The Pharma Innovation Journal 2021; SP-10(8): 350-357

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2021; SP-10(8): 350-357

www.thepharmajournal.com
Received: 01-06-2021
Accepted: 03-07-2021

Hauzoukim
School of Fisheries, Centurion University of Technology and Management, Odisha, India

Sagarika Swain
School of Fisheries, Centurion University of Technology and Management, Odisha, India

Anwesha Roy
School of Fisheries, Centurion University of Technology and Management, Odisha, India

Subal Kumar Ghosh
School of Fisheries, Centurion University of Technology and Management, Odisha, India

Corresponding Author
Hauzoukim
School of Fisheries, Centurion University of Technology and Management, Odisha, India

Application of seaweeds and functional properties

Hauzoukim, Sagarika Swain, Anwesha Roy and Subal Kumar Ghosh

Abstract
Seaweed has been eaten throughout Asia since the dawn of time. Marine algae have been used as raw materials in the production of numerous seaweed food products in Japan, such as jam, cheese, wine, tea, soup, and noodles, and as a source of polysaccharides for food and medicinal uses in Western nations. Since ancient times, seaweeds have been a valuable source of food, fodder, fertiliser, and medicine. Seaweed Protein Concentrates (PCs) have become more significant for the food sector, particularly in developed countries, because to its high protein concentration. Most seaweeds have a lot of ash (which implies a lot of different minerals), a lot of fibre, a little protein, and a modest quantity of fatty acids. Members of the Rhodophyta have a high protein content (32%), whereas those of the Chlorophyta have the greatest carbohydrate content of 35%. Padina Spp., Porphyra Spp., Laminaria Spp. and Undaria Spp., are the most prevalent edible seaweeds in Asian nations. Sea weeds are a great way to boost the nutritional value of a variety of meals.

Keywords: seaweeds, functional foods, applications

Introduction
Seaweeds are phytosynthetic macroalgae that live in brackish or salt water. Benthic marine algae, as the name implies, are connected algae that live in the water. Seaweeds or marine macroalgae are common names and some authors even call them sea vegetables (Dhargalkar and Neelem 2005, Wong and Cheung 2000) [11, 47]. They're basic organisms with distinct characteristics. Seaweed cultivation has become a major industry in Asia, allowing these plants to be used to their full potential (David 2002) [8]. Seaweeds are a part of the main food in Japan, Korea, and China, as well as being delicacies in several Western countries. For decades, they have been gathered for a variety of purposes in various nations, particularly on the Asian continent. Seaweed has long been consumed in Far Eastern countries and the Hawaiian Islands, but in the West, it is mostly used as a source of phycocolloids, thickening, and gelling agents for a variety of industrial applications, including food. The chemical composition of seaweed changes depending on the species, habitat, maturity, salinity, temperature, light intensity, and environment (Floreto and Teshima 1998) [16].
Seaweeds have attracted attention as nutraceuticals, or functional foods, in the last three decades, thanks to their nutritional benefits that go beyond their macronutrient composition. Furthermore, seaweed has been mined for biologically active metabolites in order to create medicinal products (Davis and Vasanthi 2011 [12]; Zerrifi *et al*. 2018 [49]). Obesity combined with mineral and vitamin insufficiency has become a public health crisis (WHO 2019) [46]. At the same time, food and lifestyle-related disorders, such as type 2 diabetes, cancer, and metabolic syndrome, are becoming more common. According to global dietary research, nations that consume seaweed on a daily basis have much lower rates of obesity and diet-related disorders (Nanri *et al.* 2017) [32]. Although a variety of dietary variables may play a role in this, the study of seaweed alone for its nutritional and therapeutic benefits has been suggested. This article discusses current advances in seaweed uses for human health.

Seaweeds resources
Seaweeds are macro-algae, multicellular plants growing in fresh as well as salt water. They were divided into three groups based on their pigmentation: Chlorophyta (green algae), Rhodophyta (red algae), and Phaeophyta (Brown algae).

Brown seaweeds:
Brown algae belong to the phylum pheophyta. These medium- to large-sized seaweeds are found at depths between the greens and the reds. They are the most widely utilised species for

alginates and are an excellent source of iodine. Alginates from macroalgae like the Laminaria (kelp) family are utilised as thickeners in a wide range of products, from salad dressings to oil-drilling muds and fluids to welding rod coatings and paper production. The coloration of these algae is brown or olive-green (Waaland 1977) [45]. The dominance of the xanthophyll pigment fucoxanthin, which conceals other pigments such as chlorophyll-a, chlorophyll-c, beta-carotene, and other xanthophylls, gives these algae their brown colour. Complex polysaccharides, sugars, and higher alcohols are common food reserves. Alginic acid, a long chained heteropolysaccharide, makes up the walls of these algae, but there is no evidence of real starch. Each year, around 26,000 tonnes of brown kelp (*Macrocystis pyrifera*) are collected for alginic acid extraction off the coasts of California, Mexico, and Chile (Dawes 1998; David 2002 [9, 8] and Kumar *et.al* 2008) [21]. There are 108 species of brown alage are present in red sea waters of Eritrean coast. The majority of the 2200 species of brown algae that exist in the world inhabit in the marine enviroment, and the majority of them are found in cold water. Sargassum, Porphyra, Undaria, Hizikia, and Fucus are examples of brown seaweeds (Kumar *et.al* 2008) [21].

