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**Review Article**

# Seaweeds as a Potential Source of Bioactive Compounds

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**ABSTRACT**

Seaweeds or marine macroalgae are the oldest members of the plant kingdom, with a history extending back many hundreds of millions of years. Based on photosynthetic pigments, marine macroalgae can be classified into three groups, namely green algae commonly known as Chlorophyta, brown algae or Phaeophyta, and red algae also called Rhodophyta. In response to different kinds of environmental stress, marine algae develop defense strategies resulting in a significant level of structural chemical diversity, from different metabolic pathways. In this review a brief description of the most important seaweed compounds and their bioactivities are presented in this study. Seaweeds contain minerals, amino acids, proteins, fatty acids, lipids, polysaccharides, dietary fibers, vitamins, and various secondary metabolites, such as phenols, alkaloids, terpenes, and pigments. Many of these constituents possess high economic values and can be extracted to obtain antioxidative, anti-inflammatory, anticancer, antimicrobial, antifungal, antiviral, anti-obesity, antidiabetic, and antihypertensive products. Therefore, a new trend to isolate and identify bioactive compounds and constituents from marine algae has emerged.

## 1. Introduction

The oceans cover more than 70% of the Earth's surface and contain a variety of marine species that constitute about half of the known worldwide biodiversity[1]. This vast marine diversity is a potential source of various functional ingredients, such as polysaccharides, bioactive peptides, polyunsaturated fatty acids, minerals, natural pigments, vitamins, and enzymes[2] . Among marine organisms, marine algae are still identified as under-exploited plant resources although they have been used for thousands of years in China, Korea, and Japan and all over the world for various food and non-food purposes[3].

The term marine algae generally refers to marine macroalgae or seaweeds, they are mostly photosynthetic organisms[4] with big morphological, taxonomical, and phylogenetic differentiation[5]. Macroalgae are taxonomically divided into red (Rhodophyceae), green (Chlorophyta), and brown algae (Phaeophyceae).

In recent years, several studies showed that marine algae are important sources of bioactive natural substances directly related to modulating chronic disease as shown in Figure 1. Several bioactivities of algal compounds were described to date ranging from antioxidant, anticancer, anti-inflammatory, antimicrobial, antifungal, and antiviral to anti-obesity, and antidiabetic activities and against specific parasites[6]. Therefore, a new trend to isolate and identify bioactive compounds and constituents from marine algae has emerged.

This article presented a review of metabolite classes produced by this biochemically rich organism as well as their bioactivity.

## 2. Seaweeds (Marine macroalgae)

Seaweeds or marine macroalgae are the oldest members of the plant kingdom, extending back millions of years. They live either in marine or saltwater environments. Compared to plants, they have little tissue differentiation, and contain no roots, stems, leaves, flowers,

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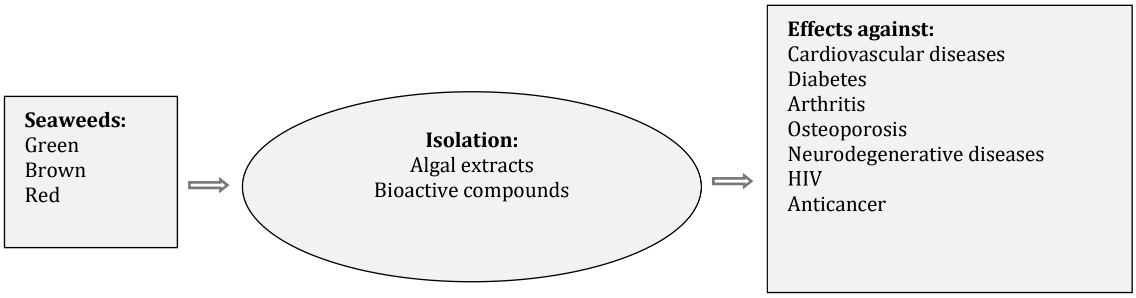



**Figure 1.** Overview of seaweeds and their effects on some chronic diseases

or vascular tissue[7].

