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A Review: Classification, Chemical Compositions and Antioxidant Properties of Red, Brown and Green Macroalgae

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Abstract

In human body, free radicals cause oxidative stress which is reported to be the main reason of many life style human diseases. This stress induced by the imbalance of antioxidants and oxidants. Many deadly diseases induced by oxidative stress as it forms the root cause of several degenerative changes in the cells and tissues. Nucleic acids, lipids and proteins in our body are demaged by this stress, made changes to cellular functions and lead to apoptosis or necrosis. Antioxidants have an important role in protection human body from oxidative damages and prevention of many chronic diseases, for example, diabetes, cardiovascular disease, aging, even diseases related to the nervous system. Currently, the exploration of natural antioxidants is trends in the pharmaceutical industries because synthetic antioxidants are reported to cause major side effects. Antioxidants of natural origin are considered safe and highly effective. These substances are abundant in many medicinal herbs including algae, fungi, plants and animals. Among them, seaweed is believed to be a potential source of medicinal herbs capable of synthesizing compounds with good biological activity. Off these, macroalgae, including red, brown, and green macroalgae, are considered a natural source of antioxidant components that can provide a valuable contribution to the innovation of pharmaceutical and industrial fields. Since algal products' antioxidant properties and nutritional benefits have been increasingly recognized, their properties as antioxidants require further investigative studies. This review provides information on various aspects of antioxidants, including algal sources containing antioxidants, the chemical composition of macroalgae, and antioxidant components, as well as their benefits to human health.

Keywords*: antioxidants, algal sources, chemical composition, human health, macroalgae*

Introduction

Our earth is covered by 70% oceans, aquatic habitats inhabited by a great variety of organisms. Sea creatures are essential and bring us many benefits, including seafood, raw materials, tourism, and cultural heritage. There are many services provided by macroalgae or seaweeds. They have been consumed as a resource of nutritional food and in traditional medicine for a long time (Lyu *et al*., 2017). However, until the last decades, based on advanced technologies, the biological properties of macroalgae for biotechnological purposes have been possible to characterize and apply widely. Studies showed that macroalgae are a source of special compounds which can be applied in pharmaceutical and industrial fields. In addition, seaweeds have non-toxic, edible, cheap, and easy culturing characteristics, so they are ideal candidates containing natural origin for replacing synthetic compounds (Lomartire and Gonçalves, 2022). Seaweeds are also a natural origin of secondary metabolites with peculiar bioactivities (Rocha *et al*., 2018). Indeed, there is an increasing consumption trend of seaweed-based food since scientists reported the antioxidant, antimicrobial, and antiviral effects of seaweed metabolites. The seaweed potentiality can change depending on the algae type, harvesting period, and environmental conditions; thus, every seaweed species has peculiar compounds that can act in different ways, showing diverse properties (Lomartire and Gonçalves, 2022).

Through the literature, macroalgae are considered a great source of antioxidants, vitamins, protein, minerals, dietary fiber, and essential fatty acids with low caloric value (Agregán *et al*., 2017). Many studies have shown that the complementarity of macroalgae in daily alimentation benefits digestive health and contributes to decreasing the incidence of numerous diseases like cancer, diabetes, and cardiovascular (Cao *et al*., 2016; Charoensiddhi *et al*., 2017), as well as bacterial and viral infections (Swamy, 2011; Gheda *et al*., 2016).

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Studies have demonstrated that seaweed extracts possess potent antioxidant properties (Al-Araby *et al*., 2020; El-Sheekh *et al*., 2021). Seaweeds are a well-established source of diverse, naturally occurring bioactive compounds. These include polyphenols, vitamins, polysaccharides, peptides, and fatty acids, each with a unique range of functional properties and structures (Hayes, 2015; Okolie, Mason and Critchley, 2018). These bioactive compounds are believed to contribute to the various health benefits associated with seaweed consumption. Moreover, research has revealed that green, red, and brown algae contain compounds exhibiting a range of biological activities, including antioxidant properties (Vega *et al*., 2020).