Red seaweed:

The most numerous and commercially lucrative marine algae are red algae. Rhodophyta is the phylum in which they are categorised. From the intertidal to the subtidal zones, red algae may be found on stony coastlines. Some algae species can be found considerably deeper than brown or green algae. Red seaweed is the biggest category of seaweeds, with 550 species reported worldwide. The most common reserves are floridean starch and floridoside. Because no algae have flagella, certain red algal cells can crawl about like amoebae, but none can swim quickly. The Red Sea is home to a diverse range of red algae, with a total of 128 different types identified (Waaland 1977) [45]. The pigments phycoerythrin and phycocyanin are dominant in these algae, giving them their red colour (Lee 2008) [77]. Carrageenan and cellulose agar make up their walls. Both of these long-chain polysaccharides are widely used in industry. Coralline algae, which secrete calcium carbonate on the surface of their cells, are an important type of red algae. These corallines have been utilised in the treatment of bone loss. There are over 6500 different species of red algae, the majority of which are marine. Carrageenan, a frequently used food component, is currently mostly sourced from the red algae Kappaphycus and Betaphycus. Gracilaria, Gelidium, Euchema, Porphyra, Acanthophora, and Palmaria are examples of red seaweeds (Dawes 1998 [9], David 2002 [8], Nisizawa 2002 [31]).

Green seaweed:

Chlorophyta is the phylum that includes green algae. Green seaweeds can be found in the intertidal zone (between the high and low water marks) as well as in shallow water with lots of sunlight. Due to the closeness of their colours, they are considered to be the algae most closely linked to plants. Many types of green algae grow on or near the ocean's surface, connected to stony substrates (Shannon and Abu-Ghanam 2019) [42]. They are not swept up on the beach by waves because they are connected to a substrate. During storms and severe wave activity, however, certain green algae may be ripped off their substrates. Around 140 species have been identified around the world's coasts, with about 50 species found in the Eritrean Red Sea coast. Sea lettuce (*Ulva lactuca*), which grows in brilliant green sheets up to 30 cm in diameter, is one of the simplest to recognise. It is edible, as its common name suggests, however its profuse growth generally signals sewage contamination. Gut weed (*Enteromorpha intestinalis*), a tubular green seaweed that prefers high-nutrient environments, is another example. Sea rimu (*Caulerpa brownii*) is common green seaweed that is edible and resembles the leaves of the big tree rimu (Kasimala, 2015) [20]. Ulva, Monostroma, Enteromorpha, and Caulerpa are some of the examples of green algae (Dawes 1998 [9], David 2002 [8], Nisizawa 2002 [31], Kumar 2008 [21])

Micro and macro nutrients present in seaweeds

Seaweed has been harvested and consumed by coastal communities all over the world since the dawn of civilization (Dillehay *et al*. 2008) [13]. Improved understanding of dietary sciences and the nutrient-dense nature of algae have led the incorporation of seaweeds or their extracts into meals to increase nutritional qualities.

Seaweeds contain about 10 to 100 times more minerals and vitamins per unit dry mass than terrestrial plants or animal-derived meals Rupérez (2002) [40]. Vitamins like A, D, E, K, C, B1, B2, B9, B12, as well as important minerals calcium, iron, iodine, magnesium, phosphorus, potassium, zinc, copper, manganese, selenium, and fluoride are among them (Misurcova 2011; Qin 2018) [26, 37]. The amount of content varies depending on the species. For example, a study on total tocopherol (vitamin E) content in brown, red, and green seaweeds ranged from 1.6 to 122 mg kg1, 10–26 mg kg1, and 8.8–12.0 mg kg1, respectively on dry weight basis (Biancarosa *et al.* 2018) [4]. Many seaweeds outperform plant and animal meals in terms of adult reference nutrient intake (Astorga-Espaa *et al.* 2015) [2], *Palmaria palmata*, red seaweed, contains 6.4 mg of iron per 8 g serving, compared to 1.2–3.1 mg in a 100 g meal of lean beef (Branscheid and Judas 2011) [3]. 8 g of *Ulva lactuca*, green seaweed, has on average 260 mg of calcium, or 37% of the RNI, whereas 8 g of cheddar cheese contains on average 5% of the RNI (Finglas *et al*. 2015; MacArtain *et al.* 2007) [15, 25].

Protein contributes for 5%–47% of the dry mass of seaweed. Red seaweeds have the highest protein, and brown seaweeds have the least amount (Cerná 2011) [6]. 42% to 48% of the total amino acids in seaweeds are essential amino acids (Wong and Cheung 2000) [47]. *Undaria pinnatifida* gets a 1.0, Porphyra gets a 0.91, and Laminaria saccharina gets a 0.82. (Murata and Nakazoe 2001) [27]. The high polyphenolic concentration in seaweeds, on the other hand, can make algal proteins more difficult to digest (Wong and Cheung, 2001) [48]. If soy or mycoprotein are added as a source of amino acids in the diet, seaweeds remain a viable alternative to animal-derived protein (Shannon and Abu-Ghannam 2019) [42].

Seaweeds have a total lipid content ranging from 0.60 percent to 4.14 percent (El Maghraby and Fakhry 2015; Rodrigues *et al.* 2015) [14, 39]. Polyunsaturated fatty acids such as docosahexaenoic and eicosapentaenoic acid make up the majority of algal lipids. The most prevalent mono-unsaturated (n-6, or omega-6) fatty acids found in algae are linoleic and arachidonic acids (Belattmania *et al*. 2018) [5]. Palmitic and myristic acids are two of the most important saturated fatty acids. Consuming them in an unbalanced ratio, on the other hand, can lead to chronic inflammatory illnesses including obesity, rheumatoid arthritis, non-alcoholic fatty liver disease, and cardiovascular disease (Patterson *et al.* 2012) [34]. In addition to basic nutrition, fucoxanthin, phycobiliproteins, phlorotannins, and sulphated polysaccharides have therapeutic benefits (Mysliwa-Kurdziel and Solymosi 2017; Pérez *et al.* 2016) [28, 35].

