Nutritional value of marine seaweeds and their potential to serve as nutraceutical supplements

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Abstract
Seaweeds are marine autotrophic organisms with numerous bioactive compounds of interest. Several seaweed products are available in the form of food or medicine due to their myriad beneficial biomolecules like anti-diabetic, anti-inflammatory and antioxidants compounds. The information presented herein gives an overview about the current knowledge of seaweed nutritional values and their potential application as nutraceutical supplements for health benefits in terms of mineral contents, vitamins, fatty acids, antioxidants, and dietary fibres. Seaweeds rich in essential fatty acids and vitamin B\textsubscript{12} (cobalamin) can be an alternative food for vegetarians, as vegetables and fruits are poor sources of these elements. The seaweed-based functional food products and supplements have great potential health benefits and can potentially help to improve malnutrition.

Keywords: antioxidant; bioactive molecules; dietary fibres; nutrition; polysaccharides; seaweed; vitamins.
Introduction

Seaweeds contain major macronutrients like carbohydrates, protein and lipids, vitamins and other micronutrients, and numerous biologically active compounds, such as polyphenols (Pereira 2011). Some of these bioactive compounds are derived from biomass structural constituents, such as carbohydrates, protein, fatty acids, and others as a by-product of biochemical processes such as sterols, polyphenols. However, the nutritional properties and biochemical composition of seaweeds can be affected by seasonality, geographic location and species (Marinho et al. 2015; Zhou et al. 2015; Nunes et al. 2017; Kumar et al. 2018; Circuncisão et al. 2018). Bioactive molecules of seaweeds have been observed to exert positive effects on high-incidence chronic diseases such as arteriosclerosis, coronary heart disease, thrombosis and apoplexy (Cardoso et al. 2015; Collins et al. 2016). Considering their biological activity and the mechanisms involved in their absorption, biologically active compounds are broadly divided into two groups: i) non-absorbed high molecular substances like dietary fibres, and ii) low molecular substances, which are absorbed and affect the human homeostasis directly (Holdt & Kraan 2011).

Seaweeds are a rich source of bioactive molecules with potential as nutritional supplements, pharmaceuticals, cosmeceuticals, fine chemicals and enzymes (Pereira 2018a, b; Penalver et al. 2020). Seaweed nutraceuticals, defined as food and food products that have been demonstrated to produce health-promoting benefits, can lower the risk of chronic diseases such as obesity, diabetes, heart disease, and cancer. Hence, they enhance the ability of chronic disease management and improve the quality of life (Holdt & Kraan 2011; Shannon & Abu-Ghannam 2019). Due to various health-benefiting properties, there is a growing interest and recognition for seaweed nutraceutical supplements and functional foods. A recent study indicated that countries where people regularly consume seaweeds suffer less from obesity and diet-related ailments (Nanri et al. 2017). The consumption of fibre-rich seaweeds and derived supplements is known to boost appetite, satiety and lowers the cholesterol and glycaemic index (Brown et al. 2014). The undesirable side effects of allopathic drugs also make nutraceutical supplements an attractive alternative in palliative care such as biliary tract, breast and colon cancer (Nelson et al. 2017). Regular intake of seaweeds can greatly reduce the risk of these cancers, attributed to bioactive compounds such as fucoxanthin, polyphenols, phlorotannins, antioxidants, and sulfated polysaccharides (fucoidan), as these compounds can induce apoptosis in cancer cells (Namvar et al. 2012; Gutiérrez-Rodriguez et al. 2018; Jiang & Shi 2018). Besides, polyphenolic compounds, vitamin A, C and E are strong antioxidants (Shannon & Abu-Ghannam 2019), and bioactive compounds such as phlorotannins, fucoxanthin, polyphenolics and polysaccharides have effective antidiabetic properties (Murray et al. 2018). These latter compounds
inhibit hepatic gluconeogenesis and reduce the activity of the digestive enzymes such as α-amylase, lipase and aldose reductase (Sharifuddin et al. 2015; Shannon & Abu-Ghannam 2019). Omega 3-fatty acids (eicosapentaenoic and docosahexaenoic acids) of seaweeds play an important role in reducing the risk of heart disease by influencing ionic channels within the cardiac cell membrane and maintaining intracellular calcium homeostasis (Kanoh et al. 2017).

The excellent quality of proteins (containing all essential amino acids), polyunsaturated fatty acids (omega-3 fatty acids), vitamins, minerals (magnesium and calcium), dietary fibres (alginites, agar and carrageenan), pigments (carotenes, xanthophylls and chlorophylls) and secondary bioactive metabolites (phytosterols and polyphenols) in seaweeds have attracted great interest in their nutritional use (Holdt & Kraan, 2011; Pereira 2018a, b). The growing demand for seaweed-based food supplements is further fuelled by their low caloric content. In East Asian countries like China, Japan and Korea, seaweeds have been used as food for centuries (Penalver et al. 2020). For instance, dried Porphyra spp and Pyropia spp (mainly from Porphyra umbilicalis, Pyropia tenera and P. yezoensis) commonly called nori is a well-known seaweed food supplement in Japan (Baweja et al. 2016). In other parts of the world, consumption of seaweeds is not a common practice. But in recent years the perception towards seaweed is changing and they are considered as ‘superfoods’ because of their bioactive compounds (Cofrades et al. 2017).

Seaweeds also produce many primary and secondary metabolites which have great potential use as pharmaceuticals, nutraceuticals and cosmeceuticals (Pereira 2018a). The diverse bioactive compounds of seaweeds, nutritional values and the benefits ascribed are reviewed in this article. An exhaustive literature survey has been carried out using Google scholar and PubMed.

**Nutritional value of seaweeds**

In recent years, studies on seaweeds have unveiled their nutritional value and their richness in essential molecules that benefit our health and wellness (Wells et al. 2017; Pereira, 2018a, b; Roleda & Hurd 2019; Cikoš et al. 2020; Penalver et al. 2020). Proximate composition analysis of seaweeds indicate high levels of carbohydrates, minerals, vitamins, dietary fibres, essential fatty acids, carotenoids, and trace elements like iodine (Holdt & Kraan 2011; Tabarsa et al. 2012; Syad et al. 2013; Circuncisăo et al. 2018). For instance, the vitamin C levels in Porphyra umbilicalis, Himanthalia elongata, and Gracilaria changii are comparable to vitamin C found in tomatoes and lettuce (Ferraces-Casais et al. 2012). Seaweed polysaccharides are the most exploited and widely used seaweed molecules (Bilal & Iqbal 2020). The stabilizing and texture-giving properties of polysaccharides are extensively used in the food industry (Cotas et al. 2020a). The nanocellulose derived from seaweeds has multiple
applications, and the biocomposites developed from these are used for controlled drug release (Ditzel et al. 2017).