Since there is an increasing awareness of the benefits of seaweeds, especially the possible use of macroalgae as a natural source of antioxidants, this review focuses on the recent progress in investigation of different macroalgae species which belong to three major groups as a source of antioxidants, mainly emphasizing the latter published data (from 2011 onwards) regarding their composition and properties.

Macroalgae Classification

Marine macroalgae, also commonly referred to seaweeds, are multicellular organisms exhibiting plant-like characteristics. They are typically found in coastal regions, where they adhere to rocks and other hard surfaces. Unlike true plants, their body structure lacks differentiation into distinct organs such as leaves, stems, and roots. It is important to distinguish between seaweeds and seagrasses. While both inhabit marine environments, seagrasses are flowering plants possessing a more complex body plan with recognizable leaves, stems, and root systems (Teo and Wee, 1983).

Marine macroalgae or seaweeds belong to multicellular photosynthetic primary producers that play the role of a fundamental component of the ecosystem because they are responsible for providing oxygens, food resources, and shelter substrates for various organisms. In addition, seaweed lowers the acidity of the ocean and contributes to solving global warming (Duarte *et al*., 2017; Kim *et al*., 2017; Hasselström *et al*., 2018).

Literature has described approximately 15,000 species of seaweeds (Vuong *et al*., 2018). The most abundantly present with more than 7,000 species is the red macroalgae, followed by brown macroalgae with 2030 species and green macroalgae with 600 species, respectively (Baweja *et al*., 2016).

Macroalgae can be classified into three main groups depending on pigment and color such as red algae (Rhodophyta), brown algae (Ochrophyta, Phaeophyceae), and green algae (Chlorophyta) (Hamid *et al*., 2019; Cermeño *et al*., 2020).

Marine algae encompass a diverse assemblage, and within this group, brown algae (Phaeophyceae) are distinguished by their pigmentation, which exhibits a spectrum ranging from yellow to dark brown (Seely *et al*., 1972). The brown seaweed color is due to pigments such as xanthophyll and fucoxanthin (Gupta and Abu-Ghannam, 2011). Fucoxanthin, a carotenoid pigment, is particularly abundant within edible brown algae. Notably, it contributes more than 10% to the total production of carotenoids observed in the natural environment (Aryee *et al*., 2018).

Red algae (Rhodophyta) contain many pigments, including carotenoids, chlorophyll (a and d), phycoerythrin, phycocyanin, and allophycocyanin. The color of red seaweed is due to the presence of pigments such as phycocyanin, phycoerythrin, chlorophyll a, and xanthophyll (Baweja *et al*., 2016). Their size is small, ranging from a few centimeters to one meter long (FAO, 2014).

Green algae (Chlorophyta) are characterized primarily by chlorophyll, a green lipid-soluble pigment commonly found in plants, algae, and cyanobacteria. The green seaweed color is yellow to green due to the presence of pigments such as beta-carotene, chlorophyll a and chlorophyll b, and xanthophylls (Gupta and Abu-Ghannam, 2011). Chlorophyll plays an important role in photosynthesis and several biological functions (Aryee *et al*., 2018). Like red macroalgae, green seaweed is small (FAO, 2014).

The present review shows chlorophyll, carotenoid, and phycobiliprotein as the three main groups of pigments of seaweeds. Carotenoids, including more than 1,100 molecules, are widely distributed in nature (Yabuzaki, 2017). They are divided into two classes: xanthophylls containing oxygen, and carotenes, which are pure hydrocarbons. Carotenoids absorb energy for photosynthesis and protect chlorophyll from photodamage in photosynthetic organisms such as plants and algae. Carotenes, lycopene, fucoxanthin, astaxanthin, zeaxanthin, lutein, neoxanthin, and violaxanthin are the main carotenoids present in macroalgae. One of the most abundant carotenoids found in edible brown seaweed is fucoxanthin, which contributes over 10% of total carotenoid production (Aryee *et al*., 2018).

Phycobiliproteins belong to a group of water-soluble pigments, classifying three groups of molecules with protein structure differences: phycocyanins (blue pigment), allophycocyanins (light blue pigment), and phycoerythrins (red pigment). The most abundant is the latter. Most pigments have been used as a natural food colorant. Pigments are important in photosynthesis and help plants and algae prevent negative effects from UV radiation and cell damage. They also have an important role in several activities. Therefore, it might be possible to apply pigments in pharmaceuticals (Dumay *et al*., 2014; Aryee *et al*., 2018)).