The polysaccharide content ranges from 4% to 76% (dry mass) (Paniagua-Michel *et al.* 2014) [36]. Cellulose is an indigestible, non-nutritive polymer that provides structure to the cell walls of many seaweeds, accounting for between 2% and 10% of total polysaccharides. Different phyla have different digestible polysaccharides. Brown algae poly saccharides include alginates, fucoidans, and laminarin; red algae poly saccharides include carrageenans and agarans; and green algae poly saccharides include ulvans (Jiao *et al.* 2011) [17]. The majority of algal polysaccharides are non-starchy fibre, which helps to maintain normal blood glucose levels and contributes to the RNI of 30 grams of fibre per day1 (BNF 2016) [18]. Algal fibre's structural chemistry varies from that of terrestrial plants. This provides them with functional and bioactive characteristics that are not present in land-based fibre sources (Jimenez-Escrig and Goi 1999) [19].

Use of Seaweeds in Food

Seaweeds are eaten in salads, soups, pickles with sauce, and pasta jellies, among other dishes. Alginates are used as thickening agents in sauces, syrups, and ice cream toppings (Hsu 1985, Leigh 1979), pie fillings by reducing moisture retention by the pastry, cake mixes as it thickens the batter and aids moisture retention (Mabeau *et al.* 1992) [29]. Alginic acid swells in the stomach and fills it so that the dieter no longer feels hungry. Alginic acid cannot be assimilated by the body so no calories are absorbed (Mc Neely and Pettitt 1973 [30], Ooraikul and Aboagye 1986 [33]). Alginates are used in restructured meat products like shrimp or crab meat products and also for making structured fruit products (Morimoto 1985, Schmidt and Means 1986, Ooraikul and Aboagye 1986 [33]). Seaweed carrageenan and agar are used as thickening and gelling agents in food, pastry, yoghurts, chocolate milk and as growth medium for microorganisms (Mc Neely and Pettitt 1973) [30].

Meat based foods

Meat is part of the staple diet of billions of people worldwide and is a good source of protein, bioavailable iron, zinc, selenium, magnesium, and vitamins B, D, and A. However, red meats like pork and beef can raise the LDL cholesterol levels due to their high levels of saturated fat. Meat-derived products such as burgers, frankfurters, salami, and deli-sliced meats also contain salt as a necessary ingredient for preservation (monosodium glutamate and sodium nitrate), flavour and texture enhancement, contributed to disorders such as heart disease, obesity cancer and other disorders (Ramesh & Muthuraman 2018). López-López *et al.* (2009) [38, 23] reported an integrated 5.6 percent of dried, milled seaweed into pork frankfurters, beef burgers, and restructured chicken steaks using *Undaria pinnatifida, Porphyra umbilicalis, and Himanthalia elongata.* By raising the ratio of n-3 to n-6 polyunsaturated fats, the seaweeds considerably reduced the thrombogenic index of the goods' fatty acid profile. Sodium levels were substantially lower, but calcium, magnesium, and manganese, vitamin K, and soluble polyphenolic compounds were significantly higher.

The incorporation of seaweeds has produced several meat products of high consumer acceptance with significantly lower levels of saturated fat and salt, no artificial additives, plus increased fibre and polyunsaturated fat content (Cofrades *et al.* 2017) [7]. The polyphenolic compounds, vitamins A, C, E and selenium act as preservatives and natural antioxidants in the meat. Fucoxanthin extracted from *Cystoseira barbata* improved the functional and nutritional attributes of cured turkey meat sausages with the addition. An increase in antioxidant capacity, inhibition of lipid peroxidation, colour stability, and angiotensin-I converting enzyme, which raises blood pressure was observed within 15 days of studies Sellimi *et al.* (2017) [43].

Plant based foods

Aside from unprocessed vegetables, fruit, pulses, and rice, grains are the source of the bulk of plant-based processed goods consumed globally, and they are part of nearly everyone's daily diet (Stephen *et al.* 2017) [44]. Thousands of various types of bread, pasta, noodles, and pastries are made from these grain or cereal-based goods. Because the bulk of these meals are made with refined white flours, they are low in fibre, protein, minerals, and vitamins, but rich in starch. As a result, adding high-fiber, nutrient-dense functional ingredients like seaweed to cereal-based products has the potential to boost nutritional intake. *Himanthalia elongate* enhanced the phytochemical content of wholemeal and white wheat flour breadsticks, the texture and colour acceptibility with 17.07% H. elongata and 21.89% white flour. Total phenolic content rose by 427%, as compared to 27.67 mg GAE/100 g in the control to 145.88 mg GAE per 100 g in the *H. elongata*-enriched sample. The antioxidant capacity increased by 87% as measured by DPPH activity and total dietary fiber increased by 71% as reported Cox & Abu-Ghannam (2013). Arufe *et al.* (2018) [50, 51] studied the techno-functional properties of *Fucus vesiculosus* to improve the antioxidant profile of white bread while maintaining acceptable density and crumb texture. Dried and milled *Eucheuma cottonii* helps improved the protein, lipid, fibre and the mineral profile of wheat flour noodles (Kumoro *et al.* 2016) [22].

Epidemiological Evidence and Dietary Intervention Studies

The prevalence of chronic dietary-related diseases such as type 2 diabetes, obesity, and cardiovascular disease has risen to epidemic proportions. Pharmaceutical medicines are frequently used as first-line therapy by doctors to treat diseases and associated symptoms. While they might be beneficial, many conventional medications have significant side effects and can lose their effectiveness over time. Nutritional intervention has long been advocated as a means of preventing and treating chronic dietary-related health problems. In recent years, the areas of natural products chemistry and pharmacognosy have advanced, revealing a plethora of plant, fungal, and algal chemicals having medicinal properties. Because of their mineral-rich maritime habitat and the necessities to thrive in it, seaweed has chemical characteristics that are unlike those of terrestrial plants. To counteract abiotic stress such as UV photo-damage, high salinity, continuous oxygen exposure, and biotic stress from bacterial colonisation and marine herbivores, seaweeds produce antioxidizing, antibacterial, and other bioactive compounds.