Based on photosynthetic pigments, marine macroalgae can be classified into three groups, including green algae commonly known as Chlorophyta, brown algae or Phaeophyta, and red algae also called Rhodophyta[8]. This differentiation is traditionally based on differences in pigmentation but further research has shown that they also differ in biochemical composition, structural features, and life cycle[4].

In response to different kinds of environmental stress, marine algae develop defense strategies resulting in a significant level of structural chemical diversity, from different metabolic pathways[9].

The green (green seaweed, Chlorophyta) color characteristic of this algae is mainly due to the presence of chlorophyll a and b in the same amount as plants.

Their brownish (*brown seaweed,* Phaeophyta) color results from the dominance of high percentages of fucoxanthin[10].

Seaweed Red (*Red seaweed,* Rhodophyta) has a reddish or purplish color that results from the dominance of phycoerythrin[10].

The presence of different pigments in seaweeds is related to their marine habitat. Thus, green macroalgae abound in coastal waters and can absorb large amounts of light energy, while brown and red seaweeds dominate at greater depths where sunlight penetration is limited[8].

## 3. Major bioactive compounds from seaweeds and their potential activities

Naturally, about 30,000 algae species are available for potential use in food, nutrition, and bioactive resources[^]. Seaweeds contain minerals, amino acids, proteins, fatty acids, lipids, polysaccharides, dietary fibers, vitamins, and various secondary metabolites. Many of these constituents possess high economic values and can be extracted to obtain antioxidative, anti-inflammatory, antimicrobial, anticancer, and antihypertensive products[11]. A brief description of the most important seaweed compounds and their bioactivities is presented in the following.

### *3.1. Proteins and amino acids*

Various bioactive properties of algal proteins and peptides have been reported to date by several studies, such as antioxidant, anticancer, antihypertensive, anticoagulant, immunomodulatory, and antiproliferative activities[12]. A particular class of bioactive proteins "lectin" could be extracted from seaweed. Lectins are specific proteins that can irreversibly bind carbohydrates and are characterized by antibacterial, antiviral, anticancer, mitogenic, cytotoxic, anti-inflammatory, and antiadhesive activities. They can be found in some seaweed species, such as *Eucheuma serra*, *Ulva sp., Griffithsia sp.*, *Gracilaria sp*., and *Boodlea coacta*[13].

Carnosine (β-alanyl-L-histidine) is a peptide found in *Ancanthophora dellei* (red seaweed) with antioxidant activity and transition metals chelating ability[14].

Seaweeds are good sources of essential amino acids. Thus, high concentrations of glutamic acid, serine, and alanine were found in *Palmaria palmata*[15]. Two amino acids, including histidine and taurine with antioxidant and antihypertensive properties were also found in *Ulva pertusa*[16].

### *3.2. Lipids*

Lipids constitute 5% of dry seaweed weight, this amount can be much higher, as it varies according to season, temperature, salinity, and algae species. Phospholipids and glycolipids are the main classes of lipids found in algae[17].

Seaweeds are a rich source of essential unsaturated fatty acids that have diverse activities, especially polyunsaturated fatty acids from group n-3(ω-3) and n-6 (ω-6)[18]. The fatty acid composition in seaweeds has been explored to decrease the risk of heart disease, thrombosis, and atherosclerosis. Moreover, they act as anti-aging, anti-inflammatory, and regenerating agents[19]. Other fatty acids derived from various macroalgae are applied in the treatment of psoriasis, eczema, hyperlipidaemia, and some cancers. They are also effective against skin inflammation[20].

### *3.3. Sulphated polysaccharides*

In the fields of food, biochemistry, and pharmacology, sulphated polysaccharides isolated from marine algae have attracted much more attention because of their efficiency as anti-HIV-1, antimalaria, antiparasitic, antioxidant, antithrombotic, antilipidemic, antiadhesive, anticoagulant, anti-cancer, and anti-inflammatory agents[21]. Moreover, the inhibitory activities of algal sulphated polysaccharides against mumps and influenza virus were reported a long time ago[22].