Chemical Composition of Macroalgae

Many studies indicates the effectiveness of various dietary antioxidants, such as α-tocopherol, ascorbic acid, amino acids, peptides, proteins, carotenoids, flavonoids and other phenolic compounds, in enhancing the body's antioxidant mechanisms. Notably, the importance of naturally occurring peptides in biological systems is well-established, and recent reports suggest their potential in developing synthetic vaccines (Appavu *et al*., 2015).

Plants have been known as a rich source of antioxidants. Recently, the marine world have been widely investigated as the potent source of bioactive components. Particularly, seaweeds boast a diverse array of such compounds, encompassing secondary metabolites, dietary fiber, minerals, proteins, lipids, omega-3 fatty acids, essential amino acids, polysaccharides, and vitamins (Lee *et al*., 2013). These components provide bioactivities, including antioxidant, anti-inflammatory, antimicrobial, and anti-cancer properties exhibited by these algae (Lee *et al*., 2013).

There are many factors affecting the chemical composition of marine macroalgae, including species, collection time, geographic habitat, water temperature, light intensity, and nutrient concentration in water. Many research articles have been evaluating the changeable component of macroalgae (Hentati *et al*., 2018) (see Table 1.). The study indicated that diverse seaweed genera determined great differences in nutrient concentrations such as proteins, minerals, lipids, or dietary fiber. It is a fact that there are huge distinctions in chemical components in the same genus of macroalgae (Cherry *et al*., 2019).

From ancient times, seaweed was consumed as a whole food or ingredient in Asian areas such as China, Japan, and Korea as it provided nutritional benefits (FAO, 2020). Studies have shown that macroalgae are a good source of nutrients, consisting of bioactive compounds, phytochemicals, polysaccharides, fibers, ω-3 fatty acids, and essential amino acids with vitamins and minerals, such as calcium, potassium, sodium, and phosphorus (Lomartire and Gonçalves, 2022).

Protein and amino acids

Proteins are a major and essential component of human nutrition. The amount of protein is one of the quality parameters for food products. The protein quality, such as amino acids, essential amino acid ratio, digestibility, and bioavailability, is considered an

Table 1. Composition on % dry weight basis of different macroalgae

Macroalgae	Protein	Fat	Carbohydrate	References
Brown seaweed				
Sargassum wightii	1.482 $mg.g^{-1}$	0.0272 $g.g^{-1}$	0.095 $mg.g^{-1}$	(Chakraborty and Santra, 2008)
Sargassum tenerrimum	12.42	1.5	23.55	(Manivanna *et al*., 2008)
Turbinaria ornata	14.68	3.1	12.5	(Parthiban *et al*., 2013)
Chnoospora minima	11.3	0.9	28.5	(Afonso *et al*., 2020)
Cystoseira compressa	89.1 $g.kg^{-1}$	18.3 $g.kg^{-1}$	396.2 $g.kg^{-1}$	(Oucif *et al*., 2020)
Red seaweed				
Gelidiella acerosa	9.18	3.83	14.34	(Chakraborty and Santra, 2008)
Gracilaria foliifera	6.98 $mg.g^{-1}$	3.23 $mg.g^{-1}$	22.32 $mg.g^{-1}$	(Manivanna *et al*., 2008)
Hypnea valentiae	8.34	1.5	23.60	(Manivanna *et al*., 2008)
Kappaphycus alvarezii	18.78	1.09	2.67	(Rajasulochana *et al*., 2012)
Acanthophora spicifera	18.9	2.1	65	(Afonso *et al*., 2020)
Green seaweed				
Ulva lactuca	8.44 $g.kg^{-1}$	4.36 $g.kg^{-1}$	35.27 $g.kg^{-1}$	(Chakraborty and Santra, 2008)
Codium tomentosum	6.13	2.53	20.47	(Gokulakrishnan *et al*., 2015)
Ulva rigida	6.64	12.0	22.0	(Satpati and Pal, 2011)
Ulva lactuca	14.7	0.5	70.1	(Afonso *et al*., 2020)
Caulerpa racemosa	18.3	19.1	83.2	(Afonso *et al*., 2020)

important factor for human health. It is a fact that macroalgae can be consumed as a nutrient source in many developing countries (Biris-Dorhoi *et al*., 2020). Seaweeds provide a high content of proteins (17 - 44%) (Lomartire and Gonçalves, 2022). Due to these high-value proteins, they can be used as a sustainable nutrient alternative source.