Compound concentrations can vary with season and seawater temperature (Nunes et al. 2017). Seaweeds from different geographical regions can exhibit varying elemental composition (Chen et al. 2018) and when grown in industrial and sewage contaminated areas can pose a risk to human health (Wang et al. 2013). The regular consumption of seaweeds harvested from such areas is detrimental to human health mainly due to heavy metal content (Burger et al. 2012; Cherry et al. 2019). However, a study by Rubio et al. (2017) indicated that for the majority of seaweeds levels of heavy metals are within the food safety limit and overall represent a low health risk. Still, they advised continuous surveillance and assessment to meet safety regulations. Following this advice, the diverse nutritional elements make seaweeds an attractive functional food and nutraceutical supplement.

Dietary fibres

Fibres of seaweeds are polysaccharides of mainly two types: structural (cellulose, hemicellulose and xylans), and storage polysaccharides (carrageenan, alginate and agar). These polysaccharides and hydrocolloids have no nutritional value, as humans lack the enzymes to metabolize them, but as dietary fibres they can play an important role in a healthy nutrition (Penalver et al. 2020).

The addition of dietary fibres to the diet reduces the transit time of faeces through the digestive tract by promoting bowel movement and lowers the risk for colorectal cancer by diluting faecal carcinogens and by promoting the production of short-chain fatty acids with anti-carcinogenic properties (Holdts & Kraan 2011; Penalver et al. 2020). The low incidence of colorectal cancer in Japan, for example, has been attributed to the regular intake of seaweeds containing high fibre (Moussavou et al. 2014). Other health benefits of dietary fibres include a reduction in cardiovascular disease and obesity and the intake of fibres also gives the feeling of contentment and satiety (Jiménez-Escrig et al. 2013; Penalver et al. 2020). The recommended fibre intake in the US and the UK is in the range of 18–30 g, which can be fulfilled by incorporating seaweed in the diet (Rajapakse & Kim 2011; Circuncisão et al. 2018). Fibres constitute about 36–60% of seaweed biomass (Circuncisão et al. 2018), comparable to, and in some cases exceeding that of fruits and vegetables (Table 1). The values of fibres (5–10 g per 100 g dw) found in Porphyra columbina, for example, is comparable to that of land vegetables (Cian et al. 2014). Similarly, the fibre content in Kombu (Laminaria digitata) (6.2%) is higher than that of brown rice (3.8%; McCance & Widdowson 2014).

Seaweed polysaccharides have numerous beneficial properties such as probiotic activity, inhibition of viruses, suppression of gastrointestinal inflammation, anticancer properties, reduction in
cholesterol uptake and anti-glycosidase activity (Rajapakse & Kim 2011; Wang et al. 2012; Necas & Bartosikova 2013; Cotas et al. 2020b; Daub et al. 2020). In addition, seaweed fibres contain negligible amounts of starchy carbohydrates, resulting in a lower glycaemic load, which is beneficial in regulating the glycaemic index of diabetic patients (Wee & Henry 2020).

Seaweeds contain both soluble and insoluble fibres. Soluble fibre content tends to be higher in red seaweeds such as Chondrus and Porphyra sp. than brown and green seaweeds (Holdts & Kraan 2011; Penalver et al. 2020), whereas brown seaweeds such as Laminaria sp. Saccharina sp. and Fucus sp. have higher insoluble fibre content (Penalver et al. 2020). Soluble fibres of seaweeds are known to produce short-chain fatty acids (SCFAs) such as acetate, propionate and butyrate in the large intestine due to fermentation (Cantarel et al. 2012). SCFAs nourish the epithelia of the large intestine and modify the intestinal microbiome (Cian et al. 2015). In addition, partially digested seaweed proteins and carbohydrates in the small intestine can stimulate the immune response in humans by indirect promotion of microbial response (Cian et al. 2015; Wells et al. 2017).

Mineral content (inorganic elements)

Minerals are essential for our body to develop and function normally, and seaweeds are a good source of these minerals (Mišurcová et al. 2011). Seaweeds contain a variety of minerals such as iron (Fe), iodine (I), calcium (Ca), magnesium (Mg), copper (Cu), manganese (Mn) and zinc (Zn) that are important micronutrients needed for human nutrition (Circuncísão et al. 2018; Cherry et al. 2019; Penalver et al. 2020) (Table 2). The mineral content in seaweeds is similar to that of seawater but varies between species and is affected by environmental factors such as season, salinity, pH, light, nitrogen source (Nunes et al. 2017; Circuncísão et al. 2018). A study showed that Halimeda macroloba contains 232 mg. 100 \(^{-1}\) g of calcium (Rattanasomboon et al. 2018), which equals ~23% of the Recommended Dose Intake (RDI) for an adult male. The total mineral content in Galaxaura rugosa is as high as 84.16 g. 100 \(^{-1}\) g dw (Nunes et al. 2017); 8 g of Palmaria palmata contain more iron than 100g of sirloin steak (McCance & Widdowson 2014). As such, the recommended dose of many essential minerals can be effectively met by consuming seaweed or from seaweed fortified foods.