Furthermore, a comparative study has reported the inhibition of herpes virus and other viruses by polysaccharide fractions from various seaweed extracts. It is proposed that polysaccharides of 10 red algae are quite efficient in disrupting the viral peptide attachments that are supposed to be highly preserved in the drug-resistance mutation process. Therefore, polysaccharides are directed to affect these peptides as potential anti-HSV targets[23]. More recently, it has been reported that the human immunodeficiency virus (HIV) inhibits the potential activity of several polysaccharides extracted from seaweed[24]. Thus, fucoidans isolated from three different brown seaweeds exhibited the ability to inhibit early steps of HIV infection. The negatively charged sulphated polysaccharides present in the alga cell wall exerted an antagonist effect with the HIV entry into cells. Table 1 summarizes the major types of sulphated polysaccharides isolated from green, brown, and red seaweeds and their biological activities.

Generally, the biological activities of sulphated polysaccharides depend on their sugar composition, sulphated content, species, and environmental factors.

### *3.4. Vitamins*

Similar to many vegetables, seaweeds contain both water and fat-soluble vitamins. The particularity of seaweed is the presence of vitamin B12, which is rare in vegetables. The vitamin composition of seaweed is variable, it depends on species, location, season, sea temperature, light, and salinity[25,26]. Besides their biochemical functions and antioxidant activities, seaweed-derived vitamins possess other health benefits such as reducing hypertension, preventing cardiovascular disease, and reducing the risk of cancer[26].

### *3.5. Phenols and phlorotannin*

Phenolic compounds especially polyphenols and tannins extracted from seaweeds possess antimicrobial activities[27]. Bromophenols were isolated for the first time by Hodgkin et al.[27] from the red seaweed *Polysiphonia lanora* and their antibacterial properties were demonstrated.

Eckol and derivatives are polyphenolic compounds isolated from the brown alga *Ecklonia cava*, they demonstrated antimicrobial and cytoprotective effects against oxidative stress[28]. The structure of Eckol is shown in Figure 2.

Due to their antioxidative properties, seaweed polyphenols may be successfully used as curative and preventive agents for the treatment of numerous diseases. They act as anticancer agents, and exhibit anti-inflammatory, antioxidant, and antiproliferative activities.

Polyphenols isolated from seaweed are known to protect the nervous and cardiovascular systems, they decrease blood glucose and limit diabetes occurrence and they are effective in the fight against obesity[29].

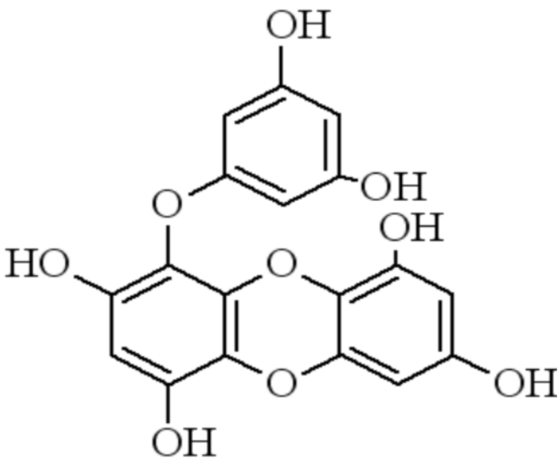



**Figure 2.** Structure of Eckol which was isolated from *Ecklonia cava*[30]

It was proved that *Laminaria* and *Porphyra sp.* algae could reduce the risk of occurrence of mammary gland and intestine cancer[31].