The content of protein in seaweeds varies depending on the species. Studies have found that brown seaweeds contain low levels of protein ranging from 3-15% on a dry weight basis (DW), the protein level is about 9-26% DW in green seaweed, red seaweeds can provide a high level of protein (47% DW) (Fleurence *et al*., 2018). Through present reviews, one gram of the meal from seaweed with the highest - value protein (for example, Enteromorpha intestinalis, Palmaria palmata, and Vertebrata lanosa) provides equal to or higher amounts of all of the essential amino acids in comparison to corn, wheat, and rice. The study showed that the amount of lysine accounts for three to nine times higher. In addition, the amount of free amino acids can be approximately 2-14.5%. The green algae provide the lowest amount, while the red varieties provide the highest (Mæhre *et al*., 2014). In the aspect of nonessential amino acids, the green algae proteins have high amounts of glutamic and aspartic acids (that can reach 26 and 32% of the total amino acids), alanine, and glycine (Fleurence *et al*., 2018).

Lipid and fatty acid

Macroalgae contain a low presence of lipids (<4.5%) (Lomartire and Gonçalves, 2022). The quantity and fatty acids composition differ according to environmental (light intensity, seawater salinity, temperature) and genetic variation among species. Generally, it has been reported that in comparison to green varieties, brown species provide a higher lipid content (Biancarosa *et al*., 2018).

The highest lipid content is found in Chlorophyta varieties, and the lowest lipid level is in Rhodophyta members (Kasimala *et al*., 2015). Red and brown seaweed predominantly contain polyunsaturated fatty acids such as eicosapentaenoic acid (EPA) and arachidonic acid (AA). In contrast, green seaweeds such as Ulva pertusa are rich in hexadecatetraenoic, oleic, and palmitic acids, and also high PUFAs levels, such as linoleic acid (18:2n-6) and α-linolenic acid (18:3n-3) (Biancarosa *et al*., 2018). Macroalgae are good sources of omega 3 and omega 6 fatty acids, which are reported to prevent many diseases, e.g., cardiovascular diseases, arthritis, and diabetes (Kumar *et al*., 2021).

Carbohydrate

From the nutritional point of view, carbohydrates, including mono-, oligo- and polysaccharides, play an essential role and are an irreplaceable source of energy that supports various functions and physical activity of the human body. According to literature data, macroalgae contain a high amount of carbohydrates (<60%); of these, the seaweed polysaccharide such as alginates, carrageenan, fucoidan, and laminarin exhibited biological properties including antioxidant, antithrombotic, anti-inflammatory, and neuroprotective activities (Praveen *et al*., 2019).

Studies indicated that Chlorophyceae varieties provide a maximum level of carbohydrates, followed by Rhodophyceae and Phaeophyceae members. In addition, sulfated polysaccharides are one of the major components. The highest level was reported in Ascophyllum, Porphyra, and Palmaria. Kappaphycus alvarezii and Eucheuma spinosum have a high content of polysaccharides, up to 56 and 40%, respectively (Bouanati *et al*., 2020). Carrageenans are considered one of the main compositions of cell walls of red seaweeds occupying 30-70% of the dry weight. Ulvan is one of the main compositions of cell walls of green seaweeds occupying 8-29% of the dry weight. Alginates and fucans are regarded as one of the main compositions of cell walls of brown seaweeds occupying between 17 and 45%, and 5 to 20% , respectively, of the dry weight. Additionally, brown seaweeds provide laminarin up to 35% of the dry weight (Vera *et al*., 2011).

