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

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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 phycocolloids 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 agarophyta (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                       |                         |
| 13.     | Saccharina japonica                   |                         |
| 14.     | Undaria pinnatifida                   |                         |
| 15.     | Porphyra yezoensis                    |                         |
| 16.     | Euchemia cottonii                     | Indonesia               |
| 17.     | Gracilaria coronopifolia              |                         |
| 18.     | Enteromorpha prolifera                |                         |
| 19.     | Asparagopsis taxiformis               |                         |
| 20.     | Grateloupia filicina                  |                         |
| 21.     | Ulva faseiata                         | Hawaii                  |
| 22.     | Sargassum echinocarpum                |                         |
| 23.     | Dictyopteris plagiogramma             |                         |
| 24.     | Hizikia fusiforme                     |                         |
| 25.     | Caulerpa lentillifera                 |                         |
| 26.     | Enteromorpha flexuosa                 |                         |
| 27.     | Monostroma oxyaspernum                | India & Hawaii          |
| 28.     | Eucheuma denticulata                  |                         |
| 29.     | Gracilaria parvispora                 | Spain                   |
| 30.     | Bifurcaria bifurcata                  |                         |
| 31.     | Laminaria saccharina                  |                         |
| 32.     | Mastocarpus stellatus                 |                         |
| 33.     | Gigartina pistillata                  |                         |
| 34.     | Saccorhiza polyschides (Brown)        |                         |
| 35.     | Laminaria ochroleuca                  |                         |
| 36.     | Gracilaria coronopifolia              |                         |
| 37.     | Gracilaria parvispora                 |                         |
| 38.     | Gracilaria salicornia                 |                         |
| 39.     | Gracilaria tikvahiae                  |                         |
| 40.     | Ulva rigida                           |                         |
| 41.     | Monostroma sp.                        | Asia & Japan,           |
| 42.     | Caulerpa sp.                          | (Novaczek, 2001)        |
| 43.     | Codium sp.                            |                         |
| 44.     | Alaria fistulosa                      | India & China           |
| 45.     | Cladosiphon                           |                         |
mg/100g vitamins B2 and Vitamin C ≤0.2-23 mg/100g (Garcia et al.1993). Caulerpa sp. especially Cafuerpa lentillifera and Caulerpa racemosa are abundantly growing in sandy or muddy sea bottoms of subtropical 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 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 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 pharmacologically important compound arylterpenes (Kapetanovic et al. 2005; Kukovinets et al. 2006). Ulvaria oxytsperma and Ulva spp. have high mineral and low calories, with 16-20% humidity, 17-31 ashes, 6-10 proteins, 0.5-3.2 lipids, 3-12 fibre, 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 oxytspermum 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 (Lourencio 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 %

| No. | Species                                      | Country                |
|-----|---------------------------------------------|------------------------|
| 47  | Durvillaea antarctica                       | India & China          |
| 48  | Ecklonia cava                               | India & China          |
| 49  | Undaria undarioides                         | China                  |
| 50  | Calophyllis sp.                             | Australia              |
| 51  | Mastocarpus stellatus                       | Chile                  |
| 52  | Sargassum cinetum                           | Australia              |
| 53  | Sargassum vulgare                           | China                  |
| 54  | Sargassum schwartzii                        | India & China          |
| 55  | Sargassum vulgare                           | China                  |
| 56  | Sargassum myriocystum                       | China                  |
| 57  | Fucus spiralis                              |                       |
| 58  | Sargassum echinocarpum                      |                       |
| 59  | Sargassum fusiforme                         |                       |
| 60  | Pelvetia canaliculata                       |                       |
| 61  | Ulva intestinalis                           |                       |
| 62  | Porphyra laciniata                          |                       |
| 63  | Gracilaria edulis                           |                       |
| 64  | Gracilaria corticata                        |                       |
| 65  | Gelidiella acerosa                          |                       |
| 66  | Eucheuma spinosum                           |                       |
| 67  | Eucheuma cottonii                           |                       |
| 68  | Gracilaria chilensis                        |                       |
| 69  | Durvillaea potatorum                        |                       |
| 70  | Laminaria hyperborea                        |                       |
| 71  | Lessonia trabeulata                         |                       |
| 72  | Lessonia nigrescens                         |                       |
| 73  | Macroystis pyriforma                        |                       |
| 74  | Ecklonia maxima                             |                       |
| 75  | Caulerpa racemosa                           |                       |
| 76  | Caulerpa lentillifera                       |                       |
| 77  | Grinnellia sp.                              |                       |

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 oxytspernum, 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 B1, 0.559
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. Chinoospora 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 is 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 Quirios 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, 16:1о-7, 18:1о-7 and 18:2 о-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 fucoids have nutraceutical, pharmaceutical and cosmeaceutical values (Wijesekara 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 ursinic 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) than that of Nori, but similar (p>0.05) (Cofrades et al. 2010). Kappaphycus alvarezi contains carrageenan such as 3,6-anhydro-D-galactose, Calliphearis 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 campersterol, 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 seaweed 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).

| Elements | Hizikia fusiforme (mg/kg dw) | Ulva lactuca (mg/kg dw) |
|----------|-----------------------------|------------------------|
| Cd       | 0.79±0.02                   | 0.759±0.032             |
| Cu       | 1.55±0.07                   | 1.523±0.054             |
| Fe       | 311±11                      | 315.60±5.263            |
| Ni       | 2.2±0.1                     | 2.265±0.095             |
| Pb       | 0.43±0.03                   | 0.452±0.026             |
| Zn       | 13.4±0.5                    | 13.226±0.349            |

Table 3 The heavy metals content of seaweeds

| Sl. No | Species                        | Hg                      | Pb                       | Cd         | As                       | References |
|--------|--------------------------------|-------------------------|--------------------------|------------|--------------------------|------------|
| 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             | 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             | <0.008-0.460             | 0.085-1.83  | 51.7-68.3                |            |
| 7.     | Laminaria sp.                 | 0.001-0.005             | <0.008-0.460             |            |                          |            |
| 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      |                          |            |
| 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               | 0.01-0.15                | 0.14-0.55  | 1.24-1.83                |            |
| 24.    | Undaria pinnatifida           | 0.03±0.01               | 0.23±0.05                | 35.62±3.69 | 24.                      | Smith et al. 2010 |
| 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

| Metabolite | WHO/FAO-TWIS Provisional tolerable weekly intake of edible seaweeds, Australia - New Zealand Food Authority, 2005 (Smith et al. 2010). | Certified Values of metals of *Ulva lactuca* of national Research Council, Canada. (Besada et al. 2009). |
|------------|--------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Arsenic    | 15µg/kg BW                                                                                     | 0.274±0.022                                                                                     |
| Mercury    | 1.6 µg/kg BW                                                                                    | 25 µg/kg BW                                                                                     |
| Lead       | 25 µg/kg BW                                                                                    | Cadmium                                                                                         |
|            |                                                                                                 | 0.041±0.054                                                                                    |

| Cadmium    | 0.274±0.022                                                                                     | Lead                                                                                           |
|            |                                                                                                 | 0.49±0.022                                                                                     |
| Mercury    | 0.112 mg TWI                                                                                    | Mercury                                                                                         |
|            |                                                                                                 | 1.75 mg TWI                                                                                    |
| Lead       | 0.041±0.054                                                                                    | Lead                                                                                           |

### Table 5 Arsenic content of some edible seaweed

| Sr. No. | Species Name | Total Arsenic (mg/100 g dw) | Inorganic arsenic (μg g−1) | References |
|---------|--------------|-------------------------------|-----------------------------|-------------|
| 1.      | *Palmaria* sp.| 13.0                          | 0.466                       | Almela et al. 2006; García-Sartal, et al. 2013 |
| 2.      | *Palmaria palmata* | 12.6                    | 0.596                       | Almela et al. 2006; García-Sartal, et al. 2013 |
| 3.      | *Laminaria japonica* | 116                     | 1.44                        | Kolb et al. 2004; Khan et al. 2015 |
| 4.      | *Laminaria digitata.* | 65.7                     | 0.251                       | Khan et al. 2015 |
| 5.      | *Fucus vesiculosus* | 40.4                      | 0.291                       | Khan et al. 2015 |
| 6.      | *Himanthalia elongata* | 23.6                     | <LD                         | Khan et al. 2015 |
| 7.      | *Durvillaea antarctica* | 15.2                     | 0.318                       | Khan et al. 2015 |
| 8.      | *Enteromorpha sp.* | 2.15                       | 0.346                       | Khan et al. 2015 |
| 9.      | *Ulva pertusa* | 3.24                        | 0.268                       | Khan et al. 2015 |
| 10.     | *Porphyra tenera* | 24.1                       | 0.280                       | Khan et al. 2015 |
| 11.     | *Hizikia fusiforme* | 0.746                     | 0.220 ± 0.16               | Khan et al. 2015 |
| 12.     | *Sargassum fulvellum* | 0.14                     | 0.0670 ± 0.00              | Khan et al. 2015 |
| 13.     | *Porphyra umbilicalis* | 34.5                     | 0.239                       | Khan et al. 2015 |
| 14.     | *Porphyra sp.* | 32.7                        | 0.189                       | Khan et al. 2015 |
| 15.     | *Rhodymenia palmata* | 8.80                     | 0.153                       | Khan et al. 2015 |
| 16.     | *Chondrus crispus* | 12.7                       | 0.357                       | Khan et al. 2015 |
| 17.     | *Laminaria sp.* | 39.6                        | 0.473                       | Khan et al. 2015 |
| 18.     | *Undaria pinnatifida* (Wakame) | 41.4                     | <LD                         | Khan et al. 2015 |
| 19.     | *Eisenia bicyclis* | 22.4                       | 0.167                       | Khan et al. 2015 |
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, Systosiphon 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, Bangia fusco purpurea, Pyropia yeozensis, Petalonia fascia, Monostrroma nitidum, Analipus japonicas, Desmanestia ligulata, Pterosiphonia pinnulata, Padina arborescens, Ecklonia cava, Sargassum fusiforme, Ulva prolifera, Delessiera serrulata, Schizymenia dubyi, Gelidium elegans, Chondrus giganteus, Petalonia fascia, Spatoglossum pacificum, Chaetomorpha moniligera, Chondrus socellatus, Grateloupia turuturu, Plocamium cartilagineum, Lomentaria hakodatensis, Pachydictyum coriaceum, Cladophora sp. Ahnfeltiopsis flabelliformis, Pachydictyon coriaceum, Polyopoes affinis, Cladophora albida, Mazaella japonica, Neodilsea longissima, Dictyota dichotoma, Chondrus socellatus, Grateloupia sparsa, Gastroclonium pacificum, Tinocladia crassa, Sargassum confusum, Codium lucasii, Bryopsis plsnuosa, Corallina pilulifera, Calliarthron yezoense, Chondracanthus intermedius, Laurencia oleamurae and Sargassum silikuasum were collected from Nagasaki, Fukushima 50 Km and Soma ( Fukushima Pref.), Iwawaya (Hyogo Pref.), Iwunama (Miyagi Pref.), Kamagawa and Katura (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 Asphoeyllum sp. have larger surface area and accumulate high Iodide, 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\textsuperscript{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 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.

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