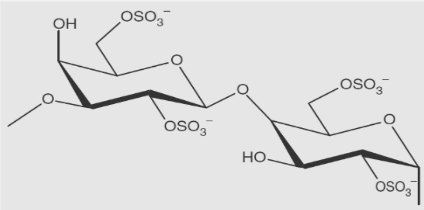
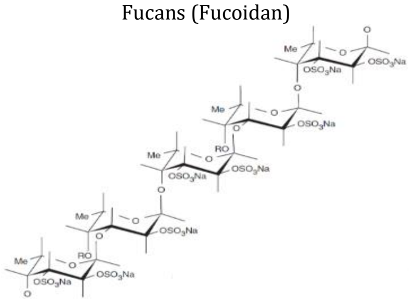
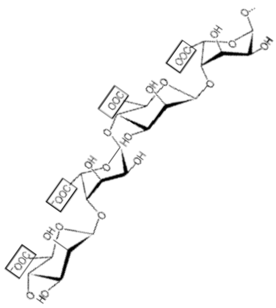
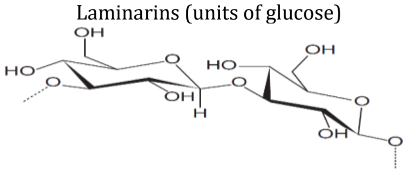
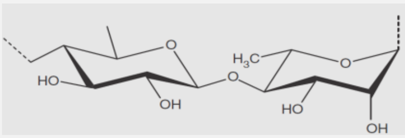
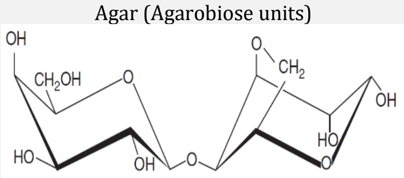
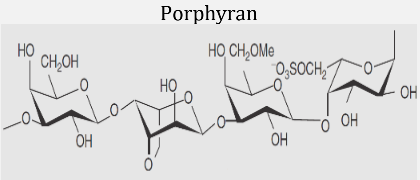
Besides, the methanol extract of brown seaweed is known to contain a large amount of phlorotannins (tannin derivatives) with bioactive properties, such as antioxidant, antibacterial, anti-inflammatory, anti-HIV, antidiabetic, antiallergic, and anti-matrix metallo-proteinase activities[32-35]. Phlorotannin, acting as a hypoglycemic agent, improves sensibility and secretion of insulin[36].

### *3.6. Terpenes and terpenoids*

Terpenes (diterpenes, triterpenes, tetraterpenes, hemiterpenes, and sesquiterpenes) are formed based on an isoprene structure and when they contain additional oxygen, they are termed terpenoids. Seaweeds contain many types of terpenes and terpenoids with several biological activities[37]. Table 2 shows terpenes and terpenoids isolated from seaweeds and their biological activities. Brown algae of the genus *Dictyota* and *Dictyopteris* are a rich source of diterpenes and sesquiterpenes, such as dictyols, dolabellane[38], and zonarols[39] with several interesting biological activities including cytotoxic, antiviral, antifungal and antibacterial properties.

On the other hand, red algae *Laurencia* genus are well known as secondary metabolites producers, mainly terpenoids. Furthermore, the green algae *Caulerpa prolifera* contains sesquiterpenes (Caulerpenyne) that exhibit antibacterial and cytotoxic activities[30].

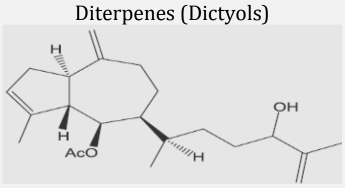
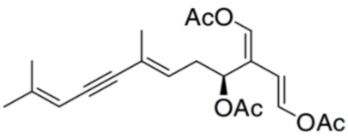
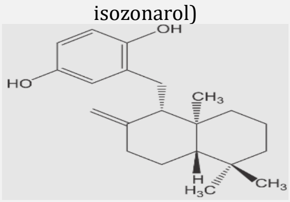
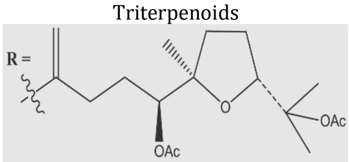
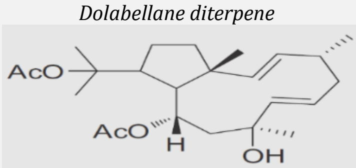
**Table 1.** Major sulphated polysaccharides isolated from seaweeds and their biological activities