Cancer

There is a clear link between high levels of seaweed consumption and decreased incidences of dietary-related diseases like cancer. Park *et al*. (2016) [52] studied the eating habits of 923 men and women with an average age of 56 who had previously had colon cancer surgery at the National Cancer Centre of South Korea (plus 1846 control participants). Prudent, traditional Korean, and Westernized dietary categories were the three dietary types. The prudent group, which consumed the most seaweed and vegetables, had the lowest risk of colorectal cancer, followed by the traditional diet (which consumed slightly less seaweed), and the Westernised diet group, which consumed little or no seaweed but a lot of red meat and processed foods, had the highest risk. According to Yang *et al*. (2010) [53], daily consumption of various species of Pyropia (as Porphyra) is inversely related to the risk of getting cancer. Pyropia known in Korea as 'gim' is a dried and roasted fruit (Herath *et al.* 2018; Jung and Choe 2017) [54, 55]. Cancer rates are among the lowest in the world among Japan's 127 million population, where daily seaweed intake is 14.3 g per adult per day (fresh mass) (Déléris *et al*. 2016) [56]. Several compounds, including fucoxanthin, polyphenols, and other antioxidants; phlorotannins; iodine; and sulphated polysaccharides such as fucoidan, have been linked to the multiple mechanisms by which seaweeds induce apoptosis in cancer cells (Namvar *et al*. 2012; Gutiérrez-Rodrguez *et al.* 2018 and Jiang & Shi 2018) [57,58, 59].

Obesity and metabolic disorder

Obesity when combined with vitamin and mineral deficiency has become a health sarcity. Obesity increases the risk of developing other diseases, including type hypertension, 2 diabetes, dyslipidaemia, and coronary heart disease (*Medina-Remón et al*. 2018) [60]. The consumption of fibre rich seaweed and its isolates has a positive effects on satiety, appetite, cholesterol and blood glucose level (Brown *et al.* 2014; Kim *et al.* 2008 [62]). Fucoxanthin occurs in brown seaweeds and many microalgae, and has anti-obesity properties (Shannon and Abu-Ghannam 2017) [63]. Hitoe and Shimoda (2017) [64] studied the effects of fucoxanthin on 50 women and men (aged 20–59) with a BMI of 26–30 kg m2 and a waist circumference of 90 cm (women) and 85 cm (men) with a BMI of 26–30 kg m2 (men). For four weeks, either fucoxanthin capsules or placebos were administered at doses of 1 mg or 3 mg d-1. BMI, visceral fat, basal metabolic rate, abdominal fat, and circumferences of the neck, arm, and thigh all decreased significantly in the 3 mg day group compared to the placebo group. Total fat mass, subcutaneous fat area, waist circumference, and right thigh circumference all fell considerably in the 1 mg d-1 group. There were no negative effects on blood pressure, heart rate, blood parameters, or other vital signs.

Hypertension and cardiac disease

Epidemiological studies have found an inverse connection between frequent seaweed eating and a lower incidence of hypertension and cardiovascular disease (Nanri *et al.* 2017 [65]; Maruyama *et al.* 2013 [66]; Chu *et al.* 2015 [67]; Cornish *et al.* 2015 [68]). Japan and South Korea have among of the world's longest average lifespans and use less medications for hypertension and cardiovascular disease than those who eat less seaweed (Lee *et al.* 2016 [52]; Yamori *et al.* 2017 [70]). A 15-year research of eating patterns in 79,594 Japanese men and women (aged 45–75) discovered that adherence to Japanese dietary standards was linked to a decreased risk of mortality from all causes and cardiovascular disease, particularly cerebrovascular illness, in the experimental group (Kurotani *et al.* 2016). Hata *et al.* (2001) [71, 72] used 3.3 g day1 *of U. pinnatifida* powder in a dietary intervention study on 36 elderly outpatients with hypertension in Japan. A placebo was provided to a control group of 18 gender-matched (2-year-old) individuals. After four weeks, the seaweed group's systolic blood pressure dropped by 13 mmHg, and after eight weeks, it dropped by 8 mmHg. After four weeks, diastolic pressure dropped by 9 mmHg, and after eight weeks, it dropped by 8 mmHg. In addition, after four weeks, the therapy group's hypercholesterolemia dropped by 8%.

Type 2 diabetes

Unlike the commonly genetically inherited type 1 diabetes (an autoimmune illness) that kills the beta cells of the pancreas and requires insulin injections, type 2 diabetes mellitus, a diet-related metabolic disorder often known as adult-onset diabetes that responds well to dietary intervention. Acarbose, alpha -amylase and alpha-glucosidase inhibitor frequently used to treat type 2 diabetes, can induce stomach pain and diarrhoea (Moore 2018) [73]. Many studies on animals have demonstrated seaweed's anti-diabetic effectiveness *in vivo* (Gabbia *et al*. 2017; Roy *et al.* 2011; Song *et al.* 2018; Zhao *et al.* 2018) [74, 75, 76, 88]. In human clinical studies, daily treatment of *Undaria pinnatifida* and *Sacchariza polyschides* (as *Gigantea bulbos*a) stabilises blood glucose levels, lowers serum triglyceride levels, and raises high-density lipoprotein cholesterol in type 2 diabetic patients (Kim *et al.* 2008) [62].

