Defence Life Science Journal, Vol. 5, No. 4, October 2020, pp. 315-322, DOI : 10.14429/dlsj.5.15632

Seaweeds – A Potential Source for Functional Foods

A.K. Pandey, O.P. Chauhan*, and A.D. Semwal

DRDO-Defence Food Research Laboratory, Mysuru - 570 011, India
**E-mail: opchauhan@gmail.com*

ABSTRACT

Seaweeds are microalgae growing in coastal regions and resistant to salinity. Seaweeds are rich resources of natural nutrients some of which cannot be obtained from terrestrial plants. Bioactive compounds of seaweeds such as sulphated polysaccharides, peptides, minerals, phlorotannins, carotenoids and sulfolipids have proven health benefits against various diseases. Traditionally, seaweeds are used as folk medicine for treating diseases like goiter, wounds, burns, rashes, inflammation, diabetes and also gaining attention of pharmaceutical industries due to their anti-cancer, anti-aging, anti-angiogenesis, anti-bacterial, anti-viral and antioxidant properties. Seaweeds polysaccharides have wide applications in foods as well as in pharmaceutical industry due to their bio-chemical properties such as stabiliser, emulsifier and gelling property. In food industry, seaweed polysaccharides are used as a functional ingredient in many products such as frozen foods, ice-cream, jam, jelly, beverages etc. Several commercial food preparations from seaweeds are also available in the market such as sea salt, nori snack wasabi, pink rock salt, seaweed thins toasted coconuts, crunchy seaweed chips, raw unroasted seaweed under different brand names. The present review is a compilation of nutritional, pharmacological and food properties of seaweeds along with its potential towards development of functional foods.

Keywords: Seaweed; Algae; Functional food; Nutrition; Health

1. INTRODUCTION

The marine environment has vast biodiversity of seaweeds. Seaweeds are plants like organisms also known as macrophytic or marine algae. These microalgae are lacking in true stems, roots and leaves and commonly classified as green algae (Chlorophyta), red algae (Rhodophyta) and brown algae (Phaeophyta) on the basis of their pigments (Table 1). These multicellular species are saline tolerant and generally found adhered to rocks, sand and other hard substances in coastal regions.

Seaweeds are rich sources of nutrients like polysaccharides, proteins with all essential amino acids, polyunsaturated fatty acids, vitamins and minerals[25]. Apart from nutrients seaweeds are also rich in fiber content which has protective effect on human health. Now-a-days, seaweeds receiving more attention for their bioactive compounds such as antioxidants like terpenes, acetogenins, alkaloids, phlorotannins, phloroglucinol, eckol, dieckol, fucodiphloroethol, 7-phloroeckol, phlorofucofuroeckol, bieckol, catechin, epicatechin, epigallocatechin, gallic acid, gallate, including sulhated polysaccharides, peptides, sulfolipids, carotenoids, minerals[1,20,26]. Dried or processed seaweeds are consumed as folk medicine against various diseases such as tuberculosis, arthritis, cold and influenza. Bioactive compounds of seaweeds are found to have pharmacological properties against anti-inflammation, anti-lipedimic, anti-tumor, anti-microbial and antioxidant activity. They also reduce the risk of cardiovascular diseases, biotic and abiotic stress in organisms which is valuable for pharmaceutical as well as food industries[8]. Edible seaweeds have historically being consumed by the costal population worldwide. But, now its uses are increasing in food, medicine and fertiliser formulations and also as a substrate for bio-fuel production[43].

There is a huge scope for supplementation of food items with edible seaweeds to provide added health benefits to the consumers. However, till now, there are only few studies conducted on improvement of nutritional properties of food as well as development of functional food through seaweed supplementation. del Olmo[13], *et al.* observed a significant improvement in physicochemical quality of hard cheese when supplemented with seaweeds i.e. *Himanathalia elongate, Laminaria ochroleuca, Porphyra umbilicalis, Ulva lactuca and Undaria pinnatifida* species. However, Zhang[45], *et al.* found a significant increase in intestinal microbiota in mice due to oral supplementation of seaweed (*Porphyra haitanensis* and *Ulva prolifera*) polysaccharides. del Olmo[12], *et al.* reported that increase or decrease in nutritional properties in seaweed supplemented hard cheese was species dependent. They observed significant increase in lipolysis of hard cheese (6 fold increase in free fatty acids as compared to control) when supplemented with *Ulva lactuca* species of seaweed. However the cheese supplemented with seaweeds resulted upto 40% more flavoring compounds as compared to control.

Modern researches have increased the commercial values of seaweeds and it is estimated to achieve million dollar business globally[43]. The global seaweed market size was valued $4.097.93 million in 2017 and by 2024 it is projected

Received : 29 April 2020, Revised : 11 July 2020
Accepted : 05 October 2020, Online published : 15 October 2020

Table 1. Types of seaweeds and their some edible species

Seaweeds type	Species
Green algae (Chlorophyta),	*Chlorella sp., Ulva sp.,Caulerpa sp., Ulva sp. Codium sp., etc.*
Red algae (Rhodophyta)	*Mastocarpus stellatus, Palmaria palmata, Eucheuma spinosum, Gelidiella acerosa, Gacilaria edulis, Gracilaria corticata, Chondrus crispus, Porphyra laciniata, Porphyra (Nori), Sarconema fucellatum, Campia compressa, Gelidium usmanghanii, Osmundea pinnatifida, Solieria robusta etc.*
Brown algae (Phaeophyta)	*Laminariles (Kelp), Eisenia bicylis, Alaria esculenta, Durvillaea antartica, Saccharina japonica, Laminariadigitata, Postelsia palmaeformis, Undaria undarioides, Sargassum muticum, Stoechospermum marginatum, Stypopodum shameelii, Sargassum swartzii, Sargassum ilicifolium etc.*

