-chemical properties, and biological properties such as swelling capacity, water-holding capacity, oil-holding capacity, and glucose absorption capacity from plant-based dietary fibers, hence increasing availability of other types of dietary fibers.

Production of free radicals results in the increased amount of oxidative stress. Disbalance in the
normal redox state of cells can cause toxic effects through the production of free radicals that damage important cell components including proteins, lipids, and DNA. Oxidative stress from oxidative metabolism causes base damage, as well as strand breaks in DNA mostly mediated by reactive oxygen species (ROS) such as superoxide radical, hydroxyl radical and hydrogen peroxide radical. Seaweeds are exposed to a range of light intensity and increased amount of oxygen in their open environment which may result in the production of the high amount of free radical production. As reported earlier, seaweeds ability makes them free from oxidative damage due to presence of protective antioxidant enzymatic system, suggesting their great stability during storage. So far, only a limited amount of research has confirmed antioxidant activity of seaweeds. Since seaweeds possess a rich amount of polysaccharide, mineral, protein, and vitamin, their antioxidant activity might be correlated due to such substances with a significant value of them to serve as a functional food and pharmaceutical supplement for human diet.

Therefore, concerning these issues, here we aimed to present an update on Korean seaweeds being used in daily life, along with their beneficial and harmful effects in human (children, pregnant women and adults) as well as their role in the current drug discovery scenario.

Risk factors related to high consumption of seaweeds

Heavy metal contents in Korean seaweeds:
The main dietary exposure to heavy metals occurs through food consumed in a large quantity and high frequency. The blood Hg level and dietary exposure level of Hg were both higher than those in the European Union. Lim et al., (2015) measured that Pb and Cd were the highest (median value) in the seaweed (94.2 μg/kg for Pb; 594 μg/kg for Cd). Seaweeds can be contaminated with heavy metals because of bioaccumulation. The heavy metal contents in most edible seaweeds are generally below the maximum concentrations permitted in most countries. Heavy metals could be a safety risk for seaweed consumption, but most countries regularly monitor the heavy metal contents in seaweed and seafood products. In this respect, the food safety risk of seaweeds in relation to dangerously high heavy metal levels is low.

Reports revealed the content of arsenic, mercury, lead, and cadmium in various seaweed samples in Korea with an average concentration of total arsenic (17.4 mg/kg), mercury (0.01 mg/kg), lead (0.7 mg/kg) and cadmium 0.5 (mg/kg) which were found under the standard limit of detection. However, variations in metallic contents were seen based on the types of seaweed analyzed. World Health Organization (WHO) has estimated a consumption limit of the above mentioned metals up to 8.5 g/day representing 0.2–6.7% weekly tolerable intake. These findings suggested that even a high consumption of seaweed represents a low probability of health risks from these metals to Korean population.

Hazardous effects of high iodine intake and limits for seaweeds:
Korea is a region abundant in foods containing iodine, such as seaweed and fish. An adequate amount of iodine consumption is extremely important as both a deficiency and an excess of iodine can result in health problems. Iodine is required throughout life and is related to proper cognition function development for children. Although iodine is essential for proper thyroid function, too much or too little iodine is harmful to health. In recent years, reports of food recalls due to excessive iodine content in Australia, Ireland, Singapore, and the European Commission Rapid Alert System for Food and Feed have raised concerns internationally, especially for seaweed and seaweed products.

Occasionally food with low iodine content will also cause consumer concern. According to the news released from the Center for Food Safety in Hong Kong, some baby milk powder products had very low iodine content. In Europe, the United States, and Australia, the recommended dietary reference intake (DRI) of 0.15 mg/d for iodine has been established. The DRI is set at 0.14 mg/d for adults in Taiwan. For consumer health, the World Health Organization set a provisional maximum tolerable daily intake of 1.0 mg iodine/d (0.017 mg/kg body weight) from all sources. The tolerable upper intake level of iodine is 1.0 mg/d for adults older than 20 years in Taiwan (FDA, 2011). The upper intake level is 1.1 mg/d for adults in the United States and Australia. According to Zimmermann and Andersson (2012), there are 32 countries with iodine deficiency problems, more than half of which are in the industrialized world. Knowledge about the iodine content in food can help consumers to maintain optimal iodine consumption and can protect human beings against excessive intake of iodine. Although the European Union has not issued any regulation on maximum permissible iodine levels in algae food products, France has set a limit of
5 mg/kg dry matter for iodine in edible seaweeds. The Federal Institute for Risk Assessment in Germany warned that dry algae food products with more than 20 mg/kg dry weight might damage health. The US Food and Drug Administration has set an upper limit of 5000 ppm for iodine in algal products on a dry mass basis, whereas Australia has set a maximum tolerable iodine level of 1000 mg/kg dried weight in algal food.

