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SEAWEEDS – NUTRITION FACTS AND HEALTH BENEFITS

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The well-established correlation between food habits and health status points out to the possibilities of improving the overall health through the consumption of tailor made foods. Furthermore, consumers all over the world are becoming increasingly aware of the food-health relationship and started demanding for foods that can provide health promoting effects in addition to the essential nutrients. Hence, researchers all over the world have started exploring newer food sources for the development of nutraceuticals to cater the ever increasing consumer demand. Marine ecosystems are considered as rich repository of structurally diverse bioactive compounds with immense potential in both biomedical and functional food arenas. Marine organisms such as fish, crustaceans, molluscs, sponges, tunicates, bryozoans, bacteria, cyanobacteria, microalgae and macro algae are often utilized for the extraction of biomolecules. Among the marine organisms, seaweeds represent as one of the richest sources of bioactive molecules. It was mainly employed as a food source in the recent past and currently, the focus has been shifted to the isolation of bioactive molecules owing to the richness of bioactive compounds in them. They are often recognized as good source of healthy food and have even gained the reputation of 'superfood" in the recent past. The bioactive compounds from seaweeds, its bioactivities, application in biomedical and nutraceutical industries are summarized here.

Seaweeds – Source of nutrients

Seaweeds, usually named as macroalgae, are an extensive group of macroscopic marine organisms that comprise of a few thousand species (Kim et al., 2008; Kumari et al., 2010). Based on the pigmentation, seaweeds are categorized into three groups: Phaeophyceae (brown), Rhodophyceae (red) and Chlorophyceae (green). Among these, the highest phytochemical content in terms of terpenes, carotenoids and phenolic compounds have been reported from brown seaweeds (Gupta and Abu-Ghannam, 2011). However, the biochemical composition of different species may vary depending on the sampling site, the season of harvest and the environment (Bourgougnon & Stiger-Pouvreau, 2012; Holdt & Kraan, 2011).

Seaweeds are recognized as treasure house of bioactive compounds as they produce wide variety of biologically active components with different structural features and functional

properties (Choi et al., 2002; Kim & Bae, 2010). The bioactive components of seaweeds include polyphenols, peptides, polysaccharides, dietary fibres, proteins, sterols, carotenoids and numerous other structurally unparalleled secondary metabolites such as monoterpenes, sesquiterpenes, diterpenes, meroterpenoids, C15-acetogenins, phlorotannins etc. (Kladi et al., 2008, Kamenarska et al., 2002). They are also reported to have rich contents of micronutrients such as vitamins (A, B1, B2, B3, B6, B12, C, D, E,B5, B7), sterols, minerals (e.g. calcium, magnesium, potassium, iodine, sodium, phosphorus, nickel, chromium, selenium, iron, zinc, manganese, copper, lead, cadmium, mercury and arsenic) (Patarra et al., 2011; Peña-Rodríguez et al., 2011, Ferraces-Casais et al., 2012, Lopes et al., 2011). These bioactive compounds were reported to possess wide range of bioactivities such as antibacterial, antioxidant, anti-inflammatory, antiviral, , anticoagulant and antitumor properties (Nylund et al., 2010; Vairappan et al., 2010, Li et al., 2007, Matloub and Awad, 2009, Xu et al., 2004a). It has been already reported that the regular consumption of marine seaweeds can prolong life expectancy and reduce the risk of CVDs and one possible reason for this can be due to the presence of the bioactive compounds and its bioactivities.

In general, seaweeds are reported to possess 15–76% of its dry weight as polysaccharides, proteins (1–50% dry weight), lipids (0.3–5% of dry weight) and mineral (11–55% dry weight, in the form of ash). Because of its high nutritional and pharmaceutical values, seaweeds are used as food source and as herbal medicine for treating gall stones, stomach ailments, eczema, cancer, renal disorders, scabies, psoriasis, asthma, arteriosclerosis, heart disease, lung diseases, ulcers, etc. (Ortiz et al., 2006; Besada et al., 2009; Cruz-Suárez et al., 2010; Lee et al., 2011). Later, the focus of utilization of seaweed has been shifted from a mere food source to source of high value nutraceuticals. Different extraction protocols were designed by various researchers for the extraction of these bioactive moieties and these isolated biomolecules were employed for development of nutraceuticals and pharmaceuticals. However, the extraction methods used will vary depending on different factors such as physicochemical properties, molecular size and solubility of the compounds.