to reach $9075.65 million with an annual growth rate of 12% from 2018 to 2024[10]. Food application of seaweeds contributed major market share in 2017, as its use for human consumption has increased globally. In many Asian countries (China, Japan, Korea and Taiwan etc.) seaweeds appear to be part of regular diet and are gaining popularity in Western countries (Brazil, California and Hawaii) due to their associated health benefits[21]. Green, red and brown algae contribute 5%, 66.5% and 33%, respectively, of total seaweed consumption in Asian countries[4]. Skrzpczyk[38], *et al.* suggested that the regular consumption of 10 g seaweed, tested in their study, could improve human health by contributing desired fatty acids, protein and fibre in diet. Cherry[7], *et al.* reported that 5g of dried brown, red and green seaweed can contribute upto 1.97%, 4.5% and 2.98%, respectively, of reference nutrient intake for protein and 14.28%, 10.64% and 12.10% for dietary fiber intake, respectively. This article is the short compilation of nutritional and pharmacological properties of edible seaweeds. It also includes the use of seaweeds in food processing industries and their associated health risks in humans. The article could provide a thought for development of futuristic functional food using seaweeds as a natural and main functional ingredient against targeted biological diseases.

2. NUTRIENTS AND BIOACTIVE COMPOUNDS IN SEAWEEDS

Seaweeds are living marine resources that are rich in macro- and micro-nutrients such as carbohydrate, protein, fiber, vitamins and minerals. The concentration of nutrients in seaweeds varies with species to species, genera and habitat. Seaweeds are natural source of macro (Na, Ca, K, Mg, S, Cl and P) and micro elements (I, Zn, Cu, Se, Ni, Co, B and Mn) and contain plenty of iodine which has important role in preventing goiter disease in humans[36]. Generally, protein content in red and green seaweeds is found to be high, i.e., up to 30% as compared to brown seaweeds. However, green seaweeds are generally rich in carbohydrate as compared to red and brown seaweeds. The green seaweed *Ulva lactuca* and *Enteromorpha intestinalis* found to have highest amount of carbohydrate i.e. 35.27% and 30.58%, respectively, whereas brown seaweed of *Dictyota dichotoma* contains minimum carbohydrate content, i.e., 10.63%[30,6]. The fiber content of edible seaweeds ranges from 33% to 62% of dry mass which is much higher as compared to fiber content found in higher plants. Lipid content of seaweeds generally ranges from 4.6% in *E. clathrata* to 1.33% in *Enteromorpha intestinalis*. However, some studies reported 12% and 1.09% lipid content in *Utricularia rigida* and *Kappaphycus alvarezii*, respectively[35,32].

Skrzypczk[38], *et al*. studied four commercially available seaweeds species i.e. *Pyropia tenera, Sargassum fusiforme, Saccharina angustata and Undaria pinnatifida*, and nine non commercial seaweeds species i.e. *Codium galeatum, Laurencia filiformis, Cystophora torulosa, Cystophora. polycystidea, Phyllotricha. decipiens, Hormosira. banksii, Durvillaea potatorum, Phyllospora comosa* and *Ecklonia radiata* for their nutritional properties. The protein, total lipid, crude fiber and ash content in commercially available seaweeds ranges from 31.86 – 366.01 mg/g, 6.86 – 30.44 mg/g, 29.19 – 45.41 mg/g and 115.52 – 298.35 mg/g, respectively, whereas in non commercial seaweeds the ranges were found to be 30.78 – 156 mg/g, 4.48 – 101.41 mg/g, 30.45 – 220.07 mg/g and 53.13 - 195.76 mg/g, respectively. Except this, seaweeds also contains considerable amount of water and fat soluble vitamins, phenolics content and essential fatty acids like ω-6 and ω-3 fatty acids[19,7]. Nutritional composition of various seaweeds species are given in Table 2, whereas, bioactivity of some seaweeds compounds are given in Table 3.

The deficiency of micro-nutrients is a most common problem throughout the world. Ganesan[15], *et al.* evaluated some under-exploited seaweed such as *U. fasciata*, *Padina gymnospora*, *Acanthophora spicifera*, *Gracilaria edulis* for their nutrients and food applications. They found that the selected seaweeds contain 14.8-72 mg/100g iron, 38.8 – 72.2mg/100g iodine and 410-870 mg/100g calcium. However, the essential amino acid content was ranging from 189 to 306 mg/g; whereas, essential fatty acid contents such as mono unsaturated fatty acid ranged from 3.05 % to 14.08%. It was found that traces of heavy metals like arsenic, cadmium, mercury etc. were below the tolerance limit and it was suggested that the consumption of 100g fresh seaweed could meet more than 70% of macro- and micro-nutrients requirement of RDA in case of pregnant women.

3. PHARMACOLOGICAL PROPERTIES OF SEAWEEDS

Apart from nutrient source, seaweeds are also being historically used for the treatment of several health problems such as microbial infection, cancer, tumor, allergy, aging and inflammation (Fig. 1). Ghislain[17], *et al.* documented anticancer effect of different seaweeds against colon and breast cancer in humans. Different types of seaweeds have shown protective effect against cancer by either reducing or destroying cancer cells formation. High antioxidant activity of seaweeds plays a major role in reducing the rate of cancer cell formation. Seaweeds have also been implicated as a potential protective agent against cardiovascular diseases. Dietary intake of seaweeds reduces

