 DOI: 10.35382/TVUJS.13.3.2023.2434

POTENTIAL APPLICATIONS OF BIOACTIVE COMPONENTS FROM BROWN ALGAE

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Abstract – *Recently, macroalgae has found extensive utilization within the domain of biotechnology. Based on their variety of bioactive components, species of class Phaeophyceae are involved in the food, cosmetic, and pharmaceutical industries. Studies have proved that these unique compounds show beneficial activities for human health. With peculiar properties, including antioxidant, antimicrobial, antiviral activities, and related functionalities, each compound holds potential value for human health. This review discusses the bioactive compounds of brown algae and the recent multiple applications of those components that make up algae's potential in industrial companies. The review was conducted by searching and selecting references related to the content of interest with popular web search engines such as Google Scholar and PubMed.*

Keywords: bioactive components, cosmetic application, macroalgae, pharmaceutical application.

I. INTRODUCTION

The earth's surface is approximately 70% covered by water, serving as habitats for diverse organisms. These organisms play a crucial role in the planet's ecology and offer numerous benefits to humanity by providing valuable resources such as seafood and raw materials and contributing to the tourism industry and cultural heritage. Macroalgae, or seaweed, has long been a source of sustenance and traditional medicine [1]. In recent years, advanced technologies have allowed us to clarify and utilize the biological properties of marine algal compounds for biotechnological purposes. Marine algae represent a reservoir of unique compounds possessing intriguing attributes that hold potential applications in the pharmaceutical and industrial sectors. Due to their non-toxic, edible, cost-effective, and easily cultivable characteristics, marine algae are considered optimal candidates to substitute synthetic compounds with natural origins. The consumption of food products derived from marine algae is on the rise as scientific reports substantiate the antioxidative, antibacterial, and antiviral effects of metabolites sourced from marine algae. The potential of marine algae may vary depending on the algal species, harvesting timing, and environmental conditions; hence, each species harbors distinct compounds that can exhibit diverse functionalities.

Marine algae constitute a rich source of protein, minerals, vitamins, dietary fiber, antioxidants, and low-calorie essential fatty acids [2], which can be readily incorporated into the development and formulation of nutritionally fortified food products. Furthermore, research has demonstrated that the inclusion of marine algae in daily dietary regimes is associated with reduced disease incidence and confers digestive health benefits, as well as implications for chronic conditions such as diabetes, cancer, and cardiovascular diseases [3, 4], along with antibacterial and antiviral properties [5, 6]. Therefore, the supplementation of marine algal compounds for the formulation of novel natural medicines stands as one of the objectives within the burgeoning field of marine pharmacology, an emerging branch of pharmacology in recent decades.

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Received date: 05th September 2023; Revised date: 27th September 2023; Accepted date: 28th September 2023

In this context, this comprehensive review assesses pertinent studies concerning the nutritional composition and biological activities of brown algae, highlighting the health advantages of brown algae consumption and the proclaimed beneficial effects of their bioactive metabolites. Furthermore, the utilization of brown algae and/or their constituents as functional ingredients for the development of cosmetic products is also deliberated.

II. METHODS

The review mainly collects literature related to potential applications of bioactive components of macroalgae, in particular brown algae. The methodology used Google Scholar and PubMed web search engines to find pertinent literature using the keywords 'application of macroalgae,' 'bioactive compounds of macroalgae,' 'brown algae with bioactive components.' From articles of interest, the authors identified useful references appropriate to the scope of the review.

III. SOME BIOACTIVE CONSTITUENTS OF BROWN ALGAE

Many biologically active products originating from algae are employed in the pharmaceutical and food industries. The bioactive compounds of algae are primarily identified using gel permeation chromatography (GPC). GPC is a liquid chromatographic technique in which polymers in a solution are separated into distinct chains based on their size (independent of chemical properties) and the presence of functional groups (using affinity chromatography, a type of chromatography involving ligands). The second type is based on the interaction between impurities and a matrix material, such as sepharose. In the case of affinity chromatography, bioactive compounds (e.g., proteins and enzymes) engage in specific biochemical interactions with ligands (typically organic) used as impurities. Gas-liquid chromatography, infrared spectroscopy (IR), proton nuclear magnetic resonance spectroscopy, 13C nuclear magnetic resonance (NMR) spectroscopy, high-performance size-exclusion chromatography, and the C-PC method (a technique for analyzing pigment-protein complexes from the phycobiliprotein family involved in light absorption, specifically C-phycocyanin) are also utilized to determine the chemical composition of algae [7].