Antioxidants

Marine algae are known for high content in PUFA, particularly n3 fatty acids. Despite the significant amount of highly unsaturated fatty acids (HUFA), which are extremely sensitive to oxidation, the quality of these oils does not deteriorate during storage (Sakata 1997 [78], Takamutsu *et al.* 2003). Certain antioxidant mechanisms are thought to protect marine algae against oxidative degradation. The antioxidant activity of lipophilic extracts from 16 seaweed species was related to the amount of unsaturated fatty acids present (Huang and Wang 2004) [80]. Indole chemicals derived from marine algae have been shown to prevent lipid oxidation (Takahashi *et al* 1998). Compounds found in the red algae *Grateloupia filicina* have antioxidant effectiveness comparable to or better than commercial antioxidants such as BHA, BHT, and alpha-tocopherol (Athukorala *et al* 2003a, b, 2005) [82, 81]. The antioxidant activity of Mediterranean sea algae of the genus Cystoseria was equivalent to that of α-tocopherol (Foti *et al* 1994, Ruberto *et al* 2001) [83, 84]. *Hizikia fusiformis* exhibited high reactive oxygen scavenging activity, suggesting that it might be a good source of both water and fat soluble antioxidants (Siriwardhana *et al* 2003). Park *et al.* (2004) [85, 86] found that enzymatic hydrolysates of the edible seaweed *Sargassum horneri* had high hydroxyl and alkyl radical scavenging activities.

Antibacterial properties

Several chemicals found in seaweed have been shown to have antibacterial effectiveness comparable to commercial medicines. Phlorotannins, polysaccharides, fatty acids, terpenes, peptides, lactones, pigments, and chrysophaentins are just a few examples (Shannon & Abu-Ghannam 2016) [41]. Many bacteria produce a mixture of polysaccharides, proteins, and extracellular DNA to create a protective coating that allows them to flourish (Aynapudi *et al.* 2017) [87]. Biofilm development in the lungs by *Pseudomonas aeruginosa* can be deadly for those with cystic fibrosis. The action of polysaccharides from algae, such as alginates, against biofilms has been investigated. Wei *et al.* (2016) [88] used phlorotannins from *Sargassum thunbergii* to inactivate *Vibrio parahaemolyticus*, with the potential to develop the extracts as food antimicrobials and aquacultured medicines. El Shafay *et al.* (2016) [89]. extracted the fatty acids cyclopentaneacetic acid and 10,13-octadecadienoic acid from *Sargassum vulgare* and *S. fusiforme.* After treatment with *S. fusiforme* (100 l diethyl ether extract) and *S. vulgare* (50 l ethanolic extract), the cell walls of *Staphylococcus aureus* and *Klebsiella pneumoniae* were clearly punctured, killing the bacterium. Antibacterial polysaccharides, such as fucoidans, have been utilised in the past. Fucoidan was isolated from *Sargassum crassifolium* by (Huang *et al.* 2018) [90]. The extract exhibited antibacterial activity against both gram-positive and gram-negative *E. coli in vitro*.

Conclusion

Due to their significant supplies of nutrients and uses in many job areas, sea weeds are now generally welcomed by people living in coastal regions all over the world. Seaweeds, in terms of food, may be able to alleviate the issues of protein, carbohydrate, and mineral deficiencies in human nutrition by being consumed on a regular basis. As a result of the findings of this study, seaweeds are a potential health food in human diets and may be useful to the food industry as a source of high-nutrient components. Seaweeds can provide a dietary alternative because of their nutritional and commercial worth, which has increased as the quality and range of seaweed-based products has grown. Seaweeds contain a high concentration of minerals, vitamins, proteins, and indigestible carbs, making them a low-calorie meal from a nutritional profile. They have a low fat content yet are excellent in nutritional value. Seaweeds have a high concentration of essential amino acids and comparatively greater quantities of unsaturated fatty acids. Antioxidant, antimutagenic, anticoagulant, anticancerous, and antitumor properties are also found in seaweeds. They also have a vital function in the alteration of lipid metabolism in the human body when eaten. To put it another way, seaweeds are futuristically promising plants that comprise one of the most significant marine living resources with great nutritional value. Seaweeds might be used for their multifunctional characteristics as food, energy, medicine, and cosmetics, as well as as biotechnological instruments, due to their unique structure and biochemical makeup.

Acknowledgement

I would like to acknowledge the co-authors for their support and contribution in writing this review paper.

References:

1. Ateweberhan M, Prud"homme Van Reine WF. A taxonomic survey of seaweeds from Eritrea. BLUMEA 2005;50:65-111
2. Astorga-España MS, Rodríguez Galdón B, Rodríguez Rodríguez EM, Díaz Romero C. Mineral and trace element concentrations in seaweeds from the sub-Antarctic ecoregion of Magallanes (Chile). Journal of Food Composition and Analysis 2015;39:69-76.
3. Branscheid W, Judas M. Detection of bone in meat. In: Handbook of analysis of edible animal by-products (Ed. by L. Nollet & F. Toldra) 2011,278p.
4. Biancarosa I, Belghit I, Bruckner CG, Liland NS, Waagbø R, Amlund H *et al*. Chemical characterization of 21 species of marine macroalgae common in Norwegian waters: benefits of and limitations to their potential use in food and feed. Journal of the Science of Food and Agriculture 2018;98:2035-2042
5. Belattmania Z, Engelen A, Pereira H, Serrao E, Custódio L, Varela J *et al*. Fatty acid composition and nutraceutical perspectives of brown seaweeds from the Atlantic coast of Morocco. International Food Research Journal 2018;25:1520-1527.
6. Černá M. Chapter 24 - Seaweed proteins and amino acids as nutraceuticals. In: Advances in food and nutrition research (Ed. by S.-K. Kim). Academic Press, San Diego, California, USA 2011,297-312p.
7. Cofrades S, Benedì J, Garcimartin A, Sànchez-Muniz F, Jimenez Colmenero F. A comprehensive approach to formulation of seaweed-enriched meat products: from technological development to assessment of healthy properties. Food Research International 2017;99:1084–1094.
8. David T. Seaweeds. Natural History Museum, London 2002.
9. Dawes CJ. Marine botany. John Wiley & Sons, Inc., New York 1998,480p.
10. Davis PJ. Cellural actions of thyroid hormones. In: The thyroid. A fundamental and clinical text, Bravarmand LE, Utigar RD (eds). Lippincott Publ, Philadelpia 1991,190-203p
11. Dhargalkar VK, Neelam P. Seaweed: Promising plant of the millennium. Sci Cult 2005;5:60-66
12. Davis GDJ, Vasanthi AHR. Seaweed metabolite database: a database of natural compounds from marine algae. Bioinformation 2011;5:361-364.
13. Dillehay TD, Ramirez C, Pino M, Collins MB, Rossen J, Pino Navarro J. Monte Verde: seaweed, food, medicine, and the peopling of South America. Science 2008;320:784-786. DOI: 10.1126/ science.1156533.
14. El Maghraby DM, Fakhry EM. Lipid content and fatty acid composition of Mediterranean macroalgae as dynamic factors for biodiesel production. Oceanologia 2015;57:86-92.
15. Finglas P, Roe M, Pinchen H, Berry R, Church S, Dodhia S *et al.* McCance and Widdowson's the composition of foods - Food standard agency, ed. 7. Royal Society of Chemistry, Cambridge, UK 2015.
16. Floreto EAT, Teshima S. The fatty acid composition of seaweeds exposed to different levels of light intensity and salinity. Botanica Marina 1998;4:467-481
17. Jiao G, Yu G, Zhang J, Ewart HS. Chemical structures and bioactivities of sulfated polysaccharides from marine algae. Marine Drugs 2011;9:196-223.
18. British Nutrition Foundation (BNF). Nutrition requirements: reference nutrient intakes for minerals 2016.
19. Jimenez-Escrig A, Goñi CI. Nutritional evaluation and physiological effects of edible seaweeds. Archivos Latinoamericanos De Nutricion 1999;49:114-120.
20. Kasimala MB, Mebrahtu L, Magoha PP, Asgedom G, Kasimala MB. A review on biochemical composition and nutritional aspects of seaweeds. Caribbean journal of