Table 2. Nutritional composition of various seaweeds species

Seaweed Species	Nutrition					References
	% Protein	% Total lipid	% Carbohydrate	% Crude fibre	% Ash	
Ulva intestinalis	13.55	2.72	57.03	-	19.01	16
Durvillaea autartica	10.4	0.80	70.90	71.40	-	
Sargassum polycystum	5.40	0.29	33.49	39.67	-	
Sargassyn vulgare	13.61	0.49	61.60	7.74	-	
Sargassum naozhouense	11.20	1.06	47.43	4.83	-	
Gracilaria cervicomis	19.70	0.43	63.10	5.65	-	7
Gracilaria edulis	0.67	0.83	10.16	8.90	-	
Hypnea pannosa	16.1	1.56	22.89	40.59	-	
Kappaphycus alvarezii	16.24	0.74	27.40	29.40	-	
Caulerpa lentillifera	9.26	1.57	64.00	2.97	-	
Pyropia tenera	36.60	3.04	-	3.26	11.55	
Sargassum fusiforme	3.19	0.69	-	3.71	20.92	26
Saccharina angustata	5.91	2.4	-	4.54	15.01	
Undaria pinnatifida	15.69	2.23	-	2.92	29.84	
Sargassum muticum	19.62	4.26	17.08	28.51	-	
Stoechospermum marginatum	14.24	4.19	13.61	21.47	-	
Stypopodium shameelii	13.11	4.23	11.43	19.66	-	
Sargassum swartzii	14.79	3.85	12.54	20.49	-	
Sargassum ilicifolium	15.68	3.91	14.28	22.54	-	
Codium tomentosum	14.16	4.97	24.57	15.04	-	
Codium shameelii	11.89	3.86	21.35	9.42	-	
Codium iyengarii	9.47	3.59	20.48	10.38	-	3
Caulerpa racemosa	10.53	3.72	20.92	11.46	-	
Ulva fasciata	11.06	4.16	21.27	11.94	-	
Sarconema fucellatum	10.05	2.65	12.46	6.84	-	
Campia compressa	9.46	3.27	15.32	4.93	-	
Gelidum usmanghanii	8.29	3.64	18.55	5.26	-	
Osmundea pinnatifida	9.72	2.85	14.62	5.64	-	
Solieria robusta	8.73	3.07	17.18	5.49	-	

Table 3. Bioactive compounds in seaweeds and their bioactivity

Seaweeds Bioactive compounds	Components	Bioactivity
Polysaccharide	Sulfated polysaccharides such as galactans, fucoidan, laminarin and alginates	Antioxidants, soluble dietary fiber, anti-tumor, anti-inflammatory, growth and health promoting activity and anti-microbial activity
Proteins (mainly lectins)	All essential amino acids	Intercellular communication, antioxidants, anti-inflammatory activity and anti-microbial and anti-viral activity
Fat	Polyunsaturated fatty acids including ω-3 and ω-6 fatty acids	Health-improving activity, membrane fuidity, oxygen and electron transport, thermal adaptation, anti-microbial and antibiotic activity
Minerals	All macro and micro elements (mainly Iodine)	Growth and health improving activity, prevent goiter disease
Polyphenols	Phenoic acids, flavonoids, isoflavones, cinnamic acid , benzoic acid, quercetin, lignans etc.	Strong antioxidants, host defense, anti-microbial and anti-viral, anti-photo ageing, anti-obesity, anti-allergic and anti-cancer activity
Sterols	Uco-cholesterol, brassicasterol, desmosterol, sitosterol, fucosterol etc.	Reduce cholesterol content of serum in humans
Pigments	Chlorophylls, carotenoids (mainly β-carotene), fucoxanthin and phycobiliproteins	Antioxidants, neuroprotective, anti-cancer, anti-angiogenic, anti-obesity and anti-microbial activity

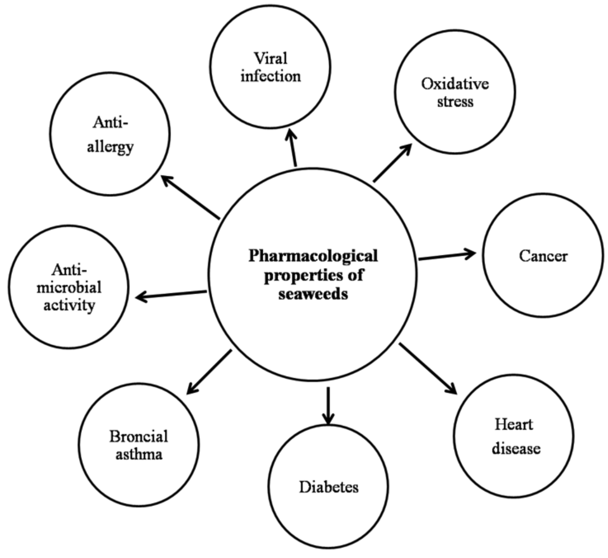

Figure 1. Some important pharmacological properties of seaweeds.

the level of plasma cholesterol and thus, reduces the risk of cardiovascular diseases. Seaweeds antioxidants are also found to have anti-ageing properties. Intake of seaweed stimulate a series of bio-chemical changes in humans such as antioxigenic activity, inhibition of cell adhesion, binding toxic compounds, induction of apoptosis and addition of important trace minerals to the diet which are mainly responsible to prevent chronic diseases and reduce ageing in humans[36]. Seaweeds are also effective against diabetes. Oral administration of aqueous extract of *Ulva faciata* significantly reduced blood glucose and glycosylated hemoglobin level as compared to other standard medicines during *in-vivo* study[2]. Methanolic extract of seaweeds have highest anti-microbial activity against bacterial species like *Staphylococcus, Bacillus, Streptococcus, Enterobacter, Escherichia coli* and *Proteus*[22]. However, sufated polysaccharides of seaweed such as carrageenans, fucoidans and rhamnogalactans were found to have effective against viral infection. These seaweed compounds possess virucidal and enzyme inhibitory properties and obstruct viruses to enter in cells[36]. However, methanolic extract of *Undaria Pinnatifida* and *Ulva linza* seaweeds were shown anti-inflammatory activity during *in-vivo* study[27]. Methanoic extract of *Dictyota dichotoma* was found to have significant effect against β-lactamases by inhibiting GES-22 which can help in prevention of emergence of bacterial antibiotic resistance in humans[19].