Regarding the food industry application, agar, alginates, and carrageenan, which are algal polysaccharides, are known as the most important and economically feasible obtained products with their rheological gelling and thickening properties (Holdt and Kraan, 2011). As mentioned in studies, dietary fiber is also an important constituent of algal polysaccharides. However, studying the total dietary fiber of different seaweed species is necessary because very little research has been shown to estimate dietary fiber (Kumar *et al*., 2021).

Minerals

In comparison to terrestrial plants, seaweed minerals are present in high levels ranging between 7 and 38% of dry seaweed matter. Macroalgae are a rich source of essential minerals, including potassium, sodium, fluorine, calcium, iron, magnesium, arsenic, zinc, copper, iodine, chlorine, bromine, sulfur, selenium, phosphorous, manganese, vanadium, and cobalt (Vijay *et al*., 2017). The highest microelements in the macroalgae are potassium, sodium, magnesium, and calcium, presenting over 97% of the mineral content. Other microelements presenting in small amounts are copper, iron, manganese, and zinc (from 0.001 to 0.094% of seaweeds' dry weight) (Biris-Dorhoi *et al*., 2020). Studies indicated that the brown macroalgae (*Sargassum* sp., *Laminaria* sp., and *Undaria* sp.) provide a higher level of minerals compared to red macroalgae (*Porphyra* sp. and *Eucheuma* sp.) (Vijay *et al*., 2017).

Vitamins

Macroalgae are a rich source of vitamins. Especially seaweed is a significant source of water-soluble vitamins and provides vitamins A, B12, C, ß-carotene, pantothenate, folate, riboflavin, and niacin. Seaweed-based products with a richness in vitamin B12 are considered dietary supplements for vegans at risk for vitamin B12 deficiency. Macroalgae are also rich in vitamins compared to fruits and vegetables. The class Phaeophyceae contains high amounts of water-soluble vitamins such as vitamins B1 (thiamine), B2 (riboflavin), B6, and nicotinic acid (Kasimala *et al*., 2015). As a result, macroalgae are the potential source to solve the iodine problem and deficiency of other minerals and vitamins. Moreover, these seaweed bioactivity compounds are considered candidates for functional food, which play an important role in preventing numerous harmful diseases (Kasimala *et al*., 2015).

Antioxidant components of macroalgae

Antioxidants are groups of chemical compounds that scavenge the reactive oxygen species such as superoxide anion (O^{2-}), hydrogen peroxide (H_2O_2), hydroxyl radical (OH))/ reactive nitrogen species (NO), and free radicals which cause oxidative stress in the human body. Biological macromolecules, including DNA, proteins, and nucleic acid, are damaged due to oxidative stress and cause many diseases, such as cancer, diabetes, stroke, Alzheimer's, Parkinson's, and cardiovascular diseases. Hence, antioxidant compounds are crucial to protecting health from harmful factors (Debnath *et al*., 2020). Compared to terrestrial plants, seaweeds provide bioactive components with potentially higher antioxidant properties since there are up to eight interconnected polyphenols rings (Debnath *et al*., 2020). Macroalgae are known as a source of natural antioxidants, including polyphenols, polysaccharides, pigments of β-carotene, astaxanthin, phycocyanin, and phycoerythrin, and sulfated polysaccharides of fucoidans and heterofucans. Antioxidant components produced from macroalgae have a wide range of biological properties and benefits that are anticancer, antimicrobial, anti-inflammatory, and antidiabetic activities (Debnath *et al*., 2020).

Phenolic compounds

Seaweeds are a rich source of polyphenolic compounds with a wide range of biological properties such as antioxidant, anticancer, antimicrobial, anti-inflammatory, and antidiabetic activities. Consequently, there are various research and examination for the seaweed application in food, cosmetics, and pharmaceutical applications. Experimental studies have widely explored these components' antioxidant properties (Debnath *et al*., 2020).