Iodine regulates the metabolism and proper growth of the human body and is an essential constituent of thyroid hormones T3 (3,5,3-triiodothyronine) and T4 (thyroxine or 3,5,3,5-tetraiodothyronine). Thyroid hormones T3 and T4 regulate major metabolic processes such as catabolism of carbohydrates, lipids and protein, cellular respiration, thermoregulation, intermediary metabolism and nitrogen retention (Abbaspour et al. 2014; Nunes et al. 2018). Iodine deficiency results in metabolic disorders such as goitre and developmental delay, including mental retardation and brain
damage especially amongst children (Pearce 2012; Eastman & Zimmermann 2018). Consequently, iodine deficiency is recognised as an important global health issue (Biban & Lichiardopol 2017). Seaweeds are an excellent source of iodine; brown seaweeds contain the highest iodine content, with some species exceeding the RDI (150 µg per day) (Rajapakse & Kim 2011). Red and green seaweed species such as Eucheuma cottoni, E. spinosum, Palmaria palmata, Porphyra sp., Ulva lactuca also contain iodine but at lower concentrations (Zava & Zava 2011; Nitschke & Stengel 2016; Rasyid 2017; Cherry et al. 2019). Thus, the iodine requirement can be met by consuming seaweeds or seaweed-based nutraceutical supplements.

Zinc plays a vital role in the synthesis of DNA and RNA (Sharif et al. 2012), whereas Mn is required for several metabolic processes including blood clotting and hemostasis (Chen et al. 2018). Zinc and Mn coupled with Ca and Cu aid in improving bone mass density in postmenopausal women (Razmandeh et al. 2014). Osteoporosis is common among elderly people, so the requirement of these minerals can be fulfilled by the intake of seaweeds directly or as supplements. Manganese is also a constituent of an important antioxidant called superoxide dismutase (SOD). SOD protects against free radicals that cause cellular damage and contribute to aging, chronic kidney disease and heart disease (Kitada et al. 2020). Rich in Zinc are Chondrus crispus, Porphyra umbilicalis and Gracilaria corticata, G. edulis (Circuncisão et al. 2018), and Chondrus crispus, Palmaria palmata and Gracilaria vermiculophylla are rich in Mn (Parjikolaei et al. 2016; Circuncisão et al. 2018).

Fatty Acids

Fatty acids are long-chained hydrocarbons and are broadly divided into four categories: saturated, monounsaturated, polyunsaturated and trans fats. Overall, lipids make up about 1–5% of seaweed dry weight (Penalver et al. 2020). A recent study showed that the lipid content of Asparagopsis taxiformis was 2.9–6.2 g per 100 g dw, which contributed about 9.5% to the RDI (Mellouk et al. 2017; Nunes et al. 2019). Polyunsaturated fatty acids (PUFA) constitute a significant part of the seaweed lipid profile (Penalver et al. 2020) (Table 3). The growing interest in seaweed-derived polyunsaturated fatty acids is mainly ascribed to the presence of ω-3 and ω-6 PUFA (Kendel et al. 2015; Goncalves et al. 2017; Alencar et al. 2018; Michalak 2018).

Fatty acids influence many biological activities such as the regulation of membrane structure and function, intracellular signalling and gene expression (Gonçalves et al. 2017). Particularly important are essential fatty acids (EFAs) because they are not synthesized in the human body and are important for immunomodulation, brain development, cellular signalling, regulation of transcription factors, prevention of cancers such as breast, prostate, colon and renal cancer, cardiovascular,
neurodegenerative and autoimmune diseases, and inflammation due to rheumatoid arthritis (Imhoff-Kunsch et al. 2011; Cardoso et al. 2015; Cornish et al. 2017; Goncalves et al. 2017; Cotas et al. 2020a) (Table 4). Essential fatty acids such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (ω-3 fatty acids) are also known to protect from dementia and suppress inflammation in patients with rheumatoid arthritis (Cotas et al. 2020a). Red seaweeds are a particularly good sources of several essential fatty acids such as eicosapentaenoic acid (20:5ω-3), arachidonic acid (20:4 ω-6), linoleic acid (18:2 ω-6), α-linolenic acid (18:3 ω-3) and stearidonic acid (18:4 ω-3) (Galloway et al. 2012), and several studies on health benefitting properties of seaweed derived fatty acids indicate promising potential nutritional and nutraceutical applications (Rajapakse & Kim 2011; Belattmania et al. 2018; Cherry et al. 2019; Shannon & Abu-Ghannam 2019).

**Vitamins**

Vitamins, except D and K, are mainly obtained through animal-sourced food products such as meat, fish, eggs and dairy, as the human body does not produce these vitamins. Vitamin D is synthesized in the skin with the help of ultraviolet light and can be supplied as supplements, whereas vitamin K is produced in the intestine by bacteria (McKenna & Murray 2014).

Seaweeds contain both water-soluble and fat-soluble vitamins (Leandro et al. 2020). Seaweed vitamins such as thiamine, riboflavin, beta-carotene and tocopherols can reduce the risk of heart disease, thrombosis and atherosclerosis (Kong et al. 2018; Fischer 2019). Vitamin B₁₂ is an essential water-soluble vitamin and regulates the production of red blood cells and DNA (Koury 2016; Green et al. 2017). Unlike terrestrial plants, seaweeds are a good source of vitamin B₁₂. *Ulva lactuca* and *Pyropia yezoensis* can produce biologically available vitamin B₁₂ (Watanabe et al. 2014) (Table 5). The vitamin B₁₂ found in Pyropia sp. is approx. 1 g. kg⁻¹ fresh weight (Castillejo et al. 2018), indicating that seaweeds can be a reliable source of vitamin B₁₂.

Some seaweed species are also known to contain vitamins like vitamin E and K. The concentration of vitamin E, an important antioxidant is reported to be higher (1.16 mg. kg⁻¹) in *Undaria pinnatifida* than in peanuts (0.8 mg. kg⁻¹) (McCance & Widdowson 2014). Vitamin E and K are also found in Grateloupia turuturu (Kendel et al. 2013).

**Proteins**

Proteins are essential for growth and repair as they form the structural and functional elements of cells in the body (Blanco & Blanco 2017). Green and red seaweeds have higher protein contents than brown seaweeds, as high as 47% of their dry weight (Černá 2011; O’Connor et al. 2020). Porphyra spp,
*Pyropia* spp, *Palmaria palmata*, and *Ulva* spp are the protein richest seaweeds (Pereira 2011; Taboada *et al.* 2013; Angell *et al.* 2016).

Aspartic and glutamic acid are the principal amino acids of seaweed proteins. The unique taste of umami is due to glutamic acid present in the seaweed *Laminaria japonica*. The flavour of umami formed the basis for the synthesis of monosodium glutamate (Druehl 2013). Monosodium glutamate is one of the most used flavour enhancers, and although its use is recognized as safe, it remains controversial (Zanfirescu *et al.* 2019). Some essential amino acids like histidine in *Ulva lactuca* are comparable to egg protein (Shuuluka *et al.* 2013). Seaweed proteins contain all the essential amino acids (Diniz *et al.* 2011), but they can vary with species, seasons and geographic location (Circuncisão *et al.* 2020).