Sulphated polysaccharides of red algae, mainly *Aghardhiella* tenera and *Nothogenia fastigiate*, are widely known for their antiviral activity[11]. Nakashima[29], *et al.* reported that the sulphated polysaccharide of *Schizymenia pacifica* prevents replication of HIV by inhibiting the HIV reverse transcriptase during *in vitro* study. Trinchero[41], *et al.* also reported that the polysaccharides including fucoidans obtained from *Adenocystis utricularis* brown seaweed showed antiviral activity against wild type drug resistant strains of HIV-1. Carrageenan from seaweeds is having a proven *in vitro* antiviral activity as well as ability to block HIV and other sexually transmitted viruses[44].

Some seaweeds compounds such as aldehyde, ketone, hydroquinone, alkenes haloforms, alkanes, sterols, terpenes, natural pigments, polyphenols and alcohols possess diverse biological activities as antibiotic, antioxidant, antimalaria, cytotoxic, antiseptics as well as cleansing property. A halogenated compound furanone of *Delisea pulchara* seaweed has a promising antibacterial activity against *Pseudomonas aeruginosa* infection in humans[19].

Phenolic extract of seaweeds combat with bronchial asthma and can also be used as natural antioxidant source in different foods and pharmaceutical products. The fucoidans obtain from brown algae (*Eclonia cava, Costaria costalla, Sargassum horney, Undaria pinnnatifida*) inhibit the proliferation of human melanoma and colon cancer cells and can be used as a effective anti-tumour agents[14,39]. The potent antioxidant activity of diverse seaweed compounds are mainly responsible for reducing the oxidative stress of biological cell and cure several chronic diseases. However, the exact mechanism of action of seaweeds biologically active metabolites on diseases such as cancer, cardiovascular disease, HIV prevention, Malaria is still unknown. Besides these, seaweeds also possess anthelmintic, hepatoprotective and wound healing properties[36].

4. USE OF SEAWEEDS IN FOOD PROCESSING

Today major part of harvested seaweed is extracted to produce tones of polysaccharides isolates (hydrocolloids). Some seaweed polysaccharides isolates and their properties are given in Table 4. Seaweed isolates, particularly polysaccharides, are used to improve the quality and extend the shelf-life of food products[5]. The most common polysaccharides isolates of seaweeds are agar, agroses, alginate and carrageenan. These polysaccharides isolates are commonly used in food industry for various purposes such as stabilizing and gelling agents to maintain the structure of food. Utilisation of agar depends on its purity, low quality agar is used for industrial production of various food products such as ice-cream, fruit juice, candies, bakery etc., whereas, medium quality agar is used for making substrate for microbiological study and high quality agar is used in molecular biology for gel electrophoresis and chromatography. Carrageenan is highly preferred stabiliser and emulsifier in foods as compared to agar. Kappa, lota and lambda are three main classes of carrageenan used for commercial application (Fig .2). The *κ* and *ι* form of carrageenan are mainly added in milk based products such chocolate, ice-cream, deserts gels and evaporated milk due to their thickening and suspension properties. Sodium salt of alginate has wide application in food and pharmaceutical industry for making highly viscous solution because of its ability to chelate metal ions. It is also used in food industry as a natural source of dietary fiber for developing functional foods[24,28].

Apart from polysaccharide isolates seaweeds are also utilised in food as a whole like salad dressing. In Asian countries like China and Japan seaweeds are used as cooking ingredient in food. Brownlee[5], *et al.* summarised studies on use of whole seaweed as a composite ingredient of food. Use of whole seaweeds such as *Ascophyllum nodosum* and *Undaria pinnatafida* at a level of 5 % w/w and 10 % w/w, respectively, in bread and pasta making were got positive response from

Table 4. Functional property and use of seaweeds polysaccharides

Seaweed polysaccharide isolates	Source	Property	Uses
Agar	Red seaweed	Laxative agent, stabiliser, solidifying agent, emulsifier	Solid substrate for microbial growth in microbiology and Biotechnology, Food products like jam, jelly, cakes, chocolates, candies, sauces etc.
Alginate	Brown seaweed	Thickening agent, gelling agent, stabiliser, emulsifier	Frozen food, ice creams, instant food drinks, In pharmaceuticals as tableting agent, matrix for immobilised system, drug delivery etc
Carrageenan	Red seaweed	Thickening, gelling and stabilizing agent	Food industry, air freshener gels, toothpaste binder, drug delivery, tissue engineering, biosensor applications
Fucoidan	Brown algae	Bioactivity	Nutraceutical purpose, cancer treatment, tissue engineering
Ulvan	Green algae	Antixidant, anticoagulant, immuneomodulation activity, antihyperlipidemic activity	Tissue engineering and drug delivery

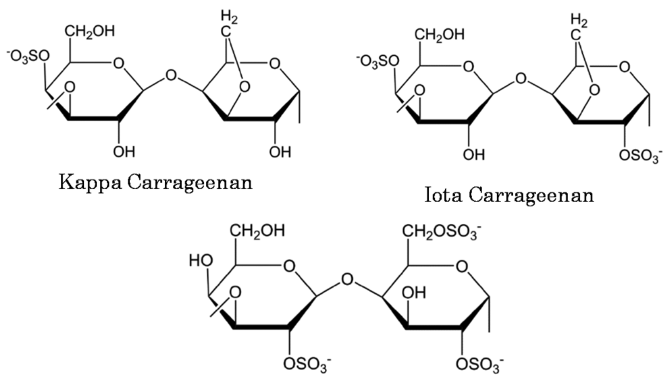

Figure 2. Types of carrageenan used mainly for commercial application.