Iodine intake effects from seaweeds in Korean cancer patients:

Recent statistics have confirmed about 22.3% of the increase in thyroid cancer in Korea. A number of researches through the use of radioactive iodine therapy have been conducted for the initial management and curation of thyroid cancers. Successful application of radioactive iodine therapy increase the level of thyroid-stimulating hormone (TSH) thereby deplete the whole body iodine pool through a low-iodine diet in thyroid patients. The American thyroid association has a set an optimized parameter of less than 50 μg daily for 1-2 weeks before radioactive iodine therapy for thyroid patients, which is less than 100 μg daily in Korea due to consumption of iodine-rich diet. Despite variation in the intake of iodine level differ region to region, Koreans are classified as having more than adequate amount of iodine intake. Three-side water boundaries have made a surplus availability of seaweeds and seafoods in Korea, which has led the Korean population to have an iodine-rich diet. Current survey data confirm the median iodine intake level as high as 375.4 μg per day in Korea, where seaweeds, vegetables and fish represent for 65.5, 18 and 4.8% of iodine, respectively. Recently it was confirmed that consumption of a low iodine diet was able to significantly reduce the level of iodine intake for thyroid associated patients. This resulted in the simultaneous decrease in other essential nutrients suggesting the need of developing a practical dietary protocol for a low iodine diet patients in Korea.

Health beneficial facts of seaweed consumption

Salt iodization is the method used by most countries to combat iodine deficiency disorders. However, salt has long been known to elevate blood pressure, which is the most important cause for 62% of strokes and 49% of coronary heart diseases. According to NAHSIT 2005-2008, salt intake was 11.4 g in men and 8.0 g in women aged 19-64 years, which is much higher than the salt DRI of 6.0 g, and salt intake should be reduced. Reducing salt intake has become a global trend to decrease the risk of cardiovascular diseases. Seaweed with its high iodine content could be useful to remedy a dietary iodine deficiency without the side effect of hypertension brought on by the salt. Seaweed consumption has been shown to lower blood pressure as revealed in the studies of Fitzgerald et al. (2011), and Wada et al. (2011). Bocanegra et al. (2009) linked the hypotensive effects to the dietary fiber found in seaweeds, and Fitzgerald et al. (2011) ascribed the antihypertensive effects to the bioactive peptides in seaweeds. Sobko et al. (2010) attributed the blood pressure-lowering effect of seaweeds to their rich nitrate content and noted that the seaweed laver could contain nitrates as high as 3990 to 3940 mg/kg.

Use of Korean seaweeds in food and medicine sector

There are some controversial facts about the consumption of seaweed food in daily life. According to Yeh et al. (2014) algal products with different iodine concentrations need to be taken into account in the nutritional survey for health hazards and benefits evaluation. To prevent excessive consumption, it is imperative for consumers to be knowledgeable about the iodine contents in different food groups. Adequate consumption of seaweed is beneficial for health. Iodine fortification with seaweeds of high iodine content will not cause hyperthyroidism if the seaweed is prepared by boiling in the soup with abundant goitrogenic vegetables. Further studies should be conducted to understand the bioavailability of iodine in humans and to comprehensively profile the goitrogenic contents in different food groups.

Consumption of seaweed in Japan and Korea has been developed to assess dietary intake of seaweeds, consumption is so infrequent in most Western cultures that it is not considered within nationwide dietary intake assessment surveys. In the USA and Canada seaweed is cultivated in onshore tanks and the market for it is growing. In Ireland there is a renewed interest in seaweed that once formed part of the traditional diet. As consumer health and nutrition become more influential in the food industry, the use of seaweed as an ingredient is on the rise. Sargassum muticum (Korean seaweed), a species of brown algae called “Mojaban” has been a favorite food for years as it is used for preparing “Mom-guk” soup, a well-known traditional seafood broth of Jeju Island, South Korea. “Mom-guk” is blessed with the abundance of various minerals, vitamins and dietary
fibers. Brown algae are increasingly on the focus as a natural healthy diet. It seems important to rectify a poorly-balanced nutritional condition of dietary habits to prevent life-style related diseases, such as metabolic syndrome\textsuperscript{15}. More recently, food industry, agricultural community and now the consumers have all shown a growing interest in the field of functional foods. Brown algae is a rich source of structurally-novel and biologically active metabolites\textsuperscript{45}.