Bioactive compounds from seaweeds

Polysaccharides and Sulphated Polysaccharides

Polysaccharides are a class of macromolecules which are garnering attention in the biochemical and medical areas due to their immunomodulatory and anticancer effects. Different polysaccharides are found in seaweeds and their major role is to confer strength and flexibility. The composition may differ according to several intrinsic and extrinsic factors such as seaweed species, geographic area, season, age and parts of the seaweed collected etc. The major polysaccharides from phaeophyceae (brown algae) include alginates, laminarin, sargassan, fucoidans, sulphated galactofucans and ascophyllans. Polysaccharides derived from Rhodophyceae (red algae) include floridean starch, agars, carrageenans, xylans,

galactans, sulphated galactans and sulphated rhamnans. Chlorophyceae contain sulphated galactans, xylans and ulvans as the major polysaccharides. Among the seaweed polysaacharides, the one which have spurred great deal of interest in the last decade is fucoidan.

Fucoidans

Fucoidans are mainly found in many species of brown seaweed, especially in the cell wall matrix of marine brown algae, some terrestrial plants, animals, and microorganisms and fucoidans are sulfated hetero-polysaccharides. Fucoidans is made up of polymeric carbohydrate structures that consist of monosaccharide units linked by glucosidic bonds and enriched in fucose monomers (Holdt and Kraan, 2011). Researches across the globe have well documented various biological activities of fucoidans such as antiviral, anti-inflammatory, anti-coagulant, anti-angiogenic, immunomodulatory, and antiadhesive activity. Research in the biomedical sector has proven the potential use of fucoidans for the development of a novel drug against tumor cancer. Further, fucoidans may play a role as dietary fiber uptake contributing to lower cancer incidence risk (Tiwari et al., 2015).

Proteins and aminoacids

Seaweeds are widely recognized as cheaper protein alternative source due to its high-value proteins containing essential amino acids. The protein content in brown, green and red algae is 1–24%, 4–44% and 5–50% of the dry weight respectively. The major proteins in seaweeds include lectins and phycobiliproteins (Aneiros & Garateix, 2004). Phycobiliproteins are water-soluble and coloured components of the photosynthetic system in red macroalgae.

Lipids

The lipid content in seaweeds is generally low, however, almost half of lipids present are polyunsaturated fatty acids such as eicosapentaenoic acid (EPA) and arachidonic acid (AA), which can regulate blood pressure and reduce the risk of cardiovascular diseases, osteoporosis, diabetes etc. (Maeda et al., 2008). Furthermore, green seaweeds like *Ulva pertusa* are reported to have sufficient amounts of hexadecatetraenoic, oleic, and palmitic acids (Norziah and Ching, 2000; Ortiz et al., 2006).

Minerals

Seaweeds are reported to contain significant amounts of essential minerals such as sodium, calcium, potassium, magnesium and trace elements such as iron, zinc, manganese and copper. These minerals which have major role in building human tissues and as cofactors of many metalloenzymes due to their cell surface polysaccharides. Because of the richness of mineral content, seaweeds can be used as food supplements to provide the daily intake of some minerals and trace elements (Teas et al., 2004; Villares et al., 2002).

Vitamins

Seaweeds contain most of the vitamins such as l-ascorbic acid, thiamine, riboflavin, cobalamin, folic acid, and its derivatives (Mišurcová, 2011). It has been reported that vitamin C is present in very high amounts of 2000 mg/kg dry matter in red seaweed *Eucheuma denticulatum* and 3000 mg/kg dry matter in green seaweed *Enteromorpha flexuosa* (McDermi and Stuercke, 2003). Furthermore, B group vitamins, especially thiamine and riboflavin are found in substantial amounts in most red and brown seaweeds (MacArtain et al., 2007) whereas vitamin E content is higher in brown seaweed. Hence, it can be said that seaweeds are good source of vitamins also.