consumers. Whereas, addition of whole seaweed in low fat containing meat product improved water retention and gel formation in the product. del Olmo[13], *et al.* studied the effect of seaweeds (*Himanathalia elongate, Laminaria ochroleuca, Porphyra umbilicalis, Ulva lactuca and Undaria pinnatifida*) supplementation on hard cheese. They observed a significant increase in antioxidant activity and total phenolic compounds in cheese supplemented with seaweed, i.e., *Himanthalia elongate*, as compared to control. The color and textural properties of cheese varied with supplemented species, however, odour and flavour quality was found similar sensory score when cheese supplemented with *Himanthalia elongate, Laminaria ochroleuca* and *Undaria pinnatifida* species. Addition of seaweed significantly enhanced the moisture retention properties and lowered the pH value of cheese. However, the effect on microbiota and enzymatic activity of cheese was not influenced by the addition of seaweed. The oven dried powder of *Ulva intestinalis* contains 19%, 13.5%, 57% and 2.7% minerals, protein, carbohydrate and lipids, respectively. Jannat-Alipour[21], *et al.* used *U. intestinalis* edible green seaweed as an ingredient to improve physicochemical properties of surimi-based product. They observed that addition of *U. intestinalis* increased the gelling and water holding properties of surimi based product. The colour and pH of product was decreased with increased concentration of *U. intestinalis* powder whereas, on the other hand emulsifying stability was increased notably. They found acceptable sensory attributes of surimi based product when *U. intestinalis* powder was added upto a concentration of 2.8 %. The studies suggests that seaweeds as a whole can be successfully included as ingredient in various food products to improve their nutritional properties.

Moreover, in aquaculture, which is one of the fastest growing food sectors worldwide, immunity of aquatic animals against bacterial and viral diseases is one of the major concerns today. Aquaculture industries generally use toxic chemicals and antibiotics to prevent diseases, increase resistance against diseases and to enhance growth of aquatic animals. Seaweed polysaccharides such as sodium alginate, fucodian, laminarin, carrageenan etc. are a good source of prebiotics and found to be an effective immunostimulent in aquatic animals[42]. Hindu[18], *et al.* elucidated the use of seaweeds polysaccharides and probiotics as a dietary supplement in aquatic animals for promoting their growth and disease resistance. They reported that use of natural substances to feed aquatic animal's increases consumer confidence. They suggested that polysaccharides of seaweeds in combination with probiotics can be effective dietary supplement to enhance the production of healthy aquatic animals.

5. EFFECT OF PROCESSING ON SEAWEEDS

The bioactive compounds of seaweeds are affected in a similar way as in the case of vegetables by the type of processing and processing conditions. Rajauria[33], *et al.* found a drastic change in level of bioactive compounds as well as antioxidant activity of edible Irish brown seaweed *Laminaria saccharina*, *L. digitata* and *Himanthalia elongata* due to hydrothermal processing. They reported 1.6 to1.9 fold loss in total phenolic content, 1.6 to 3.3 fold loss in total flavonoids content, 1.3 to 2.6 fold loss in total surface tannin content and 1.9 to 4.3 fold loss in total sugar content after autoclaving different seaweeds at 85 ^{O}C to 121 ^{O}C for 15 min. They also found higher reduction in antioxidant activity, metal chelation capacity and peroxide scavenging capacity of seaweeds after hydrothermal processing. In another study, Cox[9], *et al.* reported the effect of different processing methods such as drying, boiling, steaming, microwave heating and the combined treatment of pre-drying + boiling and pre-drying + steaming on total phenoilics content (TPC), total flavonoids content (TFC), total surface tannin content (TTC) and antioxidant activity (AOA) of *H. elongata* seaweed. They found that the concentration of TPC was reduced at a higher extent during boiling, but in case of microwave processing the concentration increased. The losses were highest in TFC content of seaweed during microwave heating, but, the combined treatment of pre-drying + boiling resulted slight increase in TFC. Boiling of seaweed resulted highest reduction in TTC content, whereas, the losses were minimum during drying. The AOA in seaweed was found highest after steaming process; however, the combined processing of pre-drying + boiling lead to highest losses.

6. RISK ASSOCIATED WITH SEAWEED CONSUMPTION

Seaweeds are good source of nutrition mainly polyphenols which act as antioxidant and considered to be beneficial for human health. However, accumulation and concentration of nutrients in seaweeds varies with species to species, genera, growing area and climatic condition. Seaweeds can accumulate heavy metals and toxic compounds and can pose a serious health risk upon ingestion[7,28]. Roleda[34], *et al.* observed the effect of temporal and spatial variations in phenolics and heavy metal contents of seaweeds. They observed high phenolics content during winter in brown algae i.e., *Alaria esculenta* and *Saccharina latissima* and in red algae, i.e., *Palmaria palmate* during spring. However, variation in phenolics content was marginal during inter-annual and spatial variations. The concentration of heavy metal was found to be species specific and depends on growing region; however, seasonal variation was minimal. They observed that the accumulation of heavy metal was below the permissible limit as recommended by EU Commission Regulation for contaminants in food stuffs and concluded low risk for humans due to heavy metal from the seaweed species. Phaneuf[31], *et al.* reported that the higher consumption of seaweed (*Laminaria sp.*) could lead to thyroid problems due to their higher iodine levels. Michikawa[24], *et al.* found that seaweeds accounts 80 % of Japanese total iodine intake and have a clear association with increased risk of papillary carcinoma mainly in postmenopausal women. Owing to the variability and excessive iodine content in seaweed supplements, kelp based products are not recommended for pregnant women. Synergistic association of heavy metals and iodine supplemented from seaweeds could reduce the total T3 cells in blood and leads to thyroid dysfunction[7].