A. Carotenoid

Macroalgae are notably rich in the carotenoid fucoxanthin, which exhibits antioxidant, anticancer, antidiabetic, anti-inflammatory, hepatoprotective, anti-angiogenic, and antimalarial properties [8]. Marine algae are also abundant sources of pigments such as β-carotene and zeaxanthin, which possess antioxidant characteristics. When extracting carotenoids, it is essential to select an appropriate purification method that effectively removes interfering components without altering the chemical structure of the bioactive compounds. One such method involves the purification of carotenoids from chlorophyll using activated charcoal [9].

B. Phenolic compounds

The phenolic compounds from algae also exhibit various biological activities, including antioxidant, anti-proliferative, anti-obesity, and antidiabetic effects [10]. For instance, the antioxidant and anti-diabetic properties of phlorotannin isolated from *Cystoseira compressa* have been discovered and quantified [11]. Flavonoids extracted from brown algae *C. compressa* and *Padina pavonica* demonstrate antibacterial activity against pathogenic bacteria isolated from meat, meat products, milk, and dairy products. The most potent antibacterial activity is exhibited by flavonoids extracted from *C. compressa* [12]. Derivatives of phenolic acids, phlorotannins, catechins, hydroxybenzoic acids, coumaric acids, and gallocatechins have been identified in extracts from brown algae such as *Ascophyllum nodosum*, *Laminaria japonica*, *Lessonia trabeculata*, and *Lessonia nigrescens* [13].

A study has identified multiple types of phlorotannins, phenolic acids, and flavonoids

(primarily acacetin derivatives) in extracts from *A. nodosum*, *Bifurcaria bifurcata*, and *Fucus vesiculosus* [13]. The content of phenolic compounds in algae can vary under the influence of different abiotic and biotic factors [14]. Phenolic acids can be found in a free form in algal extracts, but they are often encountered in conjugated forms, such as esters. Gallic and ellagic acids can be esterified with glucose or another monosaccharide, for example [15]. Chromatographic methods like high-performance liquid chromatography (HPLC) or thin-layer chromatography (TLC) enable the separation and purification of individual phenolic compounds in their pure form without altering their chemical structure [15].

The chemical diversity of *Ulva reticulata* (Chlorophyta), *Sargassum wightii*, and *Gracillaria verrucosa* (Rhodophyta) has been demonstrated [16]. More than 30 metabolites have been identified, with steroids and fatty acids being predominant among them.

C. Carbohydrates

Carbohydrates are a common component of algae [17]. Algal polysaccharides can enhance the selective activity of beneficial bacterial populations and stimulate the production of functional metabolites by the gut microbiota. Moreover, they can stimulate various biological activities such as anticancer, antioxidant, immunomodulatory, and antidiabetic effects. Algal polysaccharides are not digested by human digestive enzymes. They have the ability to resist digestion in the upper gastrointestinal tract and are subsequently fermented in the colon [18]. High carbohydrate content has been measured in red algae like *Chondrus crispus*, *Mastocarpus stellatus*, and *Gigartina pistillata*. Research has identified that brown algae *Himanthalia elongata* and *Laminaria ochroleuca* contain a high content of sulfate polysaccharides known as fucoidan [19]. Fucoidan extracted from algae possesses a complex structure, which depends on the type of algae, plant part, and extraction method employed [20]. Depending on their structure, they may offer various health benefits, such as anticancer, antioxidant, and antiviral activities [21]. Besides fucoidan, other polysaccharides like alginate have also been found in *Sargassum fusiforme* and other brown algae [22].

D. Minerals and vitamins

Algae are rich sources of minerals. Marine algae are particularly abundant in iodine, making them potential candidates for the production of preventive medicines for iodine deficiency-related diseases such as endemic goiter, Graves' disease, and hyperthyroidism [23]. Significant amounts of calcium, magnesium, potassium, copper, iron, and selenium have been found in *Sargassum fusiforme* and *Sargassum oligocystum*, collected from May to August [24]. *S. oligocystum*, harvested in February, has higher levels of sodium, iodine, and zinc. *Laminaria japonica*, for instance, contains calcium content 13 times higher than that of milk [25].