Recently, many studies have identified numerous polymeric structures in red, green, and brown marine algae species. Studies showed that red and green seaweeds contain flavonoids and phenolic acids as the major phenolic components (Gunathilake *et al*., 2022). Nevertheless, red seaweeds mainly provide bromophenols (halogenated phenolics), while phlorotannins exclusively exist in brown seaweeds. Brown macroalgae are a rich source of phlorotannins (polymerized forms of phloroglucinolonly) which have a size ranging from 400 to 400,000 Da. The isolation of these polymers and their derivatives has been done from Sargassum fusiforme and S. muticum (Debnath *et al*., 2020). In addition, quantification research reported that S. scoparium (brown seaweeds) aqueous extract contained a high amount of phenolic acids and flavonoids; 90 mg.100 g^{-1} dry weight (DW) of gallic acid followed by catechin and epicatechin (6 - 7 mg.100 g^{-1} DW) (Gunathilake *et al*., 2022). Studies showed the presence of flavonoids in methanolic extracts of 27 Japanese macroalgae species (6 green, 11 brown, and 10 red macroalgae), revealing a significant distribution of flavonoids in red seaweeds compared to green and brown seaweeds. Hesperidin and catechol were found in all red, green, and brown macroalgae. Although rutin and caffeic acids were most prominent in red seaweeds (23,200 - 4,000 $\mu g.g^{-1}$), they were distributed amongst all three groups (Gunathilake *et al*., 2022).

Pigments

Seaweed pigmentation arises from three distinct pigment groups: chlorophylls, carotenoids, and phycobiliproteins. Carotenoids, encompassing over 1100 diverse molecules (Yabuzaki, 2017), are further subdivided into xanthophylls (oxygenated) and carotenes (hydrocarbons). Within photosynthetic organisms like plants and algae, carotenoids serve a dual purpose: absorbing light energy for photosynthesis and safeguarding chlorophyll from photooxidative damage. Pigments in plants and algae exhibit diverse functions beyond photosynthesis. Their role in mitigating UV radiation and cellular damage, coupled with their known biological activities, suggests potential applications in the pharmaceutical realm (Aryee *et al*., 2018; Dumay *et al*., 2014). The pigment is widely applied in food and beverage industries, animal feed, cosmetics, and pharmaceutical products. There has been a dramatic increase in the demand for natural food colors recently. The market of food colors is planned to gain 5.12 billion dollars in 2023, and it is an expectation that the greatest part of this plan will be natural food colors (MarketsandMarkets, 2019).

Carotenoids

Carotenoids produced from C4 isoprenoid units are yellow-orange tetra-terpenoid pigments. They exist in plants, algae, fungi, and bacteria but are not synthesized in animals. Carotenoids have important roles in the functions of the human body (Nisar *et al*., 2015; Eggersdorfer and Wyss, 2018). The major carotenoids, including α-carotene, β-carotene, lutein, and zeaxanthin, are present in most red macroalgae (Nisar *et al*., 2015). It is well known that the carotenoids from seaweeds show multiple biological properties. *Pyropia yezoensis* belonging to Bangiales (Rhodophyta), is one of East Asia's most economically valuable marine foods, providing many nutrients and health-promoting compounds. In Koizumi *et al*. (2018) indicated that α-carotene, β-carotene, lutein, and zeaxanthin were crucial carotenoids in the thallus and conchocelis phases of *P. yezoensis* (Koizumi *et al*., 2018). In brown macroalgae, one of the most prevalent carotenoids is fucoxanthin which belongs to the xanthophyll group and performs several biological activities such as anti-obesity, antioxidant, antimicrobial, and anticancer activities (D'Orazio *et al*., 2012). Zeng *et al*. (2018), proved that the defensive effects of fucoxanthin and fucoxanthin prevent tributyltin-induced oxidative stress in HepG2 cells. There was a significant decrease in the ROS and malondialdehyde (MDA) for the treatment utilizing fucoxanthinol; furthermore, the expression level of Bcl-2/Bax in tributyltin caused HepG2 cells was raised clearly by both fucoxanthin and fucoxanthinol (Zeng *et al*., 2018). *Undaria pinnatifida* ethanolic extract is a rich source of fucoxanthin that was determined to improve the lipid and plasma composition in high-fat diet mice (Biris-Dorhoi *et al*., 2020). Consequently, it is established that fucoxanthin is considered a promising and upcoming antitumor and anticancer agent and can suppress metastatic potential (Biris-Dorhoi *et al*., 2020).