Essential amino acids help to build up muscles, support their functioning and regulate the blood sugar level (Breitman *et al.* 2011; Hayashi *et al.* 2018). Amino acids are normally obtained from non-vegetarian diets such as meats, eggs and fish. Essential amino acids such as leucine, valine and threonine are rich in red seaweed species such as *Porphyra dioica*, *Porphyra umbilicalis* and *Gracilaria vermiculophylla* (Machado *et al.* 2020). Pepsin is a principal protein-digesting enzyme that helps to absorb amino acids in the small intestine. Pepsin obtained from *Pyropia yezoensis* exhibits numerous health benefiting properties such as angiotensin-converting enzyme (ACE) inhibitory effect, antimutagenic, anti-diabetic, inhibition of calcium precipitation, reduction of cholesterol levels, antioxidant activity and improvement of hepatic function (Harnedy & Fitzgerald 2011; Admassu *et al.* 2018).

**Chlorophyll a**

Chlorophylls are green lipid-soluble pigments in seaweeds, higher plants and cyanobacteria for photosynthesis (Holdts & Kraan 2011) (Table 5). Besides, chlorophyll has an antioxidant property that can be useful as nutritional as well as health supplement (Tumolo & Lanfer-Marquez 2012; Pérez-Gálvez *et al.* 2020). Seaweeds contain different types of chlorophylls (chl), such as chl *a* and *b* in green seaweeds, chl *a* in red seaweeds, and chl *a* and *c* in brown seaweeds (Takaichi 2013). Chlorophylls are normally included in our diet by consuming green vegetables. A study by Vaňková *et al.* (2018) showed that chlorophylls have an antiproliferative effect in pancreatic cell lines. They observed that chlorophylls inhibited heme-oxygenase (HMOX) activity, which subsequently affected the redox environment of pancreatic cancer cells and suppressed their proliferation. Chlorophyll degradation products, such as pheophytin, pyropheophytin and pheophorbide have anti-cancer properties (Holdt & Kraan 2011).
Carotenoids

Carotenoids are tetraterpenoid pigments present in plants, bacteria, fungi, and seaweeds. Major seaweed carotenoids are α-carotene, β-carotene, lutein and zeaxanthin. Alpha- and β-carotene is the precursor of vitamin A. It plays an important photoprotective role against damage by reactive oxygen species (ROS) (Pérez-Gálvez et al. 2020) and exhibits numerous biologically active properties such as antioxidant, anti-inflammatory and antitumor activity (Di Tomo et al. 2012; Galasso et al. 2017; Viera et al. 2018). Carotenoids like lutein and zeaxanthin prevent the progress of age-related macular degeneration (Murray et al. 2013; Wu et al. 2015; Buscemi et al. 2018).

The reactive oxygen species (ROS) that accumulate during metabolic processes cause oxidative damage (Nita & Grzybowski 2016; Pérez-Gálvez et al. 2020). The oxidative damage in humans results in degenerative diseases and cancer (Nita & Grzybowski 2016; Aggarwal et al. 2019). However, these reactive oxygen species are effectively eliminated by carotenoid antioxidants (Miyashita 2014; Rengasamy et al. 2015; Patlevič et al. 2016). Important carotenoids like lutein, α-carotene and zeaxanthin are produced by Asparagopsis taxiformis (Holdt & Kraan 2011; Chan et al. 2015; Pereira 2015) and Pyropia yezoensis (Koizumi et al. 2018). The carotenoid content in the red seaweed *Gracilaria lanceola* is high (131 mg. 100 g⁻¹ dw) (Nunes et al. 2017).

**Beta Carotene**

Beta carotene is a precursor of vitamin A (retinol), an essential vitamin that promotes a healthy immune system, good skin and eye health (Pérez-Gálvez et al. 2020). Beta carotene also has antioxidant properties that protect the body from free radicals produced by oxidation of other molecules (Boominathan & Mahesh 2015; Corsetto et al. 2020). Oxidative stress is believed to be a cause of cognitive decline (Kandlur et al. 2020), and β-carotene based antioxidants prevent the decline of cognition (Hira et al. 2019). In Codium fragile (199 μg per g) and Gracilaria chilensis (114 μg. g⁻¹), the β carotene content exceeds that of carrots (Wells et al. 2017) (Table 5).

Nagayama et al. (2014) found a positive correlation between the intake of carotenoids with dietary supplements by lactating women and carotenoid content in breast milk, improving carotenoid supply to the developing child.

**Fucoxanthin**

Fucoxanthin, a marine carotenoid, is a xanthophyll pigment in the chloroplast of brown seaweeds such as Eisenia bicyclis, Laminaria japonica and Undaria pinnatifida (Jung et al. 2012; Jang et al. 2018; Table 5). It is the most abundant carotenoid in nature, and the characteristic brown colour of brown seaweeds is due to this pigment. Fucoxanthin exhibits several bioactive properties such as strong
antioxidant capacity, anti-obesity, anticancer, antidiabetic, hepatoprotective activity and anti-inflammatory effect (Miyashita et al. 2011; Abdul et al. 2016). Although fucoxanthin contains numerous nutritional qualities and medicinal properties, the use of fucoxanthin is challenging due to its poor water solubility, chemical instability and low bioavailability (Zhang et al. 2015; Huang et al. 2017). It readily gets oxidised in pure form (Abu-Ghannam & Shannon 2017). Fucoxanthin will be easier to develop into a safe nutraceutical supplement with the development of new methods to improve stability and bioavailability (Zhang et al. 2015), such as the encapsulation in oil emulsion (Huang et al. 2017; Xiao et al. 2020). Tsuboi et al. (2011) showed that fucoxanthin reacts with nitrate and forms nitrofucoxanthin. This exhibited a strong inhibitory effect on Epstein–Barr virus and on human pancreatic carcinoma. Other bioactive properties of fucoxanthin that have potential health benefits are anti-osteoporotic effect (Koyama 2011), anti hypertensive property (Abu-Ghannam & Shannon 2017) and protection against lipid peroxidation (Takashima et al. 2012). The study by Miyashita et al. (2011) showed that ingestion of fucoxanthin can improve insulin resistance and decrease blood glucose level.