Seaweeds polysaccharides are generally considered as anti-allergens which inhibit production of IgE and T_H2 response in the body and prevent allergy. However, some authors reported allergic problems like respiratory allergy, hypersensitivity, fatal anaphylaxis and anaphylaxis in patient due to seaweeds[23,37]. Thomas[40], *et al.* observed seaweed allergy in a 27 year old patient during their clinical study. They observed that phycobiliproteins and phycolectins are the possible allergens in red seaweeds and advised patient to strictly avoid consuming seaweed containing products.

7. FUTURE ASPECTS OF SEAWEEDS

Now-a-day, people are more conscious regarding health and prefer natural remedies for treating life style related health complications instead of using synthetic chemical. Studies over last few decades advanced the knowledge of bio-chemical and medicinal properties of seaweeds. Literature shows that seaweeds as a natural source of nutrition can be used to fulfill nutrition requirement. Seaweeds are also found to have pharmacological properties against various diseases like obesity, diabetes, cardiovascular complications, aging, cancer etc. Seaweeds are rich in polyphenols, polysaccharides, all essential amino acids, macro and micro minerals as well as dietary fiber. However, direct consumption of edible seaweeds as food is limited to only coastal population of Asian countries. Only few studies assessed the effect of fortification of food with seaweeds as a functional ingredients and their consumer acceptability. Therefore, there is ample scope for developing functional foods containing seaweeds to prevent targeted diseases in organisms. Seaweeds can be used as a natural source of minerals and dietary fiber for developing food for those who suffer from abdominal complications. Seaweeds containing foods can be also used for treating malnutrition among low income population around the world. It can be also used for developing functional foods and drinks. Studies on effect of long term consumption and assessment of effective concentration of seaweed in food and beverages could be a novel area for further studies.

8. CONCLUSION

Seaweeds are excellent source of almost all nutritional and bioactive compounds required for human health. Seaweeds could be an effective substitute of synthetic chemicals used in treatment of chronic diseases in organisms. Assessment of nutrition and functional components in seaweed is required before their utilisation as it changes with species, genera, temporal and spatial variations. Due to richness in biochemical activity and antioxidant properties, seaweeds are important not only for nutraceutical and pharmaceutical industries but also for food and beverage industries. Seaweeds can be used as a source of natural ingredients in food fortification and for the treatment of cancer, tumour, aging, inflammation and heart diseases. Apart from health benefits, some seaweed could cause allergic problems in humans and, therefore, the selection of suitable edible seaweed is mandatory before their consumption.

REFERENCES

1. Abirami, A.; Uthra, S. & Arumugam, M. Nutritional value of seaweeds and the potential pharmacological role of polyphenolics substances: A review. *J. Emerg. Technol. Innov. Res.*, 2018, **5**, 930-337. www.jetir.org
2. Abirami, R.G. & Kowsalya, S. Antidiabetic activity of *Ulva fasciata* and its impact on carbohydrate enzymes in alloxan induced diabetic in rats. *Int. J. Res. Phytochem. Pharmacol.,* 2013, **3**, 136-141.
3. Ahmed, K.; Munawar, S.; Mahmood, T. & Mahamood, I. Biochemical analysis of some species of seaweeds from Karachi coastal area. *Fuuast. J. Biol.,* 2015, **5**, 43-45.
4. Ashwini, S. & Shantaram, M. Prospects of seaweeds: A search along Surathkal beach of Karnataka. *J. Algal Biomass. Utln.,* 2018, **9**, 86-90.
5. Brownlee, I.A.; Fairclough, A.C.; Hall, A.C. & Paxman,

J.R. The potential health benefits of seaweed and seaweed extracts. *In* Seaweed: ecology, nutrient composition and medicinal uses. Marine Biology: Earth Sciences in the 21st Century. edited by Pomin Vitor H. Hauppauge, New York, Nova Science Publishers, 2012, 119-136. http://shura.shu.ac.uk/id/eprint/4980