Macroalgae produce or store various vitamins. Algae are valuable candidates for preventing diseases related to iron and vitamin B12 deficiencies (nutritional anemia) as well as vitamin A deficiency (xerophthalmia). Algae are rich in antioxidant vitamins C and E. Vitamin C prevents scurvy, while vitamin E helps control nervous system issues stemming from poor nerve conduction and anemia caused by oxidative damage to red blood cells [25].

Chlorella vulgaris and *Palmaria palmata* algae show high levels of vitamin B12 [19]. Retinol, α-tocopherol, and ergocalciferol have been identified in *Cystoseira barbata* algae [26].

IV. APPLICATIONS OF BIOACTIVE COMPOUNDS

The brown algae (Phaeophyceae) owe their predominantly brown color due to the high content of carotenoid fucoxanthins. These algae are recognized as a valuable source of bioactive compounds and other health-promoting factors. Fucoxanthin is an orange xanthophyll pigment found in high concentrations in Phaeophyceae, Haptophyta, Bacillariophyceae, Chrysophyceae, and to a lesser extent in Rhodophyta, Raphidophyceae,

and Dinophyta. These pigments not only give algae their distinctive color but also exhibit various biological activities, including anti-inflammatory [27, 28], anti-obesity, anti-atherosclerosis [29], and potentially exploitable anti-cancer properties for pharmaceutical purposes. *In vivo* and *in vitro* experiments have shown that fucoxanthin isolated from *L. japonica* inhibits tumor growth in a lung cancer model [30], while fucoxanthin from the seaweed *Ishige okamurae* inhibits malignant B16-F10 cells when implanted in mice [31]. Chung et al. [32] isolated fucoxanthin from *L. japonica* to evaluate its effects on an *in vitro* metastasis model of B16-F10v malignant cells. The tests demonstrated a significant reduction in metastasis, paving the way for *in vivo* trials of fucoxanthins in lung metastasis. In summary, Chung et al. [32] demonstrated significant inhibition of lung cancer cell growth, suggesting that fucoxanthins may hold promise in preventing cancer metastasis. Atya et al. [33] isolated fucoxanthin from *Colpomenia sinuosa* and *Sargassum prismaticum* to assess their anticancer activities *in vitro* and antioxidant activities in the body. HCT-116 (colorectal cancer cell line), MCF-7 (breast cancer cell line), and HepG-2 (liver cancer cell line) showed growth inhibition, while *in vivo* tests evaluated the hepatoprotective ability of fucoxanthin in mice. The results were highly positive as the antioxidant and anti-inflammatory properties of the extracts protected liver cells from inflammation and membrane damage in mice [34]. Wang et al. [34] investigated the growth-inhibiting ability of fucoxanthin extracts from *Undaria pinnatifida*. Among the studied cancer cell lines, the malignant tumor Malme-3M and SiHa cervical squamous cell carcinoma exhibited significant growth inhibition [34]. While the *in vitro* results are promising, further improvement in *in vivo* studies is needed. The correlation between antioxidant activity and total phenolic or fucoxanthin content has been clearly demonstrated. The results showed higher antioxidant activity in *Sargassum Horneri* and *Cystoseira hakodatensis* compared to *Eisenia bicyclis*, *Kjellmaniella crassifolia*, and *Alaria crassifolia*. This may be explained by the higher total phenolic and fucoxanthin content in *S. Horneri* and *C. hakodatensis* [35].

Among the polysaccharides, fucoidan has exhibited various pharmacological properties. The structure and composition of fucoidan vary among different brown algae species, leading to different beneficial effects. Some fucoidan has shown anti-proliferative properties against cancer cells. Boo et al. [36] demonstrated the individual anticancer activity of fucoidan from *U. pinnatifida* against A549 human lung carcinoma cells. Palanisamy et al. [37] isolated fucoidan from *Spatoglossum asperum* and found antibacterial activity against *Aeromonas hydrophila* (Gram-negative bacteria) through agar well diffusion assays. *In vitro* antioxidant activity was assessed using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging assay, leading to energy reduction and overall antioxidant activity. The results indicated that fucoidan extracts exhibited dose-dependent antioxidant properties, as well as antibacterial characteristics [38].