The inclusion of fucoxanthin in dietary supplements can help to prevent lifestyle-related diseases such as atherosclerosis, diabetes, heart disease, obesity and stroke. However, more human clinical trials are necessary to determine the safety and recommended daily dosage (Zhang et al. 2015; Abu-Ghannam & Shannon 2017). Fucoxanthin derived from Phaeodactylum tricornutum, a microalga, is allowed by the food and drug administration (FDA) to be used in dietary supplements (Bae et al. 2020).

**Phenolics**

Phenolic compounds are secondary metabolites, found mainly in brown seaweeds such as Fucus, Ascophyllum and Sargassum (Mekinić et al. 2019; Penalver et al. 2020). They are structurally diverse and different polyphenolic compounds such as bromophenols, flavonoids, phenolic terpenoids, etc. are found in brown seaweeds (Cotas et al. 2020b). Phenolics have attracted great attention in recent years due to their promising bioactivity of potential pharmacological applications and many other health-benefiting properties.

Phlorotannins are the most studied polyphenols of seaweeds, as they have many bioactive properties such as antioxidant, antidiabetic, and antibiotic properties. Consequently, they have been identified as potential candidates for the development of natural antioxidant-based functional foods (Farvin & Jacobsen 2013). Phlorotannins play important ecological functions such as cell wall hardening, protection against herbivory, protection against UV radiation, wound healing, as a chelating agent of toxic metals, adaptation to wave exposure and desiccation (Singh & Sidana 2013; Mannino
& Micheli 2020). The bromophenol present in *Gracilaria* sp. is anti-diabetic, anticancer and antioxidant (Liu et al. 2011). The antioxidant activity of seaweed phlorotannins is more potent than that of polyphenols derived from terrestrial plants (Ferrer et al. 2012; Vizetto-Duarte et al. 2016; Sellimi et al. 2017). The numerous bioactivities associated with polyphenolics, particularly of phlorotannins, provide many potential applications in nutraceutical, pharmaceutical and cosmeceuticals industries.

**Sterols**

Sterols are another group of secondary metabolites with health benefits, showing antioxidant, antiviral, antifungal and antibacterial properties (Abdul et al. 2016). Fucosterols and desmosterols are the main sterols (Lopes et al. 2011), but some seaweeds sterols such as desmosterol, cholesta-4,6-dien-3-ol and cholester-5-ene-3,7-diol have cholesterol like properties (De Andrade Tomaz et al. 2012; Santos et al. 2015; Xu et al. 2015).

*Porphyra* sp. and *Osmondea pinnatifida* contain cholesterol (Lopes et al. 2011; Hernández-Ledesma & Herrero 2013). Cholesterol is essential for cellular activities as they increase the fluidity of cell membranes (Lopes et al. 2013). Fucosterols are anti-diabetic, antioxidant, improve digestion and reduces cholesterol concentration in animals and humans (Christaki et al. 2013; Abdul et al. 2016; Mouritsen et al. 2017) (Table 6). The phytosterols of *Ulva armoricana* induce a cholesterol lowering effect by decreasing intestinal absorption of cholesterol (Kendel et al. 2015), and offer protection against colon, breast and prostate cancer by increasing immune system efficiency (Lopes et al. 2013; Shahzad et al. 2017). These qualities of seaweed sterols have applications in nutraceutical and pharmaceutical formulations to manage and regulate cholesterol for human health.

**Species-specific molecules**

Some notable seaweed specific molecules such as laminarin, ulvan, porphyran, floridean starches are species-specific polysaccharides of brown (*Laminaria* sp.), green (*Ulva* sp.) and red (*Porphyra* sp.) seaweeds (Holdts & Kraan 2011; Penalver et al. 2020). These molecules have shown promising nutraceutical and pharmacological properties. Laminarin is a water-soluble polysaccharide, a bioactive compound with antioxidant, anticoagulant, anti-inflammatory, immunostimulatory, antitumor activities and it contributes to seaweed dietary fibres (Lee et al. 2012; Kadam et al. 2015a; Deleris et al. 2016; Zargarzadeh et al. 2020). The laminarin extracted from *Laminaria hyperborea* showed strong antimicrobial activity against Gram positive (*Staphylococcus aureus* and *Listeria monocytogenes*) and Gram negative (*Escherichia coli* and *Salmonella typhimurium*) bacterial strains (Kadam et al. 2015b). Porphyran is a complex sulfate-containing polysaccharide and its greatest health benefit lies in fibre. Porphyran possesses several active biological properties such as anti-inflammatory, antioxidant,
hypolipidemic and anticancer activity in humans (Jiang et al. 2012; Wang et al. 2017). Ulvan is a sulfated heteroglycan. Bioactivity such as antioxidant, antiviral, antilipidemic, immunoregulatory effects and antitumour activities have been observed (Thanh et al. 2016; Abou El Azm et al. 2019; Kidgell et al. 2019). Mycosporine-like amino acids (MAAs) are water-soluble and photostable secondary metabolites (La Barre et al. 2014). MAAs are known for their cosmeceutical use such as in sun care products due to their highly efficient ultraviolet protective capability (Thiyagarasaiyar et al. 2020). However, studies have demonstrated that MAAs also have other important bioactive properties like anti-inflammatory, immunomodulatory and antioxidant activities (Lawrence et al. 2018). The strong antioxidant activity of MAAs could effectively inhibit the oxidation of β-carotene and reduce lipid peroxidation that is involved in aging process (Chrapusta et al. 2017).

**Conclusion**

The regular consumption of seaweeds reduces the occurrence of chronic diseases such as obesity and diabetes (Turan & Cirik 2018). This is attributed to the presence of numerous health-benefiting bioactive molecules essential for healthy wellbeing. Although seaweeds are consumed in very few countries, they can be used as an ingredient in various food products to enhance nutritional quality. This improvement of food products will alleviate malnutrition due to the growing scarcity of proteins and essential vitamins. In recent years, a better understanding of dietary science has led to increased incorporation of seaweeds into foods to improve the nutritional properties (Shannon & Abu-Ghannam 2019).