The incorporation of seaweed into foods has also been shown to have a preservative effect, particularly with regards to Gram-negative bacteria, reducing the need to add salt\textsuperscript{46}. The antimicrobial properties of seaweed extracts have been well documented over the years\textsuperscript{47}. However, there would appear to be a lack of published information regarding the antimicrobial properties and preservative effects when seaweed as a 'whole food' is incorporated into a food matrix. Interestingly, when a methanolic extract of the seaweed is used in a typical antimicrobial susceptibility test, then the trend is also mirrored with Gram positive organisms, on the whole, showing more susceptibility to the antimicrobial agent(s) contained within the seaweed.

Additionally, fucoxanthin, and phlorotannins present in seaweeds exhibit potent antihypertensive effect. Seaweed extracts of Korean red algae have been found to exhibit significant ACE-I inhibitory effect with IC\textsubscript{50} value ranging from 12.21–124.69 μg/ml\textsuperscript{48}. Also ethanolic extracts derived from various Korean seaweeds including the members of Rhodophyta, Phaeophyta and Chlorophyta were found to exhibit remarkable ACE-I inhibitory effect with 50% inhibitory effect\textsuperscript{49}. In addition, ingestion of Korean seaweed had a dramatic physiological effect on lowering blood glucose levels and lipid profile, along with significant enzymatic antioxidant properties in type-II diabetes, suggesting an enormous role of Korean seaweeds in glycemic control\textsuperscript{13}.

### Current updates on seaweed drug discovery

Nature has been the traditional source for organic chemical compounds used in medicine. For over 3,000 years, early societies recognized that their immediate environments were a rich source of plants that provided methods to treat ordinary infections, inflammation, arthritis, cancers, and many human diseases. Over the centuries, it became apparent that discrete chemical components of plants were responsible for these effects. It was not, however, until the seventeenth century that science would be sufficiently developed to begin to isolate, purify, and define these drug substances. Among the first pure drugs isolated were the powerful painkiller morphine purified from “tincture of opium,” and aspirin, from the bark of the willow tree. Still today, especially in Asia, traditional medicines are prescribed and dispensed in ways similar to the historical past. However, many industrialized societies have moved in the direction of prescribing pure drugs with well-defined physiological effects. In the context of natural product-based drug discovery, bioinformatics is producing new information that affects many of the key steps in the drug discovery process. The development of new healthcare products relies on the availability of a continuous pipeline of novel molecules. The discovery process typically takes about 4-8 years. Schematic flow chart of the drug development process is shown in Figure 1.

![Figure 1 - Schematic flow chart of drug development process using seaweeds.](https://example.com/fig1.png)

The revolutionized therapy of infectious diseases by the use of antimicrobial drugs has certain limitations due to changing patterns of resistance in pathogens and the side effects they produce. These limitations demand for improved pharmacokinetic properties, which necessitates continued research for the search of new antimicrobial compounds for the development of drugs. Seaweeds are used in traditional remedies in many parts of the world. The production of inhibitory substances by seaweed was noted as early as in 1917. The extracts and active constituents of various algae have been shown to have antibacterial activity in vitro against Gram-positive and Gram-negative bacteria; some examples are given in Table 1. The production of antimicrobial activities
was considered to be an indicator of the capacity of the seaweeds to synthesize bioactive secondary metabolites. There are numerous reports of compounds derived from macroalgae with a broad range of biological activities, such as antibacterial, antivirals, anti-tumors, anticoagulant and antifouling. Compounds with cytostatic, antiviral, anti-helminthic, antifungal and antibacterial activities have been detected in green, brown and red algae. Also, considering their great taxonomic diversity, investigations related to the search of new biologically active compounds from algae can be seen as an almost unlimited field.

Recently, Korean seaweed polysaccharides have been extensively studied for alternative energy application. Because their producing cost is high and efficiency is low, their industrial applications have been limited. The main component of cell wall of red algae members belonging to orders, Gelidiales and Gracilarias is agar. Red-algae agar or galactan, consisting of D-galactose and 3,6-anhydro-L-galactose, is suitable for bio-product application if hydrolyzed to monomer unit. For the hydrolysis of agar, chemical or enzymatic treatment can be used. Since, research is a crucial part of the response to new and emerging diseases, a sustained, forward-thinking applied research program would enable scientists to identify the weak links in the armor of emerging microbes, create novel ways to fight microbial foes, and evaluate the preventive power of new approaches. The priority for the next decades should be focused in the development of alternative drugs and/or the recovery of natural molecules that would allow the consistent and proper control of pathogen-caused diseases. The general trend to more widespread antibiotic resistance is relentless and if it continues unabated, deaths from what were previously treatable infections will occur with increasing frequency. The initiatives must be implemented now because the battle against antibiotic resistance is being lost. Complacency and delay will have major detrimental effects on future public health. Seaweeds may be an answer to unsolved and the growing problem of resistance, a novel untapped source to combat infectious diseases.