Science and Technology 2015;3:789-97.
21. Kumar CS, Ganesan P, Suresh PV, Bhaskar N. Seaweeds as a source of nutritionally beneficial compounds-a review. Journal of Food Science and Technology 2008;45(1):1
22. Kumoro A, Johnny D, Alfilovita D. Incorporation of microalgae and seaweed in instant fried wheat noodles manufacturing: nutrition and culinary properties study. International Food Research Journal 2016;23:715-722.
23. López-López I, Bastida S, Ruiz-Capillas C, Bravo L, Larrea M, Sánchez-Muniz F *et al*. Composition and antioxidant capacity of low-salt meat emulsion model systems containing edible seaweeds. Meat Science 2009;83:492-498.
24. Lee B. Seaweed potential as marine vegetable and other opportunities. Can print, Australia 2008. ISBN 1 74151 598
25. MacArtain P, Gill CIR, Brooks M, Campbell R, Rowland IR. Nutritional value of edible seaweeds. Nutrition Reviews 2007;65:535-543.
26. Misurcova L. Chemical composition of seaweeds. In: Handbook of marine macroalgae: biotechnology and applied phycology (Ed. by S.- K. Kim). John Wiley & Sons, Hoboken, New Jersey, USA 2011,171-192p.
27. Murata M, Nakazoe J. Production and use of marine algae in Japan. Japan Agricultural Research Quarterly: JARQ 2001;35:281-290.
28. Mysliwa-Kurdziel B, Solymosi K. Phycobilins and phycobiliproteins used in food industry and medicine. Mini-Reviews in Medicinal Chemistry 2017;17:1173-1193.
29. Mabeau S, Cavaloc E, Fleurence J, Lahaye M. New seaweed based ingredients for the food industry. Int Food Ingred 1992;3:38-45
30. McNeely WH, Pettit DJ. Algin. In: Industrial gums. 2nd edn. Whistler RL (ed). Academic Press, New York 1973,31-49p.
31. Nisizawa K. Seaweeds Kaiso - Bountiful harvest from the seas sustenance for health and well being by preventing common life style diseases. Japan Seaweed Association, Japan 2002,59-68p
32. Nanri A, Mizoue T, Shimazu T, Ishihara J, Takachi R, Noda M *et al*. for the Japan Public Health Center-Based Prospective Study G. Dietary patterns and all-cause, cancer, and cardiovascular disease mortality in Japanese men and women: the Japan public health center-based prospective study. PLoS One 2017;12:e0174848.
33. Ooraikul B, Aboagye NY. Synthetic food product. US Patent 1986,4,582,710
34. Patterson E, Wall R, Fitzgerald G, Ross R, Stanton C. Health implications of high dietary omega-6 polyunsaturated fatty acids. Journal of Nutrition and Metabolism 2012;2012:16.
35. Pérez MJ, Falqué E, Domínguez H. Antimicrobial action of compounds from marine seaweed. Marine Drugs 2016;14:52.
36. Paniagua-Michel JDJ, Olmos-Soto J, Morales-Guerrero ER. Algal and microbial exopolysaccharides: new insights as biosurfactants and bioemulsifiers. In: Advances in food and nutrition research (Ed. by S.-K. Kim). Academic Press, San Diego, California, USA 2014,221-257p.
37. Qin Y. Applications of bioactive seaweed substances in functional food products. In: Bioactive seaweeds for food applications: natural ingredients for healthy diets (Ed. by Y. Qin). Academic Press, San Diego, California, USA 2018,111-134p.
38. Ramesh M, Muthuraman A. Chapter 1 – flavoring and coloring agents: health risks and potential problems. In: Natural and artificial flavoring agents and food dyes (Ed. by A.M. Grumezescu & A.M. Holban). Academic Press, San Diego, California, USA 2018,1-28p.
39. Rodrigues D, Freitas AC, Pereira L, Rocha-Santos TA, Vasconcelos MW, Roriz M *et al*. Chemical composition of red, brown and green macroalgae from Buarcos Bay in central west coast of Portugal. Food Chemistry 2015;183:197–207.
40. Rupérez P. Mineral content of edible marine seaweeds. Food Chemistry 2002;79:23-26.
41. Shannon E, Abu-Ghannam N. Antibacterial derivatives of marine algae: an overview of pharmacological mechanisms and applications. Marine Drugs 2016;14:81.
42. Shannon E, Abu-Ghannam N. Seaweeds as nutraceuticals for health and nutrition. Phycologia 2019;58(5):563-577
43. Sellimi S, Ksouda G, Nasri R, Rinaudo M, Nasri M, Hajji M. Enhancing colour and oxidative stabilities of reduced-nitrite turkey meat sausages during refrigerated storage using fucoxanthin purified from the Tunisian seaweed *Cystoseira barbata*. Food and Chemical Toxicology 2017;107:620–629.
44. Stephen AM, Champ MMJ, Cloran SJ, Fleith M, van Lieshout L, Mejborn H *et al*. Dietary fibre in Europe: current state of knowledge on definitions, sources, recommendations, intakes and relationships to health. Nutrition Research Reviews 2017;30:149-190.
45. Waaland JR. Common seaweeds of the pacific Coast. Pacific search press, U.S.A 1977. ISBN 0-914718-19-3
46. World Health Organization (WHO). Double burden of malnutrition 2019.
47. Wong KH, Cheung PCK. Nutritional evaluation of some subtropical red and green seaweeds. Part-1. Proximate composition, amino acid profiles and some physico chemical properties. Food Chem 2000;71:475-482
48. Wong KH, Cheung PCK. Nutritional evaluation of some subtropical red and green seaweeds Part II. *In vitro* protein digestibility and amino acid profiles of protein concentrates. Food Chemistry 2001;72:11-17.
49. Zerrifi S, El Khalloufi F, Oudra B, Vasconcelos V. Seaweed bioactive compounds against pathogens and microalgae: potential uses on pharmacology and harmful algae bloom control. Marine Drugs 2018;16:55.
50. Cox S, Abu-Ghannam N. Incorporation of *Himanthalia elongata* seaweed to enhance the phytochemical content of breadsticks using response surface methodology. International Food Research Journal 2013;20:1537-1545.
51. Arufe S, Della Valle G, Chiron H, Chenlo F, Sineiro J, Moreira R. Effect of brown seaweed powder on physical and textural properties of wheat bread. European Food Research and Technology 2018;244:1-10.
52. Park Y, Lee J, Oh JH, Shin A, Kim J. Dietary patterns and colorectal cancer risk in a Korean population: a case-control study. Medicine 2016;95:e3759.
53. Yang YJ, Nam SJ, Kong G, Kim MK. A case–control study on seaweed consumption and the risk of breast cancer. British Journal of Nutrition 2010;103:1345-1353.
54. Herath KM, Lee JH, Cho J, Kim A, Shin SM, Kim B *et al*. Immunostimulatory effect of pepsin enzymatic extract from *Porphyra yezoensis* on murine splenocytes. Journal