Malnutrition is common among young children, lactating and pregnant women, adolescents and poverty-stricken people. Poor nutrition in the early days is known to affect the cognitive development of the child (Prado & Dewey 2014; DiGirolamo et al. 2020). Incorporating seaweeds in our diet could be a panacea to counter malnourishment.

The constraint of food production and supply from terrestrial resources is expected to encourage consumption of seaweeds to meet the demand of increasing growth in the world population. Seaweed-based functional food products and nutraceutical supplements can potentially contribute to alleviate the chronic malnutrition problem. Seaweed-fortified food products are one promising route toward this goal.

The present review observed that many seaweeds are of diverse nutritional value, as they contain essential vitamins, proteins and minerals including trace elements. Further, the numerous health benefits of biomolecules make seaweeds an attractive natural resource for the development of novel nutraceutical and other functional food supplements. The growing consumer awareness of the positive
health impacts of edible seaweeds also make them an increasingly attractive nutritional source. The essential fatty acids and vitamin B$_{12}$ (cobalamin) of seaweeds would be an ideal vegetarian alternative, as vegetables and fruits are poor sources of these elements.

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**References**


# Tables

**Table 1.** Dietary fibre content in seaweeds.

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<tr>
<th>Source</th>
<th>Fibre (% dry weight)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soluble</td>
<td>Insoluble</td>
<td>Total</td>
</tr>
<tr>
<td><strong>Seaweeds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Durvilaea antarctica</em></td>
<td>27.7</td>
<td>43.7</td>
<td>71.4</td>
</tr>
<tr>
<td><em>Himanthalia elongata</em></td>
<td>25.7</td>
<td>7.0</td>
<td>32.7</td>
</tr>
<tr>
<td><em>Saccharina latissima</em></td>
<td>17</td>
<td>13.1</td>
<td>30</td>
</tr>
<tr>
<td><em>Sargassum fusiforme</em></td>
<td>33.9</td>
<td>16.3</td>
<td>49.2</td>
</tr>
<tr>
<td><em>Undaria pinnatifida</em></td>
<td>30.0</td>
<td>5.3</td>
<td>35.3</td>
</tr>
<tr>
<td><em>Caulerpa lentillifera</em></td>
<td>17.21</td>
<td>15.78</td>
<td>33</td>
</tr>
<tr>
<td><em>Ulva lactuca</em></td>
<td>18</td>
<td>36</td>
<td>54</td>
</tr>
<tr>
<td><em>Enteromorpha spp</em></td>
<td>17.2</td>
<td>16.2</td>
<td>33.4</td>
</tr>
<tr>
<td><em>Gracilaria chilensis</em></td>
<td>24</td>
<td>36</td>
<td>59.8</td>
</tr>
<tr>
<td><em>Gracilaria fisheri</em></td>
<td>18</td>
<td>43</td>
<td>61</td>
</tr>
<tr>
<td><em>Gracilaria tenuistipitata</em></td>
<td>18</td>
<td>42</td>
<td>58</td>
</tr>
<tr>
<td><em>Macrocystis pyriforme</em></td>
<td>6.4</td>
<td>44</td>
<td>50</td>
</tr>
<tr>
<td><em>Chondrus crispus</em></td>
<td>22.25</td>
<td>12</td>
<td>34.25</td>
</tr>
<tr>
<td><em>Grateloupia turuturu</em></td>
<td>48</td>
<td>12.3</td>
<td>60.3</td>
</tr>
<tr>
<td><em>Porphyra spp</em></td>
<td>17.9</td>
<td>16.8</td>
<td>34.7</td>
</tr>
<tr>
<td><strong>Food from terrestrial plants (g/100 g weight)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brown rice</td>
<td>Na</td>
<td>Na</td>
<td>3.8</td>
</tr>
<tr>
<td>Bananas</td>
<td>Na</td>
<td>Na</td>
<td>3.1</td>
</tr>
<tr>
<td>Lentils</td>
<td>Na</td>
<td>Na</td>
<td>8.9</td>
</tr>
<tr>
<td>Apple</td>
<td>5.9</td>
<td>8.3</td>
<td>14.2</td>
</tr>
</tbody>
</table>

Source: Benjama & Masniyom 2012<sup>c</sup>; McCance et al. 2014<sup>d</sup>; Sanz-Pintos et al. 2017<sup>b</sup>; Penalver et al. 2020<sup>a</sup>. Na – data not available
## Table 2. Proximate composition of seaweeds and other foods.