6. Chakraborty, S. & Santra, S.C. Biochemical composition of eight benthic algae collected from Sunderban. *Ind. J. Marine. Sci.,* 2008, **37**, 329-332. http://nopr.niscair.res.in/handle/123456789/2057
7. Cherry, P.O.; Hara, C.; Magee, P.J.; McSorley, E.M. & Allsopp, P.J. Risk and benefits of consuming edible seaweeds. *Nutri. Rev.,* 2019, doi: 10.1093/nutrit/nuy066.
8. Chojnacka, K.; Saeid, A.; Witkowska, Z. & Tuhy, L. Biologically active compounds in seaweed extracts – the prospects for the application. *Open Conf. Proc. J.,* 2012, **3**, 20-28. doi: 10.2174/1876326X01203020020
9. Cox, S.; Abu-Ghannam, N. & Gupta, S. Effect of processing conditions on phytochemical constituents of edible Irish seaweed *Himanthalia elongata*. *J. Food Process. Preserv*., 2012, **36**, 348-363. doi: 10.1111/j.1745-4549.2011.00563.x
10. Dawande, R. Seaweed market by product (Red, Brown, and Green) and application (Human food, hydrocolloids, fertilizers, animal feed additives, and others) – Global opportunity analysis and industry forecast, 2018-2024. https://www.alliedmarketresearch.com/seaweed-market, (Accessed on 30/07/2020)
11. De Clercq, E. Current Lead Natural Products for the chemotherapy of human immunodeficiency virus (HIV) infection. *Med. Res. Rev*., 2000, **20**, 323-349. doi: 10.1002/1098-1128(200009)20:5<323::AID-MED1>3.0.CO;2-A
12. del Olmo, A.; Lopez-Perez, O.; Picon, A.; Gaya, P. & Nunez, M. Cheese supplementation with five species of edible seaweeds: Effect on proteolysis, lipolysis and volatile compounds. *Int. Dairy J.,* 2019, **90**, 104-113. doi: 10.1016/J.IDAIRYJ.2018.11.012
13. del Olmo, A.; Picon, A. & Nunez, M. Cheese supplementation with five species of edible seaweeds: effect on microbiota, antiocidant activity, color, texture and sensory characteristics. *Int. Dairy J.,* 2018, doi: 10.1016/j.idairyj.2018.04.004
14. Ermakova, S.; Sokolova, R.; Kim, S.M.; Um, B.H.; Isakov, B. & Zvyagintseva, T. Fucoidans from brown seaweeds Sargassum hornery, Eclonia cava, Costaria costata: Structural characteristics and anticancer activity. *Appl. Biochem. Biotech*., 2011, **164**, 841-850. doi: 10.1007/s12010-011-9178-2
15. Ganesan, A.R.; Subramani, K.; Shanmugam, M.; Seedevi, P.; Park, S.; Alfarhan, A.H.; Rajagopal, R. & Balasubramanian, B. A comparison of nutritional value of underexploited edible seaweeds with recommended dietary allowances. *J. King Saud Univ. – Sci*., 2020, **32**, 1206-1211. doi: 10.1016/j.jksus.2019.11.009
16. Ghislain, M.; Kwak, D.H.; Obiang-Obounou, B.W. & Ogandaga, C.A.M. Anticancer effects of different seaweeds on human colon and breast cancers. *Marine Drugs,* 2014, **12**, 4898-4911. doi: 10.3390/md12094898
17. Hindu, S.V.; Chandrasekaran, N.; Mukherjee, A. & Thomas, J. A review on the impact of seaweed polysaccharide on the growth of probiotic bacteria and its application in aquaculture. *Aqua Int.,* 2018, doi: 10.1007/s10499-018-0318-3
18. Hoiby, N. Understanding bacterial biofilms in patients with cystic fibrosis: current and innovative approaches to potential therapies. *J. Cystic Fibrosis*, 2002, **1**, 249-254. http://dx.doi.org/10.1016/S1569-1993(02)00104-2
19. Houchi, S.; Mahdadi, R.; Khenchouche, A.; Song, J.; Zhang, W.; Pang, X.; Zhang, L. Sandalli, C. & Du, G. Investigation of common chemical componenets and inhibitory effect on GES-type β-lactamase (GES22) in methanolic extracts of Algerian seaweeds. *Micro. Pathogenesis,* 2018, doi: 10.1016/j.micpath.2018.10.034
20. Jacobsen, C.; Sorensen, A;M; Holdt, S.L.; Akoh, C.C. & Hermund, D.B. Source, extraction, characterization and applications of novel antioxidants from seaweed. *Ann. Rev. Food Sci. Technol.,* 2019, doi: 10.1146/annurev-food-032818-121401
21. Jannat-Alipour, H.; Rezaei, M.; Shabanpour, B. & Tabarsa, M. Edible green seaweed, Ulva intestinalis as an ingredient in surimi-based product: chemical composition and physicochemical properties. *J. Appl. Phycol.,* 2019, doi: 10.1007/s10811-019-1744-y
22. Karthikaidevi, G.; Manivannan, K.; Thirumaran, G.; Anantharaman, P. & Balasubramanian, T. Antibacterial properties of selected green seaweeds from vedalai coastal waters; the gulf of mannar marine biosphere reserve. *Global J. Pharmacol.,* 2011, **3**, 107-112. http://www.idosi.org/gjp/3(2)09/10.pdf
23. McCarthy, S.; Dvorakova, V.; O'Sullivan, P. & Bourke, J.F. Anaphylaxis caused by alginate dressing. *Cont. Dermatitis*, 2018, **79**, 396. doi: 10.1111/cod.13100
24. Michikawa, T.; Inoue, M.; Shimazu, T.; Sawada, N.; Iwasaki, M.; Sasazuki, S.; Yamaji, T. & Tsugane, S. Seaweed consumption and the risk of thyroid cancer in women: the Japan Public Health Center-based Prospective Study. *Eur. J. Cancer Prev*., 2012, **21**, 254-260. doi: 10.1097/CEJ.0b013e32834a8042
25. Misurcova, L. Chemical composition of seaweeds. *In* Handbook of marine macroalgae: Biotechnology and applied phycology. Edited by Se-Kwon Kim. John Wiley & Sons Ltd, 2012. https://download.e-bookshelf.de/download/0000/5965/37/L-G-0000596537-0002363980.pdf
26. Mohamed, S.; Hashim, S.N. & Rahman. H. A. Seaweeds: A sustainable functional food for complementary and alternative therapy. *Trends Food Sci. Technol.,* 2011, 1-14. doi: 10.1016/j.tifs.2011.09.001
27. Khan M.N.A.; Choi, J.S.; Lee, M.C.; Kim, E.; Nam, T.J. &

Fujii, H. (2008) Anti-inflammatory activities of methanol extracts from various seaweed species. *J. Environ. Biol.,* **29**, 465-469. http://www.jeb.co.in/journal_issues/200807_jul08_spl/paper_09.pdf

28. Monteiro, M.S.; Sloth, J.; Holdt, S. & Hansen, M. Analysis and risk assessment of seaweed. *Eur. Food Safety Auth. J.*, 2019. doi: 10.2903/j.efsa.2019.e170915
29. Nakashima, H.; Kido, Y.; Kobayashi, N.; Motoki, Y.; Neushul, M. & Yamamoto, N. Antiretroviral activity in a marine red alga; Reverse transcriptase inhibition by an aqueous extract of Schizymenia pacifica. *J. Cancer Res. Clin. Onco*., 1987, **113**, 413-416. doi: 10.1007/BF00390034
30. Parthiban, C.; Saranya, C.; Girija, K.; Hemalatha, A.; Suresh, M. & Anantharaman, P. Biochemical composition of some selected seaweeds from Tuticorin coast. *Adv. Appl. Sci. Res.,* 2013, **4**, 362-366.
31. Phaneuf, D.; Cote, I.; Dumas, P.; Ferron, L.A. & LeBlanc, A. Evaluation of the contamination of marine algae (Seaweed) from the St. Lawrence river and likely to be consumed by humans. *Environ. Res. Sec*., 1999, **80**, S175-S182. http://www.idealibrary.com
32. Rajasulochana, P.; Krishnamoorthy, P. & Dhamotharan, R. Biochemical investigation on red algae family of Kappahycus Sp. *J. Chem. Pharm. Res.,* 2012, **4**, 4637-4641.
33. Rajauria, G.; Jaiswal, A.K.; Abu-Ghannam, N. & Gupta, S. Effect of hydrothermal processing on colour, antioxidant and free radical scavenging capacities of edible Irish brown seaweeds. *Int. J. Food Sci. Technol*., 2010, **45**, 2485-2493. doi:10.1111/j.1365-2621.2010.02449.x
34. Roleda, M.Y.; Marfaing, H.; Desnica, N.; Jonsdottir, R.; Skjermo, J.; Rebours, C. & Nitschke, U. Variations in polyphenol and heavy metal contents of wild-harvested and cultivated seaweed bulk biomass: Health risk assessment and implication for food applications. *Food Contr.,* 2019, **95**, 121-134. doi: 10.1016/j.foodcont.2018.07.031
35. Satpati, G. & Pal, R. Biochemical composition and lipid characterization of marine green algae. *J. Algal Biomass. Utln.,* 2011, **2**, 10-13.
36. Sharma, S.D.; Pati, M.P.; Nayak, L. & Panda, C.R. Uses of seaweed and its application to human welfare: A review. *Int. J. Pharm. Pharmaceut. Sci.,* 2016, **8**, 12-20. doi: 10.22159/ijpps.2016v8i10.12740
37. Sierra, T.; Figueroa, M.M.; Chen, K.T.; Lunde, B. & Jacobs, A. Hypersensitivity to laminaria: a case report and review of literature. *Contraception*, 2015, **91**, 353-5. doi: 10.1016/j.contraception.2015.01.001
38. Skrzypczyk, V.M.; Hermon, K.M.; Norambuena, F.; Turchini, G.M.;, Keast, R. & Bellgrove, A. Is Australian seaweed worth eating? Nutritional and sensorial properties of wild-harvested Australian versus commercially available seaweeds. *J. Appl. Phyco.,* 2019, doi: 10.1007/s10811-018-1530-2
39. Suganthy, N.; Pandian, S.K. & Davi, K.P. Neuroprotective effect of seaweeds inhabiting South India coastal area (Hare Island, Gulf of Mannar Marine Biosphere Researve): Cholinesterase inhibitory effect of *Hypnea valentiae* and *Ulva reticulata*. *Neurosci. Lett*., 2010, 468, 216-219. doi: 10.1016/j.neulet.2009.11.001
40. Thomas, I.; Siew, L.Q.C.S.; Watts, T.J. & Haque, R. Seaweed allergy. Clinical communications. *J. Allergy Clin. Immunol. Pract.,* 2018, doi: 10.1016/j.jaip.2018.11.009
41. Trinchero, J.; Ponce, N.; Cordoba, O.L.; Flores, M.L.; Pampuro, S.; Stortz, C.A.; Salomon, H. & Turk, G. Antiretroviral activit of fucoidans extracted from the brown seaweed Adenocystis utricularis. *Pytotherapy Res*., 2009, **23**, 707-712. doi: 10.1002/ptr.2723
42. Van Doan, H.; Hoseinifar, S.H.; Esteban, M.A.; Dadar, M. & Thu, T.T.N. Mushrooms, seaweed, and their derivatives as functional feed additives for aquaculture and updated view. *Studies Nat. Prod. Chem.*, 2019, doi: 10.1016/B978-0-444-64185-4.00002-2
43. Venkatesan, J.; Sukumaran, A. & Se-Kwon, K. Introduction to seaweed polysaccharides. 2017, doi: 10.1016/B978-0-12-809816-5.00001-3
44. Wu, S.C.; Kang, S.K.; Kazlowski, B.; Wu, C.J. & Pan, C.L. Antivirus and prebiotic properties of seaweed oligosaccharide-lysates derived from agarase AS-II. *J. Fisheries Soc. Taiwan*, 2012, **39**, 11-21. doi: 10.29822/JFST.201203.0002
45. Zhang, Z.; Wang, X.; Han, S.; Liu, C. & Liu, F. Effect of two seaweed polysaccharides on intestinal microbiota in mice evaluated by illumine PE250 sequenceing. *Biol. Macromolecules,* 2018, doi: 10.1016/j.ijbiomac.2018.01.19

CONTRIBUTORS

Mr Arun Kumar Pandey has received his MSc (Food Science and Technology) from Banaras Hindu University, Varanasi. He is presently working as SRF in the Department of Fruits and Vegetables Technology at DRDO-Defence Food Research Laboratory, Mysuru.
In the current study, he has contributed towards literature collection and manuscript preparation.

Dr Om Prakash Chauhan received his MSc and PhD in Food Technology from GB Pant University of Agriculture and Technology, Pantnagar. He is presently working as Scientist ‘F’ and Head Department of Fruits and Vegetables Technology at DRDO-Defence Food Research Laboratory, Mysuru.
In the current study, he has contributed towards manuscript preparation.

Dr Anil Dutt Semwal has received his MSc (Organic chemistry) from Garhwal Universtiy, Srinagar, Garhwal and Ph.D. (Chemistry) from University of Mysore, Mysore. He is working as Director, DRDO-Defence Food Research Laboratory, Mysuru.
In the current study, he has contributed in planning and execution of the study.