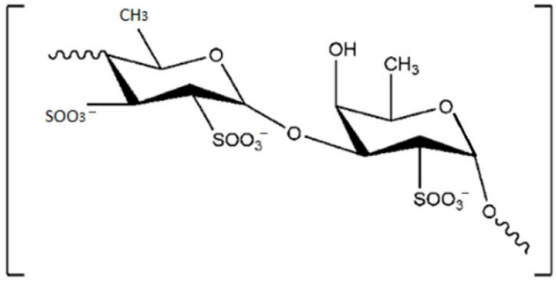

Fig. 1: Chemical structure of the polysaccharide fucoidan [38]

The antibacterial properties have also been studied with crude fucoidan and purified fucoidan from the brown algae *Fucus vesiculosus*. For both fucoidan preparations, inhibitory effects on bacteria have been observed, including *Escherichia coli*, *Staphylococcus cholermidis*, *Staphylococcus aureus* and *Bacillus licheniformis*, with *E. coli* being the most sensitive to each type of fucoidan. The results indicate that the purification of fucoidan leads to changes in the monosaccharide composition

with a reduction in sulfate and uronic acid content, which reduces its antibacterial activity [38]. In another study conducted by Liu et al. [39], crude fucoidan from *L. japonica* showed no antibacterial activity, while reduced fucoidan polymers exhibited good antibacterial activity against both *E. coli* and *S. aureus*. Reduced fucoidan polymers interacted with membrane proteins, causing membrane disruption, structural collapse, and ultimately cell death. Therefore, further research on the correlation between antibacterial activity and the structure of fucoidan needs to be conducted to better elucidate this relationship.

The antiviral effects of polysaccharides have been evaluated against herpes viruses. Natural fucoidan from *Fucus evanescens* and its derivatives have been tested against Herpes Simplex Virus Type 1 (HSV-1), Herpes Simplex Virus Type 2 (HSV-2), Enterovirus (ECHO-1), and Human Immunodeficiency Virus Type 1 (HIV-1). Studying both natural fucoidan with irregular structures and derivatives can provide insights into which structural segments of these unique polysaccharides are crucial for antiviral activity. *In vitro* experiments were performed using African green monkey kidney cells (Vero), and for *in vivo* experiments, vaginal HSV-2 infection was induced in female mice. The *in vitro* results showed that both types of fucoidan increased antiviral activity, directly affecting the cells and inhibiting the initial stages of viral replication.

Comparative analysis of the antiviral activity of crude fucoidan and fragmented fucoidan indicates that crude fucoidan more effectively inhibits the replication of both HSV types. Antiviral activity against ECHO-1 and HIV-1 was detected but was lower than that against HSV strains. Furthermore, *in vivo* studies showed that the use of fucoidan in suppositories protected animals from vaginal HSV-2 infection in mice [40]. Antiviral effects against HSV-1 and HSV-2 have also been investigated using sulfated polysaccharides isolated from *Sargassum patens* [41]. It was found that the anti-HSV activity increased with the sulfate ester content of the polysaccharide [42]. These results demonstrate the feasibility of inhibiting HSV infection using structurally specific seaweed polysaccharides with antiviral properties.

Pozharitskaya et al. [43] elucidated the anticoagulant activities of high molecular weight fucoidan from *Fucus vesiculosus* in several *in vitro* models. The anticoagulant activity of fucoidan has also been observed in *in vivo* experiments, where volunteers consumed 3 g of fucoidan from *Undaria pinnatifida* over 12 days [44].

Fucoidans have been found to have anti-diabetic effects. Fucoidan isolated from *U. pinnatifida* has been studied for its inhibition of three starch-hydrolyzing enzymes: α-amylase, α-glucosidase, and amyloglucosidase. It has been demonstrated that while fucoidan extracts exhibit significant inhibitory effects on all three starch hydrolases, they show significantly stronger inhibition of α-glucosidase, indicating that fucoidans from *U. pinnatifida* may be a diabetes therapeutic agent [45]. Jia et al. [46] investigated the structural characteristics and anti-diabetic activity of polysaccharides from *Sargassum fusiforme* and *Macrocystis pyrifera* in a high-fat diet and streptozotocin-induced diabetic mouse model. The administration of polysaccharides orally helped limit weight loss and increased water intake, significantly controlling the rise in blood sugar levels, neutral fat, and total cholesterol in diabetic mice. Therefore, polysaccharides from brown seaweeds may be promising candidates as natural medicines and functional foods to improve diabetes-related issues.