<table>
<thead>
<tr>
<th>Seaweeds (mg per 100 g wet wt)</th>
<th>Calcium</th>
<th>Potassium</th>
<th>Magnesium</th>
<th>Sodium</th>
<th>Copper</th>
<th>Iron</th>
<th>Iodine</th>
<th>Zinc</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Ascophyllum nodosum</em>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>900</td>
<td>4400</td>
<td>700</td>
<td>3900</td>
<td>Na</td>
<td>13.3</td>
<td>75–125</td>
<td>Na</td>
</tr>
<tr>
<td><em>Laminaria digitata</em>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1005</td>
<td>11,579</td>
<td>659</td>
<td>3818</td>
<td>&lt;0.5</td>
<td>3.29</td>
<td>304</td>
<td>2</td>
</tr>
<tr>
<td><em>Himanthalia elongata</em>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>909</td>
<td>6739</td>
<td>827</td>
<td>3700</td>
<td>Na</td>
<td>Na</td>
<td>Na</td>
<td>Na</td>
</tr>
<tr>
<td><em>Undaria pinnatifida</em>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>931</td>
<td>8669</td>
<td>1181</td>
<td>7064</td>
<td>&lt;0.5</td>
<td>Na</td>
<td>25</td>
<td>1.74</td>
</tr>
<tr>
<td><em>Caulerpa lentillifera</em></td>
<td>1874</td>
<td>1143</td>
<td>1029</td>
<td>8917</td>
<td>0.11</td>
<td>21.4</td>
<td>Na</td>
<td>3.5</td>
</tr>
<tr>
<td><em>Ulva rigida</em>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>525</td>
<td>1561</td>
<td>2094</td>
<td>1595</td>
<td>0.50</td>
<td>283</td>
<td>Na</td>
<td>0.60</td>
</tr>
<tr>
<td><em>Jania rubens</em>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>42344</td>
<td>328</td>
<td>2987</td>
<td>1100</td>
<td>0.7</td>
<td>47.5</td>
<td>Na</td>
<td>2.63</td>
</tr>
<tr>
<td><em>Palmaria palmata</em>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1000</td>
<td>2700</td>
<td>200</td>
<td>1100</td>
<td>0.56</td>
<td>32</td>
<td>Na</td>
<td>2.85</td>
</tr>
<tr>
<td><em>Porphyra umbilicus</em>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>687</td>
<td>1407</td>
<td>283</td>
<td>1173</td>
<td>Na</td>
<td>18.2</td>
<td>17</td>
<td>4.23</td>
</tr>
<tr>
<td><em>Chondrus crispus</em>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>420</td>
<td>3184</td>
<td>732</td>
<td>427</td>
<td>&lt;0.5</td>
<td>4</td>
<td>20–30</td>
<td>7.14</td>
</tr>
<tr>
<td><em>Gracilaria vermiculophylla</em>&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.4</td>
<td>4.9</td>
<td>0.31</td>
<td>Na</td>
<td>0.0015</td>
<td>0.04</td>
<td>Na</td>
<td>0.0024</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other foods (mg per 100 g wet wt)</th>
<th>Calcium</th>
<th>Potassium</th>
<th>Magnesium</th>
<th>Sodium</th>
<th>Copper</th>
<th>Iron</th>
<th>Iodine</th>
<th>Zinc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soya bean&lt;sup&gt;c&lt;/sup&gt;</td>
<td>200</td>
<td>Na</td>
<td>Na</td>
<td>Na</td>
<td>Na</td>
<td>6.0</td>
<td>Na</td>
<td>Na</td>
</tr>
<tr>
<td>Carrot&lt;sup&gt;c&lt;/sup&gt;</td>
<td>140</td>
<td>Na</td>
<td>Na</td>
<td>Na</td>
<td>Na</td>
<td>0.8</td>
<td>Na</td>
<td>Na</td>
</tr>
<tr>
<td>Brown rice&lt;sup&gt;c&lt;/sup&gt;</td>
<td>110.0</td>
<td>1160.0</td>
<td>520.0</td>
<td>258.0</td>
<td>1.3</td>
<td>12.9</td>
<td>Na</td>
<td>16.2</td>
</tr>
<tr>
<td>Milk&lt;sup&gt;c&lt;/sup&gt;</td>
<td>115.0</td>
<td>140.0</td>
<td>11.0</td>
<td>55.0</td>
<td>Na</td>
<td>0.1</td>
<td>15.0</td>
<td>0.4</td>
</tr>
<tr>
<td>Sirloin steak&lt;sup&gt;c&lt;/sup&gt;</td>
<td>9.0</td>
<td>260.0</td>
<td>16.0</td>
<td>49.0</td>
<td>0.1</td>
<td>1.6</td>
<td>6.0</td>
<td>3.1</td>
</tr>
<tr>
<td>Bananas&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.0</td>
<td>400.0</td>
<td>34.0</td>
<td>1.0</td>
<td>0.1</td>
<td>0.3</td>
<td>8.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Peanuts&lt;sup&gt;c&lt;/sup&gt;</td>
<td>60.0</td>
<td>670.0</td>
<td>210.0</td>
<td>2.0</td>
<td>1.0</td>
<td>2.5</td>
<td>20.0</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Source: Holdts & Kraan 2011<sup>d</sup>; McCance & Widdowson 2014<sup>c</sup>; Parjikolaei *et al.* 2016<sup>b</sup>; Penalver *et al.* 2020<sup>a</sup>. Na – data not available
Table 3. Content of fatty acids (FAs) in different seaweeds.

<table>
<thead>
<tr>
<th>Seaweeds</th>
<th>(% of the total fatty acids)</th>
<th>PUFAs</th>
<th>ω3 PUFAs</th>
<th>ω6 PUFAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Himanthalia elongataa</td>
<td></td>
<td>38</td>
<td>19</td>
<td>15</td>
</tr>
<tr>
<td>Laminaria spa.</td>
<td></td>
<td>47</td>
<td>25</td>
<td>21</td>
</tr>
<tr>
<td>Undaria pinnatifidaa</td>
<td></td>
<td>69</td>
<td>45</td>
<td>22</td>
</tr>
<tr>
<td>Zonaria tournefortib</td>
<td></td>
<td>2</td>
<td>1.11</td>
<td>0.14</td>
</tr>
<tr>
<td>Ulva armoricanad</td>
<td></td>
<td>29</td>
<td>24</td>
<td>4</td>
</tr>
<tr>
<td>Ulva lactucab</td>
<td></td>
<td>1.18</td>
<td>0.86</td>
<td>0.32</td>
</tr>
<tr>
<td>Asparagopsis taxiformisc</td>
<td></td>
<td>68</td>
<td>Na</td>
<td>Na</td>
</tr>
<tr>
<td>Chondrus crispusa</td>
<td></td>
<td>Na</td>
<td>7.2</td>
<td>8</td>
</tr>
<tr>
<td>Gracilaria sp.a</td>
<td></td>
<td>Na</td>
<td>Na</td>
<td>45</td>
</tr>
<tr>
<td>Palmaria sp.a</td>
<td></td>
<td>Na</td>
<td>Na</td>
<td>2</td>
</tr>
<tr>
<td>Porphyra sppa</td>
<td></td>
<td>16</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Soliera chordalisd</td>
<td></td>
<td>15</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