of the Science of Food and Agriculture 2018;98:3400–3408.
55. Jung L, Choe E. Lipid oxidation-related characteristics of gim bugak (Korean fried cuisine with Porphyra) affected by frying oil. Food Science and Biotechnology 2017;26:623.
56. Déléris P, Nazih H, Bard JM. Chapter 10 - Seaweeds in human health. In: Seaweed in health and disease prevention (Ed. by J. Fleurence & I. Levine). Academic Press, San Diego, California, USA 2016,319-367p.
57. Namvar F, Mohamed S, Fard SG, Behravan J, Mustapha NM, Alitheen NBM *et al*. Polyphenol-rich seaweed (*Eucheuma cottonii*) extract suppresses breast tumour via hormone modulation and apoptosis induction. Food Chemistry 2012;130:376-382.
58. Gutiérrez-Rodríguez AG, Juárez-Portilla C, Olivares-Bañuelos T, Zepeda RC. Anticancer activity of seaweeds. Drug Discovery Today 2018;23:434-447.
59. Jiang J, Shi S. Seaweeds and cancer prevention. In: Bioactive seaweeds for food applications (Ed. by Y. Qin). Academic Press, San Diego, California, USA 2018,269-290p.
60. Medina-Remón A, Kirwan R, Lamuela-Raventós RM, Estruch R. Dietary patterns and the risk of obesity, type 2 diabetes mellitus, cardiovascular diseases, asthma, and neurodegenerative diseases. Critical Reviews in Food Science and Nutrition 2018;58:262-296.
61. Medina-Remón A, Kirwan R, Lamuela-Raventós RM, Estruch R. Dietary patterns and the risk of obesity, type 2 diabetes mellitus, cardiovascular diseases, asthma, and neurodegenerative diseases. Critical Reviews in Food Science and Nutrition 2018;58:262-296.
62. Kim MS, Kim JY, Choi WH, Lee SS. Effects of seaweed supplementation on blood glucose concentration, lipid profile, and antioxidant enzyme activities in patients with type 2 diabetes mellitus. Nutrition Research and Practice 2008;2:62-67.
63. Shannon E, Abu-Ghannam N. Optimisation of fucoxanthin extraction from Irish seaweeds by response surface methodology. Journal of Applied Phycology 2017;29:1027-1036.
64. Hitoe S, Shimoda H. Seaweed fucoxanthin supplementation improves obesity parameters in mildly obese Japanese subjects. Functional Foods in Health and Disease 2017;7:246-262.
65. Nanri A, Mizoue T, Shimazu T, Ishihara J, Takachi R, Noda M *et al*. for the Japan Public Health Center-Based Prospective Study G. Dietary patterns and all-cause, cancer, and cardiovascular disease mortality in Japanese men and women: the Japan public health center-based prospective study. PLoS One. 2017;12:e0174848.
66. Maruyama K, Iso H, Date C, Kikuchi S, Watanabe Y, Wada Y *et al*. Dietary patterns and risk of cardiovascular deaths among middle-aged Japanese: JACC study. Nutrition, Metabolism and Cardiovascular Diseases 2013;23:519-527.
67. Chu SM, Shih WT, Yang YH, Chen PC, Chu YH. Use of traditional Chinese medicine in patients with hyperlipidemia: A population-based study in Taiwan. Journal of Ethnopharmacology 2015;168:129-135
68. Cornish ML, Critchley AT, Mouritsen OG. A role for dietary macroalgae in the amelioration of certain risk factors associated with cardiovascular disease. Phycologia 2015;54:649–666.
69. Lee YH, Yoon SJ, Kim A, Seo H, Ko S. Health performance and challenges in Korea: a review of the global burden of disease study 2013. Journal of Korean Medical Science 2016;31:S114–S120.
70. Yamori Y, Sagara M, Arai Y, Kobayashi H, Kishimoto K, Matsuno I *et al*. Soy and fish as features of the Japanese diet and cardiovascular disease risks. PLoS One 2017;12:e0176039.
71. Kurotani K, Akter S, Kashino I, Goto A, Mizoue T, Noda M *et al*. Quality of diet and mortality among Japanese men and women: Japan Public Health Center Based Prospective Study. British Medical Journal 2016;352:i1209.
72. Hata Y, Nakajima K, Uchida JI, Hidaka H, Nakano T. Clinical effects of brown seaweed, *Undaria pinnatifida* (wakame), on blood pressure in hypertensive subjects. Journal of Clinical Biochemistry and Nutrition 2001;30:43–53
73. Moore LE. Oral hypoglycemic agents. In: Diabetes in pregnancy: the complete guide to management (Ed. by L.E. Moore). Springer International Publishing, Cham, Switzerland 2018,103-110p.
74. Gabbia D, Dall'Acqua S, Di Gangi IM, Bogialli S, Caputi V, Albertoni L, Marsilio I *et al*. The phytocomplex from *Fucus vesiculosus* and *Ascophyllum nodosum* controls postprandial plasma glucose levels: an *in vitro* and *in vivo* study in a mouse model of NASH. Marine Drugs 2017;15:41
75. Roy MC, Anguenot R, Fillion C, Beaulieu M, Bérubé J, Richard D. Effect of a commercially-available algal phlorotannins extract on digestive enzymes and carbohydrate absorption *in vivo*. Food Research International 2011;44:3026-3029.
76. Song W, Wang Z, Zhang X, Li Y. Ethanol extract from *Ulva prolifera* prevents high-fat diet-induced insulin resistance, oxidative stress, and inflammation response in mice. BioMed Research International Article ID 1374565 2018.
77. Kim MS, Kim JY, Choi WH, Lee SS. Effects of seaweed supplementation on blood glucose concentration, lipid profile, and antioxidant enzyme activities in patients with type 2 diabetes mellitus. Nutrition Research and Practice 2008;2:62–67.
78. Sakata K. Antioxidative compounds from marine organisms. In: Food and free radicals. Hiramatsu M, Yoshikawa TM (eds). Plenum Press, New York 1997,85-100p.
79. Takamatsu S, Hodges TW, Rajbhandari I, Gerwick WH, Hamann MT, Nagle DG. Marine natural products as novel antioxidant prototypes. J Nat Prod 2003;66:605-608
80. Huang HL, Wang BG. Antioxidant capacity and lipophilic content of seaweeds collected from the Qingdao coastline. J Agic Food Chem 2004;52:4993-4997
81. Athukorala Y, Lee KW, Park EJ, Heo MS, Yeo IK, Lee YD *et al*. Reduction of lipid peroxidation and H2O2 -mediated DNA damage by a red alga (*Grateloupia filicina*) methanolic extract. J Sci Food Agric 2005;85:341-2348
82. Athukorala Y, Lee KW, Shahidi F, Heu MS, Kim HT, Lee JS *et al*. Antioxidant efficacy of extracts of an edible red algae (*Grateloupia filicina*) in linoleic acid and fish oil. J Food Lipid 2003b;10:313-327