Polyphenols are powerful compounds with interesting biological activities. Extracts found from *Padina australis* inhibit the growth of microorganisms by damaging the cytoplasmic membrane and killing bacterial cells. Phenols and flavonoids attack the phosphate group, leading to the decomposition of phospholipid molecules of bacterial cells into carboxylic, glycerol acid and phosphoric acid. As a result, the growth of bacteria is slowed down and they eventually die

[47]. Chkhikvishvili et al. [47] demonstrated the bactericidal ability of phenKolics extracted from *Padina australis* against *Bacillus cereus*; Through *in vitro* bioassay, Kumar et al. [45] showed the inhibition against beta-lactamase negative Escherichia coli ATCC 25922, Pseudomonas aeruginosa, Staphylococcus aureus and Bacillus cereus by phenolic extract of *P. australis*, indicating that this species has narrow-spectrum antibacterial activity.

Marine algae have been primarily studied for the discovery of phloroglucinol-based polyphenols, which are called phlorotannins. Among brown seaweeds, phlorotannins extracted from *Ecklonia cava*, *Ecklonia stolonifera*, *Ecklonia kurome*, *Eisenia bicyclis*, *Sargassum elasticbergii*, *Hizikia fusiformis*, *Undaria pinnatifida* and *Laminaria japonica* have been reported to have health beneficial activities [47].

Nagayama et al. [48] examined the bactericidal effect of crude and purified phlorotannins from the brown alga *Ecklonia kurome* on pathogenic bacteria. Phlorotannins indicated that it has bactericidal activity against *Staphylococcus aureus*, *Streptococcus pyogenes*, *Bacillus cereus*, *Campylobacter fetus*, *Campylobacter jejuni*, *Escherichia coli*, *Salmonella enteritidis*, *Salmonella typhimurium* and *Vibrio parahaemolyticus*. Furthermore, the effects of the administration of phlorotannins on male and female rats were studied to confirm the safety of phlorotannins for mammals. A variety of experiments demonstrated the antibacterial activity of phlorotannin from *Ecklonia kurome*. These results may suggest the potential for adding these compounds to food products or developing drugs with antibacterial activity without harming the organism. Lee et al. [49] analyzed the antibacterial activity of extracts from *Ecklonia stolonifera*. It was shown that dieckol isolated from *E. stolonifera* demonstrated antibacterial activity against methicillin-resistant *S. aureus* and methicillin-susceptible *S. aureus*, with MIC values ranging from 32 to 64 μg/mL.

Many of the activities of phlorotannins have been exploited in traditional Korean medicine, in which *Sargassum hemiphylum* has been used to treat various allergic diseases. Na et al. [50] reported the significant contribution of *S. hemiphylum* in the treatment of allergic reactions, such as atopic dermatitis. Dioxinodehydroeckol (DHE) and phlorofucofuroeckol A (PFF-A) isolated from *E. stolonifera* contribute to the reduction of allergic reactions and may be promising candidates for the design of new allergic reaction inhibitors. *In vivo* testing on mice fed with *Eisenia arborea* showed inhibition of IgE and antihistamine degradation, suggesting that *E. arborea* may have anti-allergic effects [51].