Source: Holdts & Kraan 2011a; Kendel et al. 2015d; Mellouk et al. 2017c; Nunes et al. 2019b. Na – data not available
<table>
<thead>
<tr>
<th>Seaweeds</th>
<th>Health benefits</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ulva lactuca</td>
<td>Anticancer property</td>
<td>Wang et al. 2013</td>
</tr>
<tr>
<td><em>Ulva armoricana</em></td>
<td>Property to increase immune system and lower blood cholesterol, anticancer property against skin and colon cancer</td>
<td>Kendel et al. 2015</td>
</tr>
<tr>
<td>Porphyra dioica,</td>
<td>Suppress inflammation in patients with rheumatoid arthritis, beneficial effect to ashmatic patient</td>
<td></td>
</tr>
<tr>
<td>Palmaria palmata,</td>
<td></td>
<td>Imhoff-Kunsch et al. 2011; Robertson et al. 2015</td>
</tr>
<tr>
<td>Chondrus crispus</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Porphyra umbilicalis,</em></td>
<td>Improved lipoprotein metabolism</td>
<td>Olivero-David et al. 2011; Shannon &amp; Abu-Ghannam 2019</td>
</tr>
<tr>
<td><em>Undaria pinnatifida</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Undaria pinnatifida</em></td>
<td>Antiobesity</td>
<td>Okado et al. 2011</td>
</tr>
<tr>
<td><em>Undaria pinnatifida,</em></td>
<td>Prevention of cardiovascular disease, anti-inflammatory, antiplatelets</td>
<td>Taboada et al. 2013</td>
</tr>
<tr>
<td><em>Porphyra purpurea</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Ulva rigida,</em></td>
<td>Prevention of cardiovascular, neurodegenerative, osteoarthritis, diabetes and autoimmune disease</td>
<td>Cardoso et al. 2015; Simopoulos 2016; Goncalves et al. 2017; Neto et al. 2018;</td>
</tr>
<tr>
<td><em>Gracilaria sp.,</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Fucus vesiculosus,</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Saccharina latissima</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Gracilaria spp,</em></td>
<td>Anti-inflammatory, anticancer activity against breast and bladder cancer</td>
<td>Wang et al. 2013; Da Costa et al. 2017</td>
</tr>
<tr>
<td><em>Ulva lactuca</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5. Contents of vitamins (mg per 8 dry wt.) and bioactive compounds (mg per 100 g dry wt) in seaweeds.

<table>
<thead>
<tr>
<th>Seaweeds</th>
<th>Vitamins</th>
<th>β-Carotene</th>
<th>Chl a</th>
<th>Polyphenols</th>
<th>Fucoxanthin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B&lt;sub&gt;12&lt;/sub&gt;</td>
<td>C</td>
<td>E</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Ascophyllum nodosum</em>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.4</td>
<td>81.8</td>
<td>Na</td>
<td>Na</td>
<td>Na</td>
</tr>
<tr>
<td><em>Himanthalia sp</em>&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Na</td>
<td>46.7</td>
<td>2.24</td>
<td>4.3</td>
<td>150</td>
</tr>
<tr>
<td><em>Laminaria digitata</em>&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.5</td>
<td>1.35</td>
<td>0.28</td>
<td>2.2</td>
<td>153</td>
</tr>
<tr>
<td><em>Sargassum horneri</em></td>
<td>Na</td>
<td>Na</td>
<td>Na</td>
<td>Na</td>
<td>Na</td>
</tr>
<tr>
<td><em>Undaria pinnatifida</em>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>43</td>
<td>1847</td>
<td>Na</td>
<td>Na</td>
<td>Na</td>
</tr>
<tr>
<td><em>Palmaria palmata</em>&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.84</td>
<td>0.6–5.5</td>
<td>0.2–1.3</td>
<td>2</td>
<td>80.4</td>
</tr>
<tr>
<td><em>Porphyra umbilicalis</em>&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.78</td>
<td>33.3</td>
<td>0.11–.34</td>
<td>3.9</td>
<td>161.4</td>
</tr>
<tr>
<td><em>Ulva rigida</em>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>60</td>
<td>94.2</td>
<td>1.97</td>
<td>Na</td>
<td>Na</td>
</tr>
<tr>
<td><em>Ulva spp</em>&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.3</td>
<td>10.0</td>
<td>Na</td>
<td>20.4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>93</td>
</tr>
</tbody>
</table>

Source: Ferraces-Casais *et al*. 2012<sup>b</sup>; Fung *et al*. 2013<sup>f</sup>; Susanto *et al*. 2015<sup>c</sup>; Rajauria *et al*. 2017<sup>d</sup>; Nunes *et al*. 2017<sup>c</sup>; Cherry *et al*. 2019<sup>a</sup>. Na – data not available
Table 6. Biological activities of seaweeds’ sterols and their potential health benefiting properties.

<table>
<thead>
<tr>
<th>Types of sterols</th>
<th>Seaweeds</th>
<th>Health benefits</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fucosterol, desmosterol</td>
<td><em>Macrocystis</em> sp., <em>Pyropia</em> sp., <em>Palmaria</em> sp.</td>
<td>Improve digestion, enhanced blood clearance, lowering of free and bound cholesterol</td>
<td>Yi <em>et al.</em> 2016; Mouritsen <em>et al.</em> 2017</td>
</tr>
<tr>
<td>Fucosterol, hydroperoxy-24-vinylcholesterol</td>
<td><em>Ecklonia stolonifera</em>, <em>Eisenia bicyclis</em></td>
<td>Inhibit butrlcholinesterase, enzyme that involve in Alzheimer’s disease, antiobesity, Antidiabetic</td>
<td>Jung <em>et al.</em> 2013a, b; Abdul <em>et al.</em> 2016</td>
</tr>
<tr>
<td>Fucosterol</td>
<td><em>Hizikia fusiformis</em> (=<em>Sargassum fusiforme</em>)</td>
<td>Anti-inflammatory</td>
<td>Jung <em>et al.</em> 2013a</td>
</tr>
<tr>
<td>Fucosterol, sarinosterol</td>
<td><em>Sargassum fusiforme</em></td>
<td>Hepatoprotective</td>
<td>Hoang <em>et al.</em> 2012; Chen <em>et al.</em> 2014</td>
</tr>
<tr>
<td>Fucosterol</td>
<td><em>Sargassum longifolium</em>, <em>Turbinaria conoides</em>, <em>Himanthalia elongata</em></td>
<td>Anti-pathogenic, antifungal, antiviral</td>
<td>Kumar <em>et al.</em> 2010; Santoyo <em>et al.</em> 2011; Rajendran <em>et al.</em> 2013</td>
</tr>
<tr>
<td>Fucosterol</td>
<td><em>Laminaria japonica</em></td>
<td>Hyperlipidemia</td>
<td>Lee <em>et al.</em> 2011</td>
</tr>
</tbody>
</table>