| Seaweed | Sulfated polysaccharides | Bioactivities | Reference |
|---|---|---|---|
| Green seaweed | Ulvans  | Antioxidant,<br>Antiviral | 40 |
| | Fucans (Fucoidan)  | Antitumor,<br>Anticoagulant Antithrombin Antiviral, | 41 |
| Brown seaweed | Alginates (both acid and salt forms)  | Immunization against the virus.<br>Treatment of esophagitis and urolithiasis,<br>Cholesterol-lowering, Antihypertensive<br>Preventing absorption of toxic substances;<br>Blood glucose regulating | 42 |
| | Laminarins (units of glucose)  | Antitumor, | 43 |
| | Carrageenan  | Anticoagulant, Antithrombotic<br>Antiviral, Antitumor<br>Immunomodulatory,<br>Hypocholesterolaemia<br>Antiherpetic<br>Anticoagulant | 44 |
| Red seaweed | Agar (Agarobiose units)  | Antitumor<br>Antioxidant<br>Hypoglycaemic<br>Antiaggregating effect on red blood cells.<br>Hepatoprotective, | 45 |
| | Porphyran  | Anticancer, Antioxidant, Antiaging<br>Antiviral Antibacterial<br>Anti-inflamator | 46 |

### 3.7. Steroids

Steroids are compounds possessing a characteristic tetracyclic carbon skeleton, named as perhydro-cyclopenteno phenanthrene nucleus ore sterane[48]. Marine macroalgae are a good source of steroids.

**Table 2.** Terpenes and terpenoids found in seaweeds and their bioactivities

| Seaweed | Terpenes/terpenoids | Biological activities | References |
|---|---|---|---|
| *Dictyota dichotoma* var.implexa, *Dictyota menstrualis* (Brown algae) | Diterpenes (Dictyols)   | Antibacterial activity<br>Inhibit virus replication | 47 |
| *Caulerpa prolifera*<br>(Green algae) | Sesquiterpene (Caulerpenyne)   | Antibacterial activity<br>Cytotoxic on tumor cells<br>Potent toward human nasopharyngeal carcinoma cells | 30,48 |
| *Dictyopteris zonarioides*, *Dictyopteris undulata*<br>(Bown algae) | Sesquiterpene (Zonarol and isozonarol)   | Antifungal activity<br>Prevents inflammation and Apoptosis<br>Provides neuroprotection | 49 |
| *Laurencia obtuse*<br>(Red algae) | Triterpenoids   | Potential cytotoxic activity<br>Anticancer agent | 50 |
| *Dictyota pfaff, Dilophus Fasciola (*Brown algae*)* | *Dolabellane diterpene*   | Antiviral activity | 51 |

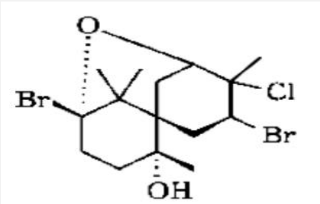
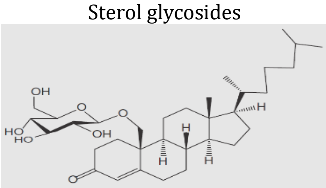
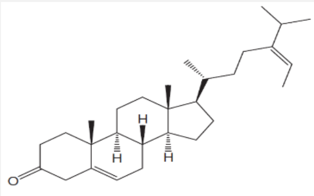
Therefore, some steroids have been isolated from various red, green, and brown seaweeds. The red seaweed genus *Laurencia* is a prolific source of steroids, including laurinterol and pecifenol. Laurinterol was reported as an antiprotozoal and antiparasitic agent, while pecifenol could be exploited for its antimicrobial, anti-allergic and inflammatory effects[52]. Table 3 summarizes the main steroid components extracted from seaweeds and their bioactivities.