The annual global production of seaweeds in Asia is accounted about $6.5 \times 10^6$ tonnes where marine resources play a significant role in its production. In Asian countries, seaweeds are often consumed as marine vegetables.

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**Table 1-List of important seaweeds used in drug formulations**

<table>
<thead>
<tr>
<th>Seaweed</th>
<th>Bioactive component</th>
<th>Pharmacological property</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undaria pinnatifida</td>
<td>Crude extract</td>
<td>Anti-inflammatory</td>
<td>[57]</td>
</tr>
<tr>
<td>Cladophy whole fucus</td>
<td>Fucan</td>
<td>Antiviral</td>
<td>[58]</td>
</tr>
<tr>
<td>Kappaphycus striatum</td>
<td>Kappa-carrageenan</td>
<td>Anticancer</td>
<td>[59]</td>
</tr>
<tr>
<td>Sargassum vulgar</td>
<td>Alginate</td>
<td>Anticancer</td>
<td>[60]</td>
</tr>
<tr>
<td>Botryocladias occidentalis</td>
<td>Sulfated galactan</td>
<td>Anticoagulant</td>
<td>[61]</td>
</tr>
<tr>
<td>Bryopsis sp</td>
<td>Kahalalide F</td>
<td>Anticancer</td>
<td>[62]</td>
</tr>
<tr>
<td>Eisenia bicyclis</td>
<td>Polyphenols</td>
<td>Antioxidant</td>
<td>[63]</td>
</tr>
<tr>
<td>Ulva fasciata</td>
<td>Crude extract</td>
<td>Antimicrobial</td>
<td>[64]</td>
</tr>
</tbody>
</table>

**Table 2-Nutritive contents in mostly used seaweeds in major Asian countries**

<table>
<thead>
<tr>
<th>Seaweed</th>
<th>Biological name(s)</th>
<th>Nutrients</th>
<th>Mostly used country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nori</td>
<td>Porphyra spp.</td>
<td>30-50% protein; 0.1% sugar; High vitamin A, C; Niacin and folic; amino acid; Low NaCl;</td>
<td>Japan, Korea, China</td>
</tr>
<tr>
<td>Anori</td>
<td>Monostroma spp., Enteromorpha spp.</td>
<td>20% protein; vitamin; mineral; low fat &amp; NaCl, high Fe, Ca, Mg; used for flavoring</td>
<td>Japan, Korea</td>
</tr>
<tr>
<td>Wakame</td>
<td>Undaria pinnatifida</td>
<td>Vitamin B, K; fucoxanthin; Mg, Ca, Cu, Co, Ni, Zn; about 4 calories per 10 g of raw; low levels of fat and carbohydrates; color can be changed from brown to green through heating</td>
<td>Korea, Japan</td>
</tr>
<tr>
<td>Kombu</td>
<td>Laminaria japonica</td>
<td>10% protein, 2% fat, moderate level vitamin (A, C); high in iodine; kombu broth, tea, soup</td>
<td>Japan</td>
</tr>
<tr>
<td>Hiziki</td>
<td>Hizikia fusiforme</td>
<td>Similar to Kombu; phlorotannins is removed before eating; inorganic arsenic; fibre; Mg/Ca=1/2;</td>
<td>Korea</td>
</tr>
</tbody>
</table>
Japanese people are the main consumers with an average of 1.6 kg (dry weight) per year per capita\(^4\). Seaweed is considered to be second largest freshwater farming industry in the world. With a global production of 7.5 million tons. Seaweed consumption is more in second-world countries, but advances in intercontinental trades and increased migration, immigration, and visits have impacted the consumption in the first and third world countries. China is the largest producer of seaweed accounting for approximately 99 percent of total production. Figure 2 shows the review and global seafood business trends at a glance\(^5\). Since seaweed farming does not require fertilizers, water cleaning, environmental impact is minimal. Moreover, China, Japan and Korea are considered intensive seaweed growers in Asia. Table 2 precises details on major seaweed species that are very popular in Asian continent.

**Fig.2 – Distribution of seaweed production in major Asian countries.**

**Future prospects and conclusion**

In addition to this, researchers urge awareness of dietary iodine intake in postpartum Korean-American women who consume brown seaweed soup. Recently this has been an important issue, as traditionally, Korean and Korean-American women eat brown seaweed soup daily during their early postpartum period, yet they are not aware of the risks associated with eating too much iodine-rich foods. The researchers conclude that additional studies need to be done to evaluate the potential adverse effects of long-term high dietary iodine consumption in Korean and Korean-American women and their infants. Additionally, the researchers recommend that health care providers be educated about Korean and Korean-American woman’s dietary habits so that they can provide more guidance as to what their patients should be eating that is healthy for both the women and their infants.

### References