The antioxidant activity of phlorotannins has been discovered in brown algae for the treatment of neurodegenerative diseases such as Alzheimer's disease. The inhibition of the AChE enzyme, which catalyzes the breakdown of Ach has been demonstrated as a useful therapeutic approach for treating symptoms of Alzheimer's disease. The anticholinesterase activity of marine algae extract was tested against acetylcholinesterase (AChE) and butyrylcholinesterase (BChE), which are the main enzymes of Alzheimer's disease [52]. Among the marine algae species tested, *Fucus spiralis*, *Bifurcaria bifurcata* and *Cystoseira stricta* have potential anticholinesterase activity, which could be used in the future as therapeutic agents for Alzheimer's disease. Phlorotannin of the South African seaweed *Dictyota humifusa* was extracted to test for acetylcholinesterase inhibitory activity. The results showed that the extract was effective in inhibiting AChE. Moreover, the inhibitory effect on AChE and BChE activity was measured by Custodio et al. [53] suggested the potential therapeutic value of phenols contained in *Cystoseira tamariscifolia* and *Cystoseira nodicaulis*, as they were reported as potential anticholinesterase inhibitors. Further screening for AChE and BChE inhibitory activity on ethanol extracts of different marine algae showed that extracts from *Cystoseira usneoides* and *Fucus spiralis* were potent inhibitors [54]. Research also found that phenols found in *Ecklonia maxima*, *Ecklonia stolonifera* and *Ishige okamurae* can also inhibit AchE [55], as well as dieckol and phlorofucofuroeckol, two phlorotannins found in

the brown alga *Eisenia sp.* and *Ecklonia sp.*.

Phlorotannin-rich fractions extracted from *Cystoseira sedoides* (PHT-SED), *Cladostephus spposis* (PHT-CLAD) and *Padina pavonica* exhibited *in vivo* antioxidant activity in all three species, with higher activity for *Cystoseira sedoides*. Phlorotannin has been demonstrated to have potent antioxidant activity against free radicals, which is shown in anti-inflammatory tests to result in a dose-dependent reduction in paw edema and ear thickness in tested mice. The anti-inflammatory ability of phlorotannins is also due to inhibition of oxidative stress by reducing malondialdehyde (MDA) production, which is manifested by an increase in free radicals [56]. The anti-inflammatory ability of phlorotannins is also due to inhibition of oxidative stress by reducing malondialdehyde (MDA) production, which is manifested by an increase in free radicals [56]. Kim et al. [57] reported anti-inflammatory effects from phloroglucinol, a monomer of phlorotannin, derived from *Ecklonia cava*. The antioxidant mechanism of phloroglucinol may be due to the three hydroxyl groups existing in phloroglucinol that can react with ROS.

The properties exhibited by phlorotannins are diverse. It is reported that eckol isolated from the brown alga *E. cava* has potent antiproliferative activity against MCF-7 human breast cancer cells. Furthermore, dioxinodehydroeckol, a phloroglucinol derivative, can induce apoptosis through an NF-κB-dependent pathway. *In vivo* studies evaluated that dietary supplementation with brown algal polyphenols significantly reduced tumor proliferation in pre-tumor-bearing mice. These polyphenols suppress tumor progression in the body by inhibiting cyclooxygenase-2 activity and cell proliferation [58]. Phlorotannin extracts from *Fucus vesiculosus*, *Alaria esculenta*, *Ascophyllum nodosum*, *Laminaria japonica*, *Sargassum muticum* and *Bifurcaria bifurcata*, with other species, have been shown to reduce cell proliferation of many tumor cell lines, in a dose-dependent manner like human fibroblasts (HFF-1), gastric cancer cells (MKN-28), human colon cancer cell lines (HT-29 and Caco-2 cells), human hepatoma (BEL-7402), murine leukemia (P388), and murine teratocarcinoma (ATDC5) [54, 55].

Phlorotannins can also be used in cosmetics, as their compounds can prevent skin aging by inhibiting hyaluronidase, an enzyme that degrades hyaluronic acid present in the extracellular matrix. Phlorotannin derivatives such as fucophloroethol, fucodiphloroethol, fucotriphloroethol, 7-phloroeckol, phlorofucofuroeckol and bieckol/dieckol extracted from *Cystoseira noticaulis* have hyaluronidase activity, becoming potential candidates for the production of anti-aging creams [59]. Dieckol, eckol, bieckol and phlorofucofuroeckol A extracted from *Eisenia bicyclis* and *Ecklonia kurome* also exhibited strong inhibition of hyaluronidase. Phlorotannins extracted from *Ecklonia cava* and *Ecklonia stolonifera* also provide UV protection by reducing cell damage caused by solar radiation, making them good candidates for the development of sunscreens [60]. 7-phloroeckol and dieckol isolated from the brown alga *Ecklonia cava* have higher inