International Journal of Trend in Scientific Research and Development (IJTSRD)
International Open Access Journal
ISSN No: 2456 - 6470 | www.ijtsrd.com | Volume - 2 | Issue – 3

Nutraceuticals, trace metals and radioactivity in edible seaweeds for food safety: An overview

Suparna Roy, P. Anantharaman
Centre of Advanced Study in Marine Biology, Faculty of Marine Sciences,
Annamalai University, Annamalai Nagar, Parangipettai-608502, Tamil Nadu, India

ABSTRACT

Seaweeds are of potential nutraceutical and medicinal values due to their wide range of constituents such as proteins, carbohydrates, fatty acids, peptides, minerals, vitamins, and hydrocolloids. However, the seaweeds accumulate toxic heavy metals from their habitats, depending on land discharges, seasons, growth phase and duration of life cycle. As seaweeds are widely used as seafood and food ingredients of various delicious food items, some countries have regulatory rules for daily consumption of seaweeds and seaweeds based food items due to presence of heavy metals, but many countries even don't have such kind of regulatory limits, according to Food Administration organization (FAO) and World Health Organisation (WHO). Realising the importance of this issues, the present review aims to revaluate the biochemical composition of edible seaweeds including their heavy metals and radioactive elements for their potential use for human consumption so as to ensure food safety of the seaweeds.

Keywords: *Seaweeds, Nutraceuticals, Heavy metals, Radioactivity, Functional food ingredient*

INTRODUCTION:

Seaweeds are marine macro algae, economically important marine renewable resources, which are utilized as food ingredients and food items, fodder for animals, soil manure, salts, iodine, and phyco-colloids like agar, alginate, carrageenan and furcellaran in different countries of the World. The marine macroalgae contain proteins and carbohydrates higher than land plants (Arasaki *et al.* 1983). Seaweeds have excellent nutritional composition of proteins, carbohydrates, lipids, minerals, vitamins and all essential amino acids, fatty acids than the common edible vegetable (Vijayaraghavan et al. 1980 and Parekh *et al.* 1982). The nutraceutical composition of seaweeds varies with species, geographical area of distribution, seawater temperature, salinity, light, nutrients and the terrestrial influences (Jensen, 1993; Dawes *et al.* 1993; Kaehler *et al.* 1996; Dawes, 1998). After evaluation of chemical composition and nutraceutical value, some marine macro algae are cultivated and intensively used as nutritious food (Darcy-Vrillon, 1993 and Mabeau *et al.* 1993). Worldwide, only about 221 species of seaweeds are commercially exploited, including 125 Rhodophyta, 64 Phaeophyta and 32 Chlorophyta. Of these 66 of 145 species including 79 Rhodophyta, 38 Phaeophyta and 28 Chlorophyta are directly used as food for human consumption. For industrial purpose, 101 species are used in phycocolloids industries, 41species as alginophyte i.e. alginic acid producing algae, 33 agar producing algae called agarophyte (agar producing seaweeds) and 27 carrageenophytes (carrageenan producing seaweeds). Totally 24 species are used in traditional medicines, 25 species for agriculture, animal feeds and fertilizers, and 12 species are cultivated in 'marine agronomy' (Pereira *et al.* 2009 and Zemke-White *et al.* 1999). In Hawaiian Islands, 70 seaweeds are edible, among which 40 seaweeds are consumed as regular diets on par with nutritious non-vegetarian food items composed with fish and meat (Karla *et al.* 2003). Daily intake of seaweed in Japan is up to 10 g/d and is 8.5 g/d in Korea, according to third Korean National Health and Nutritional Survey (Teas et al., 2004). In Korea, seaweed diet is mainly based on *Porphyra* sp., *Undaria pinnatifida*, and *Laminaria* sp. which constitute over 95% of seaweed consumption. In Japan and China, *Monostroma* sp., *Hizikia fusiformis*, *Ulva* sp., and *Palmaria palmata* are used as the most commonly consumed seaweeds as in Western dietetic habits (FAO, 2003). Other seaweeds used for human consumption are *Gracilaria*, *Gelidium*, *Sargassum*, *Caulerpa* and *Ascophyllum*. Using this information, a comparison is made using common measures (portions) of usual foods in an occidental diet.

Worldwide production of marine macro algae:

Top five cultivated seaweeds in the world are *Laminaria* sp., *Porphyra* sp., *Undaria* sp., *Eucheuma* sp., and *Gracilaria* sp., which together accounts for 5.97 million metric tonnes (Academy of agricultural sciences, 2003). China is the highest in seaweed production (59% and 4.093 fresh wt. Million tonnes), followed by other countries - Korea, Japan, Philippines, Norway, Chile and France (90% and 6.263 fresh wt. Million tonnes). The seaweeds resources along the Indian coast can be at around 100,000 tonnes including explored area - with 73,044 tonnes and unexplored area-with - 27,000 tonnes. State wise annual yield of seaweeds in tonnes (fresh wt.) is in decreasing order: Tamilnadu – (22,044; Subbaramaiah et al. 1979a), Gujarat and Maharashtra – (20,000; Chauhan et al. 1967; Bhanderi et.al, 1975; Rao et al., 1964; Chauhan et al. 1978; Untawale et al.1979), Lakshadweep islands – (8,000; Subbaramaiah et al.1979b), Goa – (2000; Dhargalkar, 1981), and Kerala – (1,000; Chennubhotla et al.1987).

Edible seaweeds:

Since prehistoric times, seaweeds have been used as staple items for low-fat diet in China, Japan, Philippine, Korea, Ireland, Scotland, Wales and other countries in Europe and South East Asia. *Undaria pinnatifida* (wakame), *Palmaria palmata* (dulse), *Porphyra* sp. (Nori), *Laminaria* sp. *Saccharina japonica* (Kombu) are the most commonly used edible species of seaweeds. These edible seaweeds are used for the preparation of tasty food recipes such as sushi dishes, pasta dishes, in spicy batter with mushrooms, seafood pizza, noodles, snack, fish, meat dishes, sauces, soups, vegetable curry and flavour-enhancer etc. The most edible seaweeds around the World are given in table 1.

Sr. No.	Species Name	Countries
1.	*Alaria esculenta*	Irish
2.	*Chondrus crispus*	
3.	*Mastocarpus stellatus*	
4.	*Gigartina mamillosa*	
5.	*Dilsea carnosa*	
6.	*Laminaria digitata*	
7.	*Saccharina lattissima*	
8.	*Palmaria palmata* or *Rhodymenia palmata*	
9.	*Ulva lactuca*	
10.	*Ulva rigida*	
11.	*Porphyra umbilicalis*	
12.	*Porphyra dioica*	
14.	*Saccharina japonica*	
15.	*Undaria pinnatifida*	
16.	*Porphyra yezoensis*	
17.	*Euchemia cottonii*	Indonesia
18.	*Gracilaria coronopifolia*	Hawaii
19.	*Enteromorpha prolifera*	
20.	*Asparagopsis taxiformis*	
21.	*Grateloupia filicina*	
22.	*Ulva fasciata*	
23.	*Sargassum echinocarpum*	
24.	*Dictyopteris plagiogramma*	
25.	*Hizikia fusiforme*	
26.	*Caulerpa lentillifera*	India & Hawaii
27.	*Enteromorpha flexuosa*	
28.	*Monostroma oxyspermum*	
29.	*Eucheuma denticulata*	
30.	*Gracilaria parvispora*	
31.	*Bifurcaria bifurcata*	Spain
32.	*Laminaria saccharina*	
33.	*Mastocarpus stellatus*	
34.	*Gigartina pistillata*	
35.	*Saccorhiza polyschides* (Brown)	
36.	*Laminaria ochroleuca*	
37.	*Gracilaria coronopifolia*	Hawaii (Paull et al.2008)
38.	*Gracilaria parvispora*	
39.	*Gracilaria salicornia*	
40.	*Gracilaria tikvahiae*	
41.	*Ulva rigida*	
42.	*Monostroma sp.*	Asia & Japan, (Novaczek, 2001)
43.	*Caulerpa sp.*	
44.	*Codium sp.*	
45.	*Alaria fistulosa*	India & China
46.	*Cladosiphon*	

	okamuranus	
47.	*Durvillaea antarctica*	
48.	*Ecklonia cava*	
49.	*Undaria undarioides*	
50.	*Callophyllis sp.*	
51.	*Mastocarpus stellatus*	
52.	*Sargassum cinetum*	
53.	*Sargassum vulgare*	
54.	*Sargassum swartzii*	
55.	*Sargassum vulgare*	
56.	*Sargassum myriocystum*	
57.	*Fucus spiralis*	
58.	*Sargassum echinocarpum*	
59.	*Sargassum fusiforme*	
60.	*Pelvetia canaliculata*	
61.	*Ulva intestinalis*	
62.	*Porphyra laciniata*	India & China
63.	*Gracilaria edulis*	
64.	*Gracilaria corticata*	
65.	*Gelidiella acerosa*	
66.	*Eucheuma spinosum*	
67.	*Eucheuma cottonii*	
68.	*Gracilaria chilensis*	China
69.	*Durvillaea potatorum*	Australia
70.	*Laminaria hyperborea*	Chile
71.	*Lessonia trabeculata*	
72.	*Lessonia nigrescens*	
73.	*Macrocystis pyrifera*	Australia & India
74.	*Ecklonia maxima*	
75.	*Caulerpa racemosa*	
76.	*Caulerpa lentillifera*	
77.	*Grinnellia* sp.	China

Table 1 Edible seaweeds in the World

Biochemical composition of edible seaweeds:

1. Chlorophyta: The commonly used green seaweeds for human consumption are *Codium fragile*, *Caulerpa lentillifera*, *Caulerpa racemosa, Ulva spp., Monostroma oxyspermum, Enteromorpha flexuosa, Enteromorpha intestinalis* and *Ulva lactuca. Codium fragile* is distributed throughout the world especially in temperate areas and it is edible in Korea, China and Japan. It contains 8-11% protein, 21-39% ash, 39-67% carbohydrate, 5.1% dietary fibre and 0.5-1.5% lipid of its % dry weight. This alga is used as an additive of Kinchi, a traditional fermented vegetable (Ortiz *et al.* 2009 and Guerra-Rivas *et al.* 2010). It also contains important vitamins such as 0.52-7 mg/100g vitamin A, 0.223 mg/100g vitamin B_1, 0.559 mg/100g vitamins B_2 and Vitamin C ≤0.2-23 mg/100g (Garcia *et al.*1993). *Caulerpa* sp. especially *Caulerpa lentillifera* and *Caulerpa racemosa* are abundantly growing in sandy or muddy sea bottoms of sub-tropical areas along the coastal area of the World and are consumed as fresh vegetable or salad. *Caulerpa lentillifera* has 10-13% protein, 24-37% ash, 33% dietary fibre, 38-59% carbohydrate and 0.86-1.11% lipid per % of dry weight (Pattama *et al.* 2006; Matanjun *et al.* 2009 and Saito *et al.* 2010). Minerals such as Na-8917, K (700-1142), P-103, Ca (780-1874), Mg (630-1650), Fe (9.3-21.4), Zn (2.6-3.5), Mn-7.9, Cu (0.1-2.2) and I-0 mg/100 g^{-1}DW are the constituents of *Caulerpa* sp. (Pattama *et al.* 2006; Matanjun *et al.* 2009 and Yuan *et al.* 2008). *Caulerpa racemosa* is composed of 17.8-18.4% protein, 7-19% ash, 64.9% dietary fibre, 33-41% carbohydrate and 9.8% lipid of % of dry weight (El-Sarraf *et al.* 1994; Akhtar *et al.* 2002; Santoso et al. 2006 and Kumar et al. 2010). It also has high minerals such as Na-2574, K-318, P-29.71, and Ca-1852, Mg (384-1610), Fe (30-81), Zn (1-7), Mn-4.91, Cu (0.6-6.8) and I-0 mg /100 g^{-1}DW (Santoso *et al.* 2006 and Kumar *et al.* 2010). The main sterols in *Ulva lactuca* are cholesterol and isofucosterol and it contains adequate amount of proteins, carbohydrates, minerals and vitamins and low lipids as well as pharmaceutically important compound arylterpenes (Kapetanovic *et al.* 2005; Kukovinets *et al.* 2006). *Ulvaria oxysperma* and *Ulva* spp. have high mineral and low calories, with 16-20% humidity, 17-31 ashes, 6-10 proteins, 0.5-3.2 lipids, 3-12fibre, 46-72 % dry base carbohydrates and 192-270 kcal/100 g wet-base (De Padua *et al.* 2004). *Ulva lactuca* and *Ulva fasciata* contain protein 15-18 and 13-16% dry-base and energy 250-272 and 225-239 kcal/100g, respectively. *Ulva* sp. has low content of lignin type of component such as polyphloroglucinols 1.3 % of dry weight and the large hemi-cellulosic fraction 9% dry weight (Xavier *et al.* 1997). The calorific value of *Monostroma oxyspermum* is over 3000 cal/g ash free dry weight and *Enteromorpha flexuosa* contains 3mg/g amount of vitamin C (Karla *et al.* 2003). Banerjee *et al.* 2009 reported the levels of proteins, lipids and carbohydrates in seaweeds such as *Enteromorpha intestinalis, Ulva lactuca* and *Catenella repens.* Among 19 tropical seaweeds *Chnoospora minima* has 10.8% amino acid (Lourenço *et al.* 2002). *Ulva lactuca* contains 54.0% dietary fibres, 19.6% minerals, 8.5% proteins and 7.9% lipids, 20.6% hemicelluloses, 9.0% cellulose and 42.0% of the total essential amino acids; about 16.0 %

of oleic acid of 60% of the total fatty acids of its dry weight (Yaich *et al.* 2011).

2. Phaeophyta: The commonly used brown seaweeds for human consumption are *Sargassum vulgare, Himanthalia elongata, Undaria pinnatifida, Laminaria digitata, Dictyota* sp. *Chnoospora minima, Padina gymnospora, Ecklonia cava,* and *Laminaria gurjanovae*. *Sargassum vulgare* contains 67.80% carbohydrates, 0.45% lipids, 7.73% fibre and 15.76% proteins including essential amino acids 1.7% such as 8.2% leucine, 6.8% alanine, 17.4% glutamic and 10.6% aspartic acid as well as polysaccharides such as alginic acid, xylofucans and two types of fucans (Barbarino *et al.* 2005 and Marinho-Soriano *et al.* 2006). In food industry, *Himanthalia elongata* (high vitamin E, α-tocopherol) and *Undaria pinnatifida* are demanding for their high content of vitamins, minerals, dietetic fibre as well as low calorie content. They also contain 24% of protein per 100 g of alga, about 1% lipids and polyunsaturated ω3-fatty acids such as eicosapentaenoic acid (EPA; C20:5 ω3). The level of fucosterol the prominent sterol in *Himanthalia elongata* and *Undaria pinnatifida* is 1706 and 1136 µg/g of dry weight respectively. Cholesterol in general present at very low quantity in edible seaweeds. Brown algae have soluble fraction of alginates, fucans and laminarins; in both cases insoluble fractions is cellulose (Sanchez-Machado *et al.* 2004 a). The edible seaweed of Japan, Australia and New Zealand, *Undaria pinnatifida* contains high amount of folic acid of 150 mg/100 g of dry algae (Rodriguez-Bernaldo de Quiros *et al.* 2004). A total of 127 volatile compounds including 4 organic acids, 34 aldehydes, 19 alcohols, 34 ketones, 8 esters, 12 hydrocarbons, 5 sulphur-containing compounds, and 11 more other different unidentified compounds are present in *Undaria pinnatifida* (Shin, 2003). Analysis of 22 Hawaiian edible seaweeds reveals the soluble carbohydrates of 4.5 to 39.9% dry weight, ash of 22.4 to 64.2%, crude lipid less than 5%, while most of the species contain β-carotene (vitamin-A), while *Dictyota* sp. contains 16% crude lipid on dry weight and the caloric content of 3000 cal/g ash free dry weight in *Dictyota sandvicensis* (Karla *et al.* 2003). *Undaria pinnatifida* has macro elements (Na, K, Ca, Mg), ranging from 8.1 to 17.9 mg/100g and trace elements (Fe, Zn, Mn, Cu), ranging from 5.1 to 15.2 mg/100g (Rupérez, 2002). The dietary fibre of Spanish seaweeds such as *Fucus vesiculosus, Laminaria digitata, Undaria pinnatifida,* ranges from 33.6 to 50%, of which 19.6-64.9% is soluble, 12 - 40 % is insoluble fibres, which includes cellulose, residual fucose-containing polysaccharides. *Laminaria gurjanovae* contains alginic acid (mannuronic and guluronic acid-3:1) at about 28% of its biomass, in addition to laminarins (linear 1, 3-β-D glucan and 1, 3 and 1, 6-β-D glucan), neutral lipids and glycerolglycolipids includes fatty acid such as 14:0, 16:0, 16:1ω-7, 18:1ω-7 and 18:2 ω-6 acids (Banerjee *et al.* 2009). The dieckol-rich phlorotannins *of Padina gymnospora* and *Ecklonia cava* have *in vivo* hepatoprotective effect (Min-Cheol *et al.* 2012). Cell walls of brown algae containing sulphated polysaccharides such as fucoidans have nutraceutical, pharmaceutical and cosmaceutical values (Wijesekaraa *et al.* 2011). The brown alga *Cystoseira adriatica* has high amount of cholesterol and stigmast-5-en-3 beta-ol (Kapetanovic *et al.* 2005). In *Laminaria digitata*, the biochemical composition such as carbohydrates, metals, laminarins and manitol changes with season and developmental growth stage (Adams *et al.* 2011). *Adenocystis utricularis* is composed of L-fucose, D-galactose and ester sulphate the galactofucan and other product uronofucoidan, significant amount of uronic acids with low proportions of sulphate ester (Ponce *et al.* 2003). Wakame powder (*Undaria pinnatifida*) has 20.51% protein, 3.71% fat, 43.05% carbohydrate, 26.06% ash and 0.72% fibre on dry weight basis, and this is used to prepare sensorial accepted pasta at 10 % (Prabhasankar *et al.* 2009).

3. Rhodophyta: The commonly used red seaweeds for human consumption are *Catenella repens Aglaothamnion uruguayense, Cryptonemia seminervis, Porphyra columbina, Porphyra* sp., *Halymenia* sp., and *Chondrus crispus*. According to Lourenço *et al.* 2002, while analysing the amino acid composition and protein content of 19 tropical seaweeds, it showed that the content of aspartic and glutamic acid of green algae are lower than red and brown algae; amino acid residues vary from 23.1% in *Aglaothamnion uruguayense,* and nitrogen-protein conversion factor ranges from 3.75 for *Cryptonemia seminervis.* The lipid content of Sea Spaghetti is higher ($p<0.05$) than that of Nori, but similar ($p>0.05$) to Wakame. Sea Spaghetti and Wakame have higher ($p<0.05$) ash content 30% and 37% respectively than Nori (Cofrades *et al.* 2010). *Kappaphycus alvarezii* contains carrageenan such as 3,6-anhydro-D-galactose, *Calliplepharis jubata* and non-fructified thalli of *Eucheuma denticulata* have iota-carrageenan consequently Kappa/iota-hybrid carrageenan of

Chondracanthus teedei and *Chondracanthus teedei* var. *lusitanicus* contains C2-sulphated 3,6-anhydro-D-galactose and C4-sulphated galactose (Pereira et al. 2009). The β-carotene and α-carotene, and the xanthophylls lutein are detected in *Halymenia floresii* and the content of lutein is of interest in the market as edible seaweed (Godínez-Ortega *et al.* 2007). *Porphyra* sp., has 337 µg/g of dry demo sterol. *Porphyra* sp. and *Chondrus crispus* contain 24% of protein per 100 g of alga, about 1% lipids and polyunsaturated ω3-fatty acids such as eicosapentaenoic acid (EPA; C20:5 ω3). *Porphyra sp*. contains up to 8.6% of sterols as cholesterol. Red seaweeds have soluble fraction of sulphated galactans (agar, carrageenan) (Sanchez-Machado *et al.* 2004 b and c). *Halymenia formosa* and *Porphyra vietnamensis* have high protein and less than 5% crude lipid and *Chondrus crispus* is used as a food supplement to negotiate the essential minerals deficiencies (Rupérez 2002). *Chondrus crispus and Porphyra tenera* contain high amount of soluble and insoluble fibres as well sulphate (2.8-10.5%), lipids (0.2-2.5%), ashes (21-39.8%) and extractable polyphenols -0.4% in the red seaweeds and these red seaweeds contain higher protein (20.9-29.8%) than brown seaweed (6.9- 16%), (Rupérez, 2001). About 78% of total fatty acids of *Chondrus crispus* includes palmitic, palmitoleic, oleic, arachidonic and eicosapentaenoic acids showing the presence of much greater quantity of unsaturated fatty acids (>80%) than saturated fatty acids as well as cholesterol (>94%) containing smaller amounts of 7-dehydrocholesterol and 12 stigma sterol and minimum amounts of campesterol, sitosterol, and 22 dehydro-cholesterol (Tasende *et al.* 2000). *Porphyra columbina* is enriched with low molecular weight peptides such as Aspartic acid, Alanine and Glutamic acid which have immunosuppressive and antihypertensive effects (Ciana *et al.* 2012).

Trace metals of edible seaweeds: Hiziki is the most edible species in the foreign country. According to National Metrology Institute of Japan, the values in Hijiki and *Ulva lactuca* fell within the range of certified value (Table 2). The red algae (*Porphyra tenera* and *Porphyra* species) contain 17-28 µg/g of arsenic (dry wet) almost in the form of arsenosugar (Shibata et al. 1990 & Francescom et al. 1993). To test the quality assurance of seaweeds based food items for heavy metals content, the limits of detection (LOD) and limits of quantification (LOQ) were calculated for Hiziki and compared with certified values. It reveals that Hiziki content heavy metals below toxic level (Khan et al. 2015). In open ocean water arsenic typical levels are 1–2 g As /L (Francesconi and Edmonds, 1998; WHO, 2001). Arsenic level is most constant in deep ocean waters, while levels in surface waters show seasonal variation. Arsenic (As) are found in seafood in different forms such as Arsenate (As [V]), Methyl Arsonate (MA), Arsenobetaine, Trimethyl Arsine, Oxide (TMAO), Arsenite (As [III]), Dimethyl Arsinate (DMA), Arsenocholine, Tetramethyl Arsonium Ion (TETRA). So, for safety assurance the edible seaweeds arsenic content is analysed in details (Borak et al. 2007). According to UK Total Diet Study, 1997, the concentration of 4.4 mg/kg of total arsenic in the fish group has been accounts 94% of the average population exposure to arsenic but seaweed was not included in these total diet samples (Ysart et al., 2000). In 1989, according to JECFA, the provisional tolerable weekly intake (PTWI) of arsenic is of 15 µg/kg body weight. Some of seaweeds had been analysed for its heavy metals compositions, of which some seaweeds heavy metals composition had been tabulated in table 3. It is clearly indicated in the table 4 of certified values of heavy metals that the edible seaweeds contain lower heavy metals than certified value of heavy metals, so it can be concluded that these studied seaweeds will be safe for use and consider it, as food items in future. The heavy metals arsenic is a toxic metal and focused of study to analyse its presence in food items, so likewise seaweeds are also considered as food items, so the arsenic composition of seaweeds were tabulated in the table 5 to identify the seaweeds as safe food items with respect to its arsenic content also.

Table 2 presents comparisons between experimental results and certified values for two seaweeds (Khaled et al. 2014; Khan et al. 2015 and Besada et al. 2009).

***Hizikia fusiforme* (mg/kg dw)**			***Ulva lactuca* (mg/kg dw)**		
Elements	**Certified Value**	**Values Found**	**Elements**	**Certified Value**	**Values Found**
Cd	0.79±0.02	0.759±0.032	Cd	0.274±0.022	0.271±0.017
Cu	1.55±0.07	1.523±0.054	Pb	13.48±0.36	13.43±2.15
Fe	311±11	315.60±5.263	Hg	0.041–0.054	0.049±0.016
Ni	2.2±0.1	2.265±0.095	Cu	13.14±0.37	13.46±0.78
Pb	0.43±0.03	0.452±0.026	Zn	51.3±1.2	50.4±2.5
Zn	13.4±0.5	13.226±0.349	As	3.09±0.20	3.22±0.81

Table 3 The heavy metals content of seaweeds

Sl. No	**Species**	**Hg**	**Pb**	**Cd**	**As**	**References**
mg/kg						
1.	*Porphyra tenera*	<100	256±0.12	1,629±0.30	32,024±7.44	Hwang et al. 2013
2.	*Porphyra haitanensis*	<100	1,566±0.22	3,408±0.45	43,895±12.04	
ng/g						Besada et al. 2009, Almela et al. 2006, Rasyid et al. 2017, Rao et al. 2007
3.	*Gelidium sp.*	0.005-0.009	0.381-0.861	0.025-0.046	<0.05-0.21	
4.	*Eisenia bicyclis*	0.023-0.047	0.029-0.096	0.585-0.827	27.9-34.1	
5.	*Himanthalia elongate*	0.008-0.016	0.203-0.259	0.310-0.326	32.9-36.7	
6.	*Hizikia fusiforme*	0.015-0.050	< 0.008-	0.980-2.50	103-147	
7.	*Laminaria sp.*	0.001-0.005	< 0.008-0.460	0.085-1.83	51.7-68.3	
8.	*Ulva rigida*	0.018-0.019	1.00-1.05	0.031-0.033	6.41-7.06	
9.	*Chondrus crispus*	0.025-0.007	0.403-0.727	0.718-0.742	23.2-25.5	
10.	*Porphyra umbilicales*	0.008-0.032	<0.008-0.270	0.008-0.032	28.9-49.5	
11.	*Undaria pinnatifida*	0.010-0.057	<0.005-1.28	0.267-4.82	42.1-76.9	
12.	*Enteromorpha* sp.		0.205	0.020	0.346	
13.	*Ulva pertusa*		< LD	0.190	0.268	
14.	*Palmaria* sp.		<LD	0.147	0.466	
15.	*Palmaria palmata*		1.52	0.877	0.596	
16.	*Laminaria japonica*		<LD	0.908	1.44	
17.	*Laminaria digitata*		0.106	0.343	0.251	
mg/gm						
19.	*Fucus vesiculosus*		0.898	0.412	0.291	
20.	*Himanthalia elongata*		0.198	0.389	< LD	
21.	*Durvillaea antarctica*		<LD	2.46	0.318	
22.	*Ulva lactuca*	<0.005	0.18	0.48	0.09	
23.	*Porphyra vietnamensis*	0.01-0.01	0.01-015	0.14-0.55	1.24-1.83	
mg/kg						Smith et al. 2010
24.	*Undaria pinnatifida*	0.03±0.01	0.23±0.05	35.62±3.69	24.	
25.	*Porphyra sp.*	0.03±0.02	0.98±0.36	12.87±7.80	25.	
26.	*Macrocystis pyrifera*	0.05	0.30	97	26.	
27.	*Ecklonia radiata*	0.17±0.08	0.61±0.40	51.32±6.49	27.	
28.	*Ulva stenophyllum*	0.10±0.03	1.83±0.99	1.88±0.63	28.	
29.	*Durvillaea antarctica*	0.04±0.04	0.14±0.02	27.13±4.64	29.	
30.	*Hormosina banksii*	0.05±0.01	0.61±0.55	31.69±10.66	30.	

Table 4 Certified values of the major toxic trace metals	
WHO/FAO-TWIS (Provisional tolerable weekly intakes of edible seaweeds, Australia -New Zealand Food Authority, 2005) (Smith et al. 2010).	
Arsenic	15µg/kg BW
Mercury	1.6 µg/kg BW
Lead	25 µg/kg BW
Certified Values of metals of *Ulva lactuca* of national Research Council, Canada. (Besada et al. 2009).	
Cadmium	0.274±0.022
Lead	13.48± 0.36
Mercury	0.041±0.054
Arsenic	3.09±0.20
World Health Organisation/ Food & Agriculture organisation of the United Nations (Hau et al. 2014).	
Cadmium(Cd)	0.49 mg TWI(tolerable weekly intake)
Mercury(Hg)	0.112 mgTWI
Lead (Pb)	1.75 mg TWI

Table 5 Arsenic content of some edible seaweed				
Sr. No.	Species Name	Total Arsenic	Inorganic arsenic	References
	mg/100 g dw			Almela et al. 2006 García-Sartal, et al. 2013 Kolb et al. 2004; Khan et al. 2015
1.	*Palmaria* sp.	13.0	0.466	
2.	*Palmaria palmata*	12.6	0.596	
3.	*Laminaria japonica*	116	1.44	
4.	*Laminaria digitata*.	65.7	0.251	
5.	*Fucus vesiculosus*	40.4	0.291	
	ppm , f. w.			
6.	*Himanthalia elongata*	23.6	<LD	
7.	*Durvillaea antarctica*	15.2	0.318	
8.	*Enteromorpha* sp.	2.15	0.346	
9.	*Ulva pertusa*	3.24	0.268	
10.	*Porphyra tenera*	24.1	0.280	
11.	*Hizikia fusiforme*	0.746	0.220 ± 0.16	
12.	*Sargassum fulvellum*	0.14	0.0670 ± 0.00	
	(µg g−1)			
13.	*Porphyra umbilicalis*	34.5	0.239	
14.	*Porphyra* sp.	32.7	0.189	
15.	*Rhodymenia palmata*	8.80	0.153	
16.	*Chondrus crispus*	12.7	0.357	
17.	*Laminaria* sp.	39.6	0.473	
18.	*Undaria pinnatifida* (Wakame)	41.4	<LD	
19.	*Eisenia bicyclis*	22.4	0.167	

Radioactivity of seaweeds:

Kelp is a strong bio-concentrator of radioisotopes in water. It is concluded that Post-Fukushima, there was a statistically significant rise in the radioactivity of nori seaweed than compared to Pre-Fukushima seaweed sampled ($p<0.05$). In addition, radioactivity in water threatens in water to destroy Canada's marine aquaculture and seafood industries. The Fukushima 1 Nuclear Power Plant accident in March 2011 released an enormously high level of radionuclides into the environment, a total estimation of Bq. represented by mainly radioactive Cs, Sr and I. Because these radionuclides are biophilic, an urgent risk has arisen due to biological intake and subsequent food web contamination in the ecosystem, showed the highest ability to eliminate radioactive Cs from the medium by cellular accumulation. The issues of radioactivity pollution, is now an international concern to stop the inclusion of radioactivity to the marine environment (WHO, 2016). An update, 2016 on the basis of 5 reviews of environmental and public health effects from radiation releases at Fukushima, it has reported that radioactive elements such as Iodine (I^{131}, I^{132}), Cesium (Cs^{137}, Cs^{134}), and tellurium (Te^{132}) released in to air, water, ocean debris and marine life are distributed through ocean to the United States and Canada and all over the World (WHO, 2013). The presence of radioactive Iodine has been reported in *Fucus* population from Vancouver, British Colombia, after Chernobyl accident (Druchl et al. 1988). In March, 2011 the Fukushima Nuclear power plant accident occurred. To assess the effect of released radioactivity to the marine environment as well as seaweeds, many seaweeds such as *Undaria pinnatifida, Eisenia bicyclis, Ulva pertusa, Sargassum thunbergii, Scytosiphon lomentaria, Sargassum muticum, Sargassum horneri, Ulva linza, Gloiopeltis furcata, Grateloupia lanceolata, Saccharina japonica, Sargassum muticum, Colpomenia sinuosa, Hypnea asiatica, Neodilsea yendoana, Sargassum myamadae, Ahnfeltiopsis paradoxa, Chondria crassicaulis, Calliarthron sp. Dasya sessilis, Analipus japonicas, Bangiafusco purpurea, Pyropia yezoensis, Petalonia fascia, Monostroma nitidum, Analipus japonicas, Desmanestia ligulata, Pterosiphonia pinnulata, Padina arborescens, Ecklonia cava, Sargassum fusiforme, Ulva prolifera, Delesseria serrulata, Schizymenia dubyi, Gelidium elegans, Chondrus giganteus, Petalonia fascia, Spatoglossum pacificum, Chaetomorpha moniligera, Chondrus socellatus, Grateloupia turuturu, Plocamium cartilagineum, Lomentaria hakodatensis, Pachydictym coriaceum, Cladophora sp. Ahnfeltiopsis flabelliformis, Pachydictyon coriaceum, Polyopes affinis, Cladophora albida, Mazzaella japonica, Neodilsea longissima, Dictyota dichotoma, Chondrus socellatus, Grateloupia sparsa, Gastroclonium pacificum, Tinocladia crassa, Sargassum confusum, Codium lucasii, Bryopsis plusnosa, Corallina pilulifera, Calliarthron yezoense, Chondracanthus intermedius, Laurencia oleamurae and Sargassum siliquastrum* were collected from Nagasaki, Fukushima 50 Km and Soma (Fukushima Pref.), Iwaya (Hyogo Pref.), Iwanuma (Miyagi Pref.), Kamogawa and Katuura (Chiba Pref.) and tested for presence of radioactivity and it has been revealed that as seaweeds accumulate ^{137}Cs in tissues, so bio-monitoring of ^{137}Cs using seaweeds may be used to track the metals loads in different geographical region and as seaweeds grow and turn over rather rapidly, so they have been not influenced by bio-concentration through food chain (Kawai et al. 2014).

After TEPCO nuclear power plant leak, radioactive iodine has been detected in six seaweeds samples in South Korea. However, 14 seaweed species are free from radioactivity except very small amount of radioactivity in tangle weed (*Laminaria japonica*). So, if the marine environment is contaminated by radioactive substances, then there is a possibility of accumulation of radioactive substances in seaweeds, still it is in negligible amount. It has been reported that after the consumption of Kelp, the uptake and deposition of radioactive Iodine are reduced in very low concentration (Irie et al. 2012).

The meltdowns at nuclear power plants (such as Chernobyl or Three Mile Island) releases large amounts of I^{131} and other radioactive elements into the ocean and atmosphere. According to the National Institute of Health, from the nuclear accident at Chernobyl the radioactive I^{131} release in high amount to the environment developing thyroid cancer worldwide. The mixing of such kind of radioactive isotope in the oceans increases the risk of circulation of radioactivity throughout the World. The seaweeds especially brown seaweeds *Laminaria* sp., *Sargassum* sp., *Turbinaria* sp. and *Ascophyllum* sp. have larger surface area and accumulate high Iodine, so, such kind of sudden accidental release of radioactivity in to the ocean may increase the risk of accumulation of radioactive Iodine (Drum, 2012). In March, 2011 the meltdown of three nuclear reactors including other two disaster a major earthquake and a resultant tsunami releases huge radioactivity to the air. To cool down the high heat of nuclear power plant, huge water is flooded to that place and that washed water flows to the ocean producing radioactivity to the ocean; the reports for three years 2013, 2014, 2016, explain that releases of radioactivity are still continuous from that area which gradually are increasing of radioactivity in ocean area.

In spite of the issue of radioactivity, it is believed that the seaweeds grow rather rapidly and, hence, turnover rapidly, so that they exert no influence of bio-concentration of radioactive substance (Cs^{137}) through the food chain (Kawai et al., 2014). Moreover, the microalgae and aquatic plants notably eustigmatophycean unicellular algal strain, nak9 can eliminate radioactive cesium, iodine and strontium, as proved in experimental studies (Shin- ya Fukuda et al., 2013). This will be an important strategy for decreasing radio pollution.

Discussion:

Traditionally, seaweeds are a natural source of food and medicines in Asian countries, especially Japan, Korea, China, Vietnam, Indonesia and Taiwan. Worldwide, six million tons of fresh algae are now cultivated and an amount of around 90% is for the commercial demand (FAO, 2002). Globally, a total of 147 seaweeds are edible for their nutritional composition (Leonel et al. 2015). Seaweeds contain an array of valuable minerals and the commercially available edible seaweeds contain less quantity of toxic heavy metals, so consumption of seaweeds within the range limit mentioned by WHO/FAO will not deliver any harmful effect (Almela et al. 2002; Van Netten et al. 2000). The edible seaweeds are safe for human consumption when the concentration of the above elements mentioned in edible seaweeds compared to World Health Organisation of the United Nations (WHO/FAO).

According to mentioned certified values and the normal toxic metals content of seaweeds, it is concluded that seaweed's content the toxic metals below its threshold levels, so seaweeds as food and food ingredient, will be safe and there is no chance to be bio-concentrated and biomagnified as well as toxicity after consumption of it.

In order, to find out the exact circulation of radioactivity through the different trophic levels of ocean ecosystem, requires an extensive estimation of radioactivity in different plants and animals in marine environment. This will help to understand whether the radioactivity is magnified in any particular organisms, or equally distributed to all animals and plants, and accumulated in sediments and water. Species specific stepwise estimation of radioactivity is required in future to predict the future risk of radioactivity.

Some heavy metals content of some mostly used edible seaweeds showed that estimated values are lower than the certified values of uptake. So, it is declared to be safe as edible items. Some of the literatures also show that after cooking, the metals are releasing into water and the content of heavy metals in cooked seaweeds are lower than the raw seaweeds. So, before making any food items with seaweeds, if seaweeds are slightly boiled with water and that water will be removed completely from seaweeds; after that if seaweeds are used for preparing food items. It will be safer. In spite of superior nutritional properties, high concentration of certain nutrients may be problematic for some, for example, overconsumption of vitamin K can interfere with blood thinning medications. Certain seaweeds have high potassium contents, which might cause issues for those with kidney problems. While the iodine content makes it especially beneficial for thyroid health, consuming too much iodine can have the opposite effect.

Future Directions:

In this review, the overall description of the biochemical composition of marine macro algae, its use as food items for human being are analysed to identify the properties of marine macro algae for use as food item in daily diet. We take daily food such as carbohydrate, protein, fat, minerals, micronutrients and macronutrients as required amount through rice, vegetables, oil, milk, fish, meat and other food ingredients; but the seaweeds contain all the mentioned food ingredients in them, so if we find out a single macro alga which is composed of all require quantity of dietary amount of daily food, we can used it as a food supplement. This review is purposive to create a nutritional detail of marine macro algae to popularize their utilization and consumption throughout the world. Comparative details with several commonly used seaweeds with daily used vegetable are available to find out the seaweeds vegetable as a potential alternative for daily diet. The nutrient composition of seaweeds varies on the basis of water quality and climatic conditions as well as nutrients supply through the seawater. This indicates the importance of cultivating selected seaweeds by augmenting nutritive values 1.through manipulating and maintaining culture medium, similar to agricultural crops for the future. Above all, the food safety of seaweeds in terms of radioactivity especially for the site around the radioactive polluting industries deserves continuous monitoring.

Acknowledgements: The authors thank the authorities of Annamalai University.

Conflict of interest: There is no conflict of interest to be declared.

Funding: Authors are thankful to Department of Science and Technology (DST), Govt. of India for financial support.

Reference:

1. Adams, J. M. M., Ross, A. B., Anastasakis, K., Hodgson, E. M., Gallagher, J. A., Jones, J. M., and Donnison, I. S. (2011). Seasonal variation in the chemical composition of the bio-energy feedstock *Laminaria digitata* for thermo-chemical conversion. Bio-resources Technology, 102, 226-234.
2. Akhtar, P., and Sultana, V. (2002). Biochemical studies of some seaweed species from Karachi coast. Records Zoological Survey of Pakistan, 14, 1-4.
3. Almela, C., Algora, S., Benito, V., Clemente, M., Devesa, V., Suner, M., Velez, D., Montora, R., (2002). Heavy metal, total Arsenic and inorganic arsenic contents of algae food products. Journal of Agricultural & Food Chemistry, 50: 918-923.
4. Almela, C., Jesus Clemente, M., Velez, D., Montora, R., (2006). Total arsenic, inorganic arsenic, lead and Cadmium contents inedible seaweed sold in Spain. Food and Chemical Toxicology, 44. (2006). 1901-1908
5. Arasaki, S., and Arasaki, T. (1983). Vegetables from the sea. Japan Publication International, Tokyo, 196.
6. http://naasindia.org (2003). The Academy of Agricultural Sciences.
7. Banerjee, K., Ghosh, R., Homechaudhuri, S., and Mitra, A. (2009). Biochemical composition of marine macro algae from Gangetic Delta at the apex of Bay of Bengal. African Journal of Basic and applied Science, 1(5-6), 96-104.
8. Barbarino, E., and Lourenco, S. O. (2005). An evaluation of methods for extraction and quantification of protein from marine macro and microalgae. J Appl. Phycol., 17 (5), 447-460.
9. Besada, V., Andrade, J. M., Schultze, F., Gonzalez, J. J., (2009). Heavy metals in edible seaweeds commercialised for human composition. Journal of Marine Systems, 75, 305-313.
10. Bhanderi, P. P., and Trivedi, Y. A. (1975).Seaweed resources of Hanuman dandi reef and Numani reef near Okha Port. Indian J. mar. Sci., 4(1), 97-99.
11. Borak J, Hosgood HD (2007) Seafood arsenic: implications for human risk assessment. Regulatory Toxicology and Pharmacology 47(2):204–212
12. J. Borak and H.D. Hosgood, Regul Toxicol. Pharmacol. 47 (2007) 204.
13. Chauhan, V. D., and Krishnamurthy, V. (1967). Observations on the output of zoospores, their liberation, viability and germination in *Sargassum swartzii* (Turn.) C. Ag. Proc. Semi. Sea Salt and Plants. CSMCRI, Bhavnagar, pp. 197-201.
14. Chauhan, V. D., and Mairh, O. P. (1978). Report on the survey of Marine algae resources of Saurashtra coast. Salt Res. India, 14(2), 21-41.
15. Chennubhotla, V. S. K., Ramachandrudu, B. S., Kaladharan, P., and Dharmaraja, S. K. (1987). Seaweed resources of Kerala coast. Seminar on Fisheries Research and Development in Kerala, Vol.29, no.1-2 pp, 54-59.
16. Ciana, E. R., Silvina, O. M-A., and Dragoa, R. (2012). Bioactive properties of peptides obtained by enzymatic hydrolysis from protein by products of *Porphyra columbina*. Food Research International, Volume 49, Issue 1, P 364-372.
17. Cofrades, S., Lopez-Lopez, I., Bravo, L., Ruiz-Capillas, C., Bastida, S., Larrea, M. T., and Jime´nez-Colmenero, F. (2010). Nutritional and antioxidant properties of different brown and red Spanish edible seaweeds. Food science and Technology International, 16(5), 361-370.
18. Darcy-Vrillon, B. (1993). Nutritional aspects of the developing use of marine macro algae for the

human food industry. International Journal of Food Science and Nutrition, 44, 23-35.

19. Dawes, C. J. (1998). Marine Botany. John Wiley and Sons, Inc. New York, 480p.

20. Dawes, C. J. Kovach, C., and Friedlander, M. (1993). Exposure of *Gracilaria* sp. to various environmental conditions II. The effect on fatty acid composition. Bot. Mar 36, 289-96.

21. De Padua, M., Fontoura, P. S. G., and Mathias, A. L. (2004). Chemical composition of *Ulvaria oxysperma* (Kutzing) bliding, *Ulva lactuca* (Linnaeus) and *Ulva fasciata* (Delile). Braz Arch Biol. Techn, 47 (1), 49-55.

22. Dhargalkar, V. K. (1981). Studies on marine algae of the Goa coast. Ph.D. Thesis. Bombay University, Bombay, 186 pp

23. Druchl, L.D. Cackette, M and D'Auria, J.M. 1988. Geographical and temporal distribution of Iodine - 131 in the brown seaweed Fucus subsequent to the Chernobyl incident. Springer link, Vol. 98, Issue – 1, pp- 125-129.

24. Drum, Ryan. Environmental Origins of Thyroid Disease, www.ryandrum.com

25. El-Sarraf, W., and El-Shaarawy, G. (1994). Chemical composition of some marine macro algae from the Mediterranean Sea of Alexandria, Egypt. The Bulletin of the High Institute of Public Health, 24, 523-534.

26. Edmonds, J. S., Shibata, Y., Francesconi, K. A., Rippingale, R. J. and Morita, M., 1998 Arsenic Transformations in Short Marine Food Chains studied by HPLC-ICP MS, Applied organ metallic chemistry

27. FAO, (2002), Perspectives para ta production de algas marinas en los paises en desarrollo Report No. 968 FIIU/C968 (Es).

28. FAO, (2002), Perspectives para ta production de algas marinas en los paises en desarrollo Report No. 968FIIU/C968 (Es).

29. Garcia, I., Castroviejo, R. Neira, C., and Galicia. (1993). Feed and other uses. Corunna: Department of Fisheries, Aquaculture and Shellfish-Government of Galicia.

30. García-Sartal, C., Barciela-Alonso, M. D. C, Moreda-Piñeiro, A., Bermejo-Barrera, P., (2013). Study of cooking on the bioavailability of As, Co, Cr, Cu, Fe, Ni, Se and Zn from edible seaweed. Microchemical Journal 108, 92–99.

31. Guerra-Rivas, G., Gomez Gutierrez, C. M., Alarcón-Arteaga, G., Soria-Mercado, I. E. and Ayala-Sanchez, N. E. (2010). Screening for anticoagulant activity in marine algae from the Northwest Mexican Pacific coast. Journal of Applied Phycology, 23(3), 495-503

32. Hau, L., Robertson, J., White, W. L., (2014). Metals in New Zealand Undaria pinnatifida (Wakame). Open Journal of Marine Sciences, 4: 163-173.

33. Hwang, Eun-Sun., Ki, Kyug-Nam. And Chung, M. (2013). Proximate Composition, Amino acids, minerals and Heavy metals content of dried laver. ; 18(2):139-144.

34. Irie, M., Radioactive Iodine and the effect of consuming seaweeds. (2012). Project.

35. Jensen, A. (1993). Present and future needs for alga and algal products. Hydrobiology, 260/261, 15-21.

36. Kaehler, S., and Kennish, R. (1996). Summer and winter comparisons in the nutritional value of marine macro algae from Hong Kong. Bot. Mar 39, 11-17.

37. Kapetanovic, R., Sladic, D., Popov, S., Zlatovic, M., Kljajic, Z., and Gasic, M. J. (2005). Sterol composition of the Adriatic Sea algae Ulva lactuca, Codium dichotonium, Cystoseira adriatica and Fucus virsoides. J Serb Chem Soc, 70 (12), 1395-1400.

38. Karla, J., Dermid, M., and Stuercke, B. (2003). Nutritional composition of edible Hawaiian seaweeds. Journal of applied Phycology,15, 513-524

39. Kawai, H., Kitamura, A., Mimura, M., Mimura, T., Tahara, T., Aida, D., Sato, K., Sasaki, H., (2014). Radioactive cesium accumulation in seaweeds by the Fukushima 1 Nuclear Power Plant accident—two years' monitoring at Iwaki and its vicinity. J Plant Res. 127:23–42

40. Khaled, A., Hessein, A., Abdel-Halim, A M., Morsy, F. M., (2014). Distribution of heavy metals in seaweeds collected along Marsa-Matrouh beaches, Egyptian Mediterranean Sea. Egyptian Journal of Aquatic Research. 40, 363–371.

41. Khan, N., Ryu, K. Y., Choi, J. Y., Nho, E. Y., Habte, G., Choi, H., Kim, M. H., Park, K. S., Kim, K. S., (2015). Determination of toxic heavy metals and speciation of arsenic in seaweeds from South Korea. Food Chemistry 169, 464–470

42. Kolb, N., Vallorani, L., Milanovi, N., Stocchi, V., (2004).Evaluation of marine algae Wakame (Undaria pinnatifida) and Kombu (Laminaria digitata japonica) as Food Supplements. Food Technol. Biotechnol. 42 (1) 57–61.

43. Kukovinets, O. S., and Kislitsyn, M. I. (2006). Natural Arylterpenes and their Biological activity. Chemistry of Natural Compounds, Vol. 42, No. 1

44. Kumar, M., Kumari, P., Trivedi, N., Shukla, M. K., Gupta, V., Reddy, C. R. K., and Jha, B. (2010). Minerals, PUFAs and antioxidant properties of some tropical seaweed from Saurashtra coast of India. Journal of Applied Phycology, Vol. 23(5), 797-810.

45. Leonel, P., Edible Seaweeds of the World. Book, ISBN10: 1498730477/ISBN 13: 9781498730471., CRC Press, 2015

46. Lourenço, S. O., Barbarino, E., Joel, C., De-Paula, O., Pereira, L. O., Ursula, M., and Marquez, L. (2002). Amino acid composition, protein content and calculation of nitrogen-to-protein conversion factors for 19 tropical seaweeds. Phycological Research, 50, 233–241

47. Mabeau, S., and Fleurence, J. (1993). Seaweed in food products: bio-chemical and nutritional aspects. Trends in Food Science and Technology, 4, 103-107

48. Marinho-Soriano, E., Fonseca, P. C., Carneiro, M. A. A., and Moreira, W. S. C. (2006). Seasonal variation in the chemical composition of two tropical seaweeds. Bioresour Technol, 97 (18), 2402-6.

49. Matanjun, P., Mohamed, S., Mustapha, N. M., and Muhammad, K. (2009). Nutrient content of tropical edible seaweeds, Eucheuma cottonii, Caulerpa lentillifera and Sargassum polycystum. Journal of Applied Phycology, 21, 75-80.

50. Min-Cheol, K., Ginnae, A., Xiudong, Y., Kil-Nam, K., Sung-Myung, K., Seung-Hong L., Seok-Chun, K., Ju-Young, K., Daekyung, K., Yong - Tae, K., Young-heun, J., and Sun-Joo, P. (2012). Hepatoprotective effects of dieckol-rich phlorotannins from Ecklonia cava, a brown seaweed, against ethanol induced liver damage in BALB/c mice. Food and Chemical Toxicology, Vol. 50, Issue-6, Pp 1986-1991.

51. Novaczek, I., (2001). A guide to the common and Edible and Medicinal Sea Plants of the Pacific Island University of the South Pacific, 40pp.

52. Ortiz, J., Uquiche, E., Robert, P., Romero, N., Quitral, V., and Llantén, C. (2009). Functional and nutritional value of the Chilean seaweeds Codium fragile, Gracilaria chilensis and Macrocystis pyrifera. European Journal of Lipid Science and Technology, 111, 320-327.

53. Parekh, R. G., and Chauhan, V. D. (1982).Seasonal variations in the chemical constituents of the marine alga Ulva sp. and seawater. Seaweed Res Utiln, 5(1), 1-4.

54. Pattama, R. A., and Chirapart, A. (2006). Nutritional evaluation of tropical green seaweeds Caulerpa lentillifera and Ulva reticulata. Kasetsart Journal Natural Science, 40, 75-83.

55. Paull, R. E. and Chen, N. J. Postharvest, (2008). The handling and storage of the edible red seaweeds Gracilaria sp. Postharvest Biology & Technology, 48, 302-308.

56. Pereira, L., Amado, A. M., Critchley, A. T., Velde, F. V. D., and Ribeiro-Claro, P. J. A. (2009). Identification of selected seaweed polysaccharides (phycocolloids) by vibrational spectroscopy (FTIR-ATR and FT-Raman). Food Hydrocolloids, 23, 1903-1909.

57. Pereira, L., Critchley, A. T., Amado, A. M., and Ribeiro-Claro, P. J. A. (2009). A comparative analysis of phycocolloids produced by underutilized versus industrially utilized carrageenophytes (Gigartinales, Rhodophyta). Journal of Applied Phycology, 21, 599-605.

58. Ponce, M. A. N., Pujol, C. A., Damonte, E. B., Flores, M. L., and Stortza, C. A. (2003). Fucoidans from the brown seaweed Adenocystis utricularis: Extraction methods, antiviral activity and structural studies. Carbohydrate Research, 338, 153-165

59. Prabhasankar, P., Ganesan, P., Bhaskar, N., Hirose, A., Stephen, N., Lalitha, R. G., Hosokawa, M., and Miyashita, K., (2009). Edible Japanese seaweed, wakame (Undaria pinnatifida) as an ingredient in pasta: chemical, functional and

structural evaluation. Food Chemistry, 115, 501–508

60. Rao, P. V. S., Mantri, V. A., Ganesan, K., (2007). Mineral composition of edible seaweeds Porphyra vietnamensis, Food Chemistry, 102, (215-218).
61. Rao, S. P., Iyengar E. R. R., and Thivy, F. (1964).Survey of algin bearing seaweeds at Adarta reef, Okha. Curr. Sci., 33: 464-465
62. Rasyid, A., 2017. Evaluation of Nutritional composition of the dried seaweeds Ulva lactuca from Pameungpek waters, Indonesia.
63. Rodriguez-Bernaldo de Quiros, A., Castro de Ron, C., Lopez-Hernandez, J., and Lage Yusty, M. A. (2004). Determination of folates in seaweeds by high-performance liquid chromatography. J Chromatogr A, 1032 (1-2), 135-9.
64. Rupérez, P. (2002). Mineral content of edible marine seaweeds. Food Chemistry, 79 (1), 23-26.
65. Rupérez, P., and Calexto, F-S., (2001). Dietary fibre & physic-chemical properties of edible Spanish seaweeds. Eur. Food Technol, 212, 334-354.
66. Saito, H., Xue, C.H., Yamashiro, R., Moromizato, S., and Itabashi, Y. (2010). High polyunsaturated fatty acid levels in two subtropical macro algae, Cladosiphon okamuranus and Caulerpa lentillifera. Journal of Phycology, 46, 665-673
67. Shibata, K., Shimamoto, Y., Suga, K., Sano, M., Matsuzaki, M. & Yamaguchi, M. (1994) Essential thrombocythaemia terminating in acute leukemia with minimal myeloid differentiation. A brief review of recent literature. Acta Haematologica, 91, 84-88.
68. Sanchez-Machado, D. I., Lopez-Cervantes, J., Lopez-Hernandez, J., and Paseiro-Losada, P. (2004a). Fatty acids, total lipid, protein and ash contents of processed edible seaweeds. Food Chem, 85 (3), 439-444.
69. Sanchez-Machado, D. I., Lopez-Hernandez, J., Paseiro-Losada, P., and Lopez-Cervantes, J. (2004b). An HPLC method for the quantification of sterols in edible seaweeds. Biomed Chromatogr, 18 (3), 183-190.
70. Sanchez-Machado, D. I., Lopez-Cervantes, J., Lopez-Hernandez, J., Paseiro-Losada, P., and Simal-Lozano, J. (2004c). Determination of the uronic acid composition of seaweed dietary fibre by HPLC. Biomed Chromatogr, 18 (2), 90-97.
71. Santoso, J., Yoshie-Stark, Y., and Suzuki, T. (2006). Comparative contents of minerals and dietary fibres in several tropical seaweeds. Bulletin Teknologi Hasil Perikanan, 9, 1-11.
72. Shin, T. S. (2003).Volatile compounds in sea mustard, Undaria pinnatifida. Food Science and Biotechnology, 12 (5), 570-577
73. Shin-ya Fukuda, Iwamoto, K., Atsumi, M., Yokoyama, A., Nakayama, T., Ishida, K., Inouye, I., Shiraiwa, Y., (2014) Global searches for microalgae and aquatic plants that can eliminate radioactive cesium, iodine and strontium from the radio-polluted aquatic environment: a bioremediation strategy. J Plant Res 127:79–89
74. Smith, J. L., Summers, G., and Wong, R., (2010). Nutrient and heavy metals content of edible seaweeds in New Zealand. New Zealand Journal of Crop and Horticultural Sciences, 38:1, 19-28.
75. Subbaramaiah, K., Rao, K. R., Nair, M. R. P., Krishnamurthy, C. V. S., and Paramasivam, M. (1979a). Marine Algal Resources of Tamil Nadu. Proc. Int. Symp. Marine Algae of the Indian Ocean Region, CSMCRI, Bhavnagar, India. p.14.
76. Subbaramaiah, K., Rao, K. R., and Nair, M. R. P. (1979b). Marine algal resources of Lakshadweep. Proc. Int. Symp. Marine Algae of the Indian Ocean Region. CSMCRI, Bhavnagar, India, pp. 6 -7.
77. Tasende, M. G. (2000). Fatty acid and sterol composition of gametophytes and sporophytes of Chondrus crispus (Gigartinaceae, Rhodophyta). Scientia Marina, 64(4): 421-426.
78. Teas J1, Pino S, Critchley A, Braverman LE. (2004). Variability of iodine content in common commercially available edible seaweeds. Thyroid. 14(10):836-41.
79. Untawale, A. G., Dhargalkar, V. K., Agadi, V. V., and Jagtap, T. G. (1979). Marine algal resource of Maharashtra Coast. Tech. Report. Natl. Inst. of Oceanography, Goa, 48 pp.
80. Van Netten C, Hoption Cann SA, Morley Dr, van Netten JP, (2000). Elemental and radioactive analysis of commercially available seaweeds. The science of the total environment, 255, (1-3): 169-175.

81. Van Netten, C., Hoption Cann, S. A., Morley, Dr., Van Netten, J. P., (2000). Elemental and radioactive analysis of commercially available seaweeds. The science of the total environment, 255, (1-3): 169-175.

82. Vijayaraghavan, S.; Rajagopal, M. D., and Wafar, M. V. M. (1980). Seasonal variations on the biochemical composition of some seaweed from Goa Coast. Indian J. Mar Sci, 9, 61-63.

83. WHO, 2001. Environmental Health Criteria 2, 24: Arsenic and arsenic compounds. World Health Organization, Geneva.

84. Wijesekaraa, I., Pangestutia, R., and Kima, S-K. (2011). Biological activities and potential health benefits of sulphated polysaccharides derived from marine algae. Carbohydrate Polymers, Volume 84, Issue 1, P14-21.

85. World Health Organization (WHO). Sees low health Risks from Fukushima accident, www. nytimes.com 2013

86. Xavier, B., and Philippe, M (1997). Anaerobic digestion of Ulva sp.1. Relationship between Ulva composition and methanisation. Journal of applied Phycology, 9, 511-524.

87. Yaich, H., Garna, H., Besbes, S., Paquot, M., Blecker, C., and Attia, H. (2011). Chemical composition and functional properties of Ulva lactuca seaweed collected in Tunisia. Food Chemistry, Vol.-128, 895–901.

88. Ysart G., Miller P., Croasdale M., Crews H., Robb P., Baxter M. De L'Argy C. and Harrison N. (2000) 1997 UK Total diet study–dietary exposures to aluminium, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, tin and zinc. Food Additives and Contaminants 17: 775- 786.

89. Yuan, Y. V. (2008). Marine algal constituents. In: Barrow C, Shahidi F, editors. Marine nutraceuticals and functional Foods. New York: CRC Press, Taylor and Francis Group, p.259-296.

90. Zemke-White, W. L., and Ohno, M. (1999). World seaweed utilisation: An end-of-century summary. Journal of Applied Phycology, 11, 369-76