Fucoxanthin

Fucoxanthin is a xanthophyll, found as an additional pigment in the chloroplasts of the brown algae. Fucoxanthin and its de-acetylated metabolite depict anti-inflammatory, anti-nociceptive, and anti-cancer effects (Lee et al., 2013). Fucoxanthin and its metabolites can be used as a novel drug in the field of the bio-medical sector.

Bioactive properties of seaweeds

Antioxidant property

Marine algae are considered as one of the richest sources of antioxidants among the marine organisms. Seaweed phlorotannins by virtue of its eight interconnected rings are considered as very powerful free radical scavengers. These compounds have been isolated and purified from the brown algae *E. bicyclis, E. kurome, H. fusiformis* and *E. cava* and they have shown potent antioxidant activity against hydrogen peroxide induced cell damage (Kang et al., 2006). Some of the phlorotannins like eckol, phlorofucofuroeckol A, dieckol, and 8, 8-bieckol have shown anti-oxidant capacity in phospholipid peroxidation (Shibata et al., 2008). Because of their strong anti-oxidant activities they are even comparable to anti-oxidants such as ascorbic acid and tocopherol. Therefore, phlorotannins from seaweeds can be considered as potent anti-oxidants with wide applications in food and pharmaceutical industries (Kim et al., 2006).

Anti-coagulant property

Anti-coagulants are therapeutics which have ability to prevent blood coagulation or stop the formation of blood clots (Desai, 2004). Heparin, a sulfated polysaccharide is one of the most common anti-coagulant drugs used in the world against thromboembolic disorders (Fan et al., 2011). However, because of the several side effects associated with it, scientists are looking for suitable alternatives for heparin. Sulfated polysaccharides of anti-thrombotic and anti-coagulant properties have been isolated from different marine algae. Fucoidan, a sulphated polysaccharide from seaweeds are reported to display strong anticoagulant properties. The degree of its anticoagulant property is related to its sulphate and polysaccharide content. It was reported that C-2 sulfate and C-2, 3 disulfate in fucoidans is mainly associated with anti-coagulant activity (Chevolot, Mulloy, & Racqueline, 2001). The outcomes of many studies have proposed that fucoidans can be used as suitable alternatives to heparin and even certain

fractions of fucoidan can be qualified as heparinoids (i.e. molecules derived from heparin) (Mourao, 2004).

Anti-inflammatory property

Of late, it has been reported synthetic anti-inflammatory drugs can cause gastrointestinal irritations and hence forth the search for suitable and safer alternatives from natural sources is ongoing (Nguemfo et al., 2007). Sulfated polysaccharides from marine algae are reported to have effects on innate immunity by modulating the ability of immune cells to produce nitric oxide and thereby reducing inflammation (Leiro, Castro, Arranz, & Lamas, 2007). The two important biomolecules from marine algae, fucoidan and arabinogalactan are reported to have immunomodulating effects. As fucoidan can influence the activation and maturation of human monocyte-derived dendritic cells, it can be used for cancer immunotherapy (Yang et al., 2008). Fucoxanthin, another marine bioactive compound, has shown anti-inflammatory activities both in vitro and in vivo assays. Because of its strong anti-inflammatory properties, it can be comparable with predinisolone, a commercially available steroidal anti-inflammatory drug (Shiratori et al. 2005). Apart from this, certain phlorotannins isolated from marine algae such as phlorofucofuroeckol A, eckol, 8, 80-bieckol and dieckol are also reported to have strong anti-inflammatory effects.

Anti-tumor effects

Marine algae are reported to possess an extensive range of bioactive compounds which can be used to cure various types of cancers (Frestedt, Kuskowski, & Zenk, 2009). Many of these compounds have been found to destroy tumor cells by initiating apoptosis or activating signalling enzymes that affect cell metabolism and eventually lead to cell death (Sithrangaboopathy & Kathiresan, 2010), however the clinical trials are limited due to the risk factors. The extracts of Nostocmuscorum and Oscillatoria spp. have shown anti-tumor activity in vitro due to their inhibitory effect on the human hepatocellular cancer cell line (HepG2) and Ehrlich's Ascites Carcinoma Cells (EACC) (Tripathi, Fang, Leong, & Tan, 2012). Microcolin-A, extracted from Lyngbya majuscule, is a linear peptide and can be used as immunosuppressant (Koehn, Longley, & Reed, 1992). Curacin- A, peptide isolated from L. majuscule have shown anti-proliferative properties in various tumor cell lines like renal, colon and breast (Carte, 1996). Borophycin, a boron-containing metabolite purified from marine cyanobacterial strains of *N. spongiaeforme* and *Nostoc linckia* shown cytotoxic effects against human colorectal cells (Banker & Carmeli, 1999). Certain species of algae can inter-convert fatty acids to complex eicosanoids that can play a significant role in curing ailments like cancer, heart disease, asthma, psoriasis, arteriosclerosis and ulcers (Carte, 1996).

Anti-hypertensive effects and cardio-protection properties

Chlorellais is reported to lower the blood pressure by regulating the renin-angiotensin-aldosterone system in hypertensive rat model (Ko et al., 2012). Certain other polysaccharides

from marine algae such as fucoidans could be used for their cardioprotective activity (Mayakrishnan et al., 2013).

Anti-allergic effects

The seaweed extracts are proven to have anti-allergic effects. Sugiura et al. (2007) have reported that dried powder of the brown seaweed exhibits a strong anti-allergic effect on Brown Norway (BN) rats, an allergic model animal. Further, research in this line is required to isolate and characterize the bio-active compounds from seaweeds having anti-allergic effects.

Antimicrobial activities

Bio-active molecules such as phlorotannins, terpenes, and lipophilic compound extracted from seaweeds depict anti-oxidant and antimicrobial activity against gram positive and negative bacteria. Hence, they find their applications in the field of biomedicals as a natural antimicrobial agent.

Angiotensin-converting enzyme (ACE-I) inhibitors

High blood pressure plays a major role in the development of cardiovascular disease and it can be controlled by using pharmaceuticals and derivatives of synthetic drugs which inhibit Angiotensin-converting enzyme (ACE-I)**.** Diet and dietary components including peptides could play a vital role in the control and prevention of High blood pressure, CVD and other diseases without any side effects (Tiwari et al., 2015). Researchers have reported that peptides from seaweed having ACE-I inhibitory activity could possibly reduce high blood pressure.

Tyrosinase Inhibition

Phlorotannins which are the products of secondary metabolism consist of polymers of phloroglucinol. Novel application of seaweed phlorotannis is its use as an antityrosinase in cosmetic products. Tyrosinase is an enzyme with diverse physiological roles related to melanin production in human skin. In the recent past tyrosinase inhibitors has gained much attention in cosmetic sector as whitening agents. Extraction of phlorotannin from the brown seaweed *Ecklonia stolonifera* Okamura (*Laminariaceae*) found to have tyrosinase inhibitors activity (Kang et al., 2004). In addition, fucoxanthin extracted and isolated from *L. japonica* has also been reported to suppress melanogenesis in UVB-irradiated mice (Thomas and Kim, 2013). As per the scientific findings, phlorotannins and other bio-active compounds from seaweed can be used in the cosmetic sector.

Conclusions

The diversity of bioactive compounds in seaweeds which are capable of exerting bioactivities made it as a promising candidate in the development of nutraceuticals and functional foods. Though there are reports available about the bioactive compounds and its bioactivities, lot of efforts and researches still have to be carried out for the complete utilization of seaweeds. Not only the isolation of bioactive compounds will be sufficient, the structural elucidation of the

molecules along with the possible mechanisms of action also has to go hand –in-hand for developing nutraceuticals and health care compounds. Apart from all the scientific aspects, another important lacuna associated with the seaweed research is the considerably low consumer awareness about health benefits of seaweeds. Hence, these all issues need to be properly addressed before this resource can be trapped for its benefits at a large scale.

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