Chlorophylls

Chlorophylls contain a central magnesium ion in their structure. These pigments have a functional role in the seaweed photosynthesis process and an important role in protecting the algal tissue integrity from oxidative stress caused by excessive UV radiation (Koutsaviti *et al*., 2018). Chlorophyll a is dominant in terrestrial plants and brown algae, while major chlorophyll b is found in green algae. In addition, brown algae provide a rich source of chlorophyll c, while red algae have a high amount of chlorophyll d (Pereira *et al*., 2014). It is established that chlorophyll is converted into pyro pheophytin, pheophytin, and pheo-phorbide in processed vegetable food and following ingestion by humans. The derivate exhibits antimutagenic and antioxidant effects and may have a significant role in cancer prevention (Holdt and Kraan, 2011).

Polysaccharides

Seaweed polysaccharides show noticeable antioxidant properties and are effectively used to decrease oxidation damage to the human body (Wu *et al*., 2013; Xu *et al*., 2017). In the research of Xu *et al*. (2017), the water-soluble polysaccharides isolated from the brown seaweed Hizikia fusiformis exhibit free radical scavenging activities against hydroxyl radicals and the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical in vitro. In addition, they prevent oxidative stress in the carbon tetrachloride-caused liver injury model (Xu *et al*., 2017). Similarly, a dose-dependent DPPH radical scavenging effect is found in the polysaccharide fraction of Solieria filiformis (Sousa *et al*., 2016). In other studies, *Saccharina latissima* containing the polysaccharides which scavenged 2,2-azinobis-(3-ethylbenzothiazoline-6-sulfonate; ABTS) radicals and showed strong antioxidant reducing power in vitro (Jiménez-Escrig *et al*., 2015).

Based on literature reports, sulfated polysaccharides are one of the major polysaccharide components. Additionally, Ascophyllum, Porphyra, and Palmaria genera provide the highest contents. Furthermore, *Kappaphycus alvarezii* and *Eucheuma spinosum* species have high-level content of polysaccharides, accounting for 56 and 40%, respectively (Bouanati *et al*., 2020). Fucans, fucoidans, carrageenans, galactans, and laminarin belong to sulfated polysaccharides and are a major component in the algae cell wall (Deniaud-Bouët *et al*., 2017). Sulfated polysaccharides have various biological efficacy and potent antioxidant activities. Therefore, they have been used in pharmaceutical research (Wijesekara *et al*., 2011). Brown seaweeds contain fucoidan, which is a complex sulfated polysaccharide. Many studies proved that fucoidan has a variety of beneficial biological properties. Fucoidan isolated from *S. glaucescens* exhibited antioxidant properties by scavenging DPPH and ABTS radicals (Huang *et al*., 2016). Purified fucoidan from Turbinaria conoides significantly inhibited the proliferation of lung carcinoma (A549) cells (Alwarsamy *et al*., 2016). Van Weelden *et al*. (2019), found fucoidan as an effective candidate for cancer treatment in the future (Weelden *et al*., 2019). According to literature data, one of the main constituents of red algae cell walls is carrageenans, accounting for 30 to 75% of the dry seaweed weight. The main constituent of green algae cell walls is ulvans, accounting for 8 to 29% of the dry algal weight. Moreover, laminarin is present in brown seaweeds up to 35% of the dry seaweed weight (Vera *et al*., 2011). In East and Southeast Asia, Pyropia yezoensis are mainly edible red algae cultivated and consumed. These algal species contain porphyrin, a linear sulfated polysaccharide, as one of the main components (Ueno *et al*., 2019). Regarding food industry applicability, algal polysaccharides, including agar, alginates, and carrageenan, are considered the most important and economically feasible obtained products base on rheological gelling and thickening properties (Holdt and Kraan, 2011).

Conclusion

This review article gives a better understanding of the recent exploitation of the antioxidant properties of macroalgae, which is focused on the chemical components of macroalgae, and the composition of seaweed antioxidants (red algae, green algae, and brown algae). Further researchs is essential to elucidate the mechanisms of action of seaweed's antioxidants. This knowledge would pave the way for their efficacious integration into various pharmaceutical and other applications, ultimately leading to the development of sustainable and health-beneficial products.

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