### 3.8. Alkaloids

Alkaloids are chemical compounds that contain basic nitrogen atoms and are usually derived from amino acids. Most of the alkaloids are colorless and crystalline compounds.

Several alkaloids and other nitrogenous heterocyclic compounds have been obtained from seaweeds. *Caulerpa* are known as good source of alkaloids in particular caulerpin (Figure 3). Many biological activities were found

**Table 3.** Main steroids found in seaweeds and their bioactivities

| Seaweed | Steroids | Biological activities | References |
|---|---|---|---|
| *Laurencia sp* (Red algae) | Pacifenol  | Antimicrobial activity<br>Anti-inflammatory action | 52 |
| *Peyssonnelia sp* (Red algae) | Sterol glycosides  | Inhibit the growth of human cancer cells | 53 |
| *Tydemania expeditionis* (Green algae) | Steroids  | Anticancer (prostate) | 54 |

in caulerpin, such as anti-inflammatory, antinociceptive, anti-tumor, anti-microbial, neuroprotective, and protein tyrosine phosphatase-1B inhibitory activities[55].

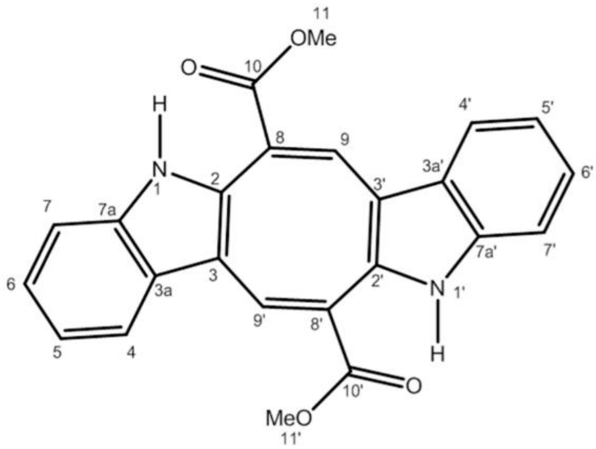



**Figure 3.** The chemical structure of caulerpin[55].

### 3.9. Pigments

Seaweeds are potentially a rich source of various natural pigments. The type of pigments varies among species, giving them different colors. Besides their important role in photosynthetic and pigmentation effects, these bio compounds have been explored to provide health benefits. Pigments, such as polyphenols, exhibit various strong bioactivities such as antioxidative, anti-inflammatory, anti-obesity, antiangiogenic, anticancer, neuroprotective, and antiosteoporosis activities, therefore, they can be used in the treatment and prevention of numerous diseases[56].

### 3.10. Other biologically active compounds

Other bioactive compounds were found in seaweeds with positive biological activities. Halogenated compounds, such as indoles, are the major secondary metabolites isolated from red and brown seaweeds, they are characterized by antifungal, antibacterial, and antiviral properties[57]. Several enzymes with protective activities, such as peroxidase, glutathione reductase, superoxide dismutase, and catalase were found in seaweed[58]. Saponins extracted from red seaweed exhibited many biological properties including antimicrobial and anti-inflammatory activities[59].

Diversity of bioactive compounds in seaweeds is a result of the aggressive environments in which they live[60].

## 4. Conclusions

In recent years, seaweed bio-compounds have attracted increasing attention because of their potential therapeutic effects to prevent or treat various diseases. Different seaweed species extracts and their secondary metabolites have antioxidant, anticancer, antiangiogenic, anti-obesity, and anti-inflammatory activities.

## Declarations

### Competing interests

The authors declare that they have no competing interests.

### *Authors' contributions*

All authors participated in the preparing data, and writing the final version of the manuscript. The authors confirmed the last edition of manuscript before publication.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The manuscript contains all datasets generated and/or analyzed in the current study.

### *Ethical considerations*

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