83. Foti M, Piattelli M, Amico V, Ruberto G. Antioxidant activity of phenolic meroditerpenoids from marine algae. J Photochem Photobiol Biol 1994;26:159-164
84. Ruberto G, Baratta MT, Biondi DM, Amico V. Antioxidant activity of extracts of the marine algal genus Cystoseira in a micellar model system. J Appl Phycol 2001;13:403-407
85. Siriwardhana N, Lee KW, Kim SK, Ha JW, Jeon YJ. Antioxidant activity of *Hizikia fusiformis* on reactive oxygen species scavenging and lipid peroxidation inhibition. Food Sci Technol Int 2003;9:339-346
86. Park PJ, Shahidi F, Jeon YJ. Antioxidant activities of enzymic extracts from an edible seaweed *Sargassam hornerii* using ESR spectrometry. J Food Lipid 2004;11:15-28
87. Aynapudi J, El-Rami F, Ge X, Stone V, Zhu B, Kitten T *et al*. Involvement of signal peptidase I in Streptococcus sanguinis biofilm formation. Microbiology 2017;163:1306-1318.
88. Wei Y, Liu Q, Xu C, Yu J, Zhao L, Guo Q. Damage to the membrane permeability and cell death of Vibrio parahaemolyticus caused by phlorotannins with low molecular weight from *Sargassum thunbergii*. Journal of Aquatic Food Product Technology 2016;23:323-333.
89. El Shafay SM, Ali SS, El-Sheekh MM. Antimicrobial activity of some seaweeds species from Red Sea, against multidrug resistant bacteria. Egyptian Journal of Aquatic Research 2016;42:65-74.
90. Huang CY, Kuo CH, Lee CH. Antibacterial and antioxidant capacities and attenuation of lipid accumulation in 3T3-L1 adipocytes by low-molecular-weight fucoidans prepared from compressional-puffing-pretreated *Sargassum crassifolium*. Marine Drugs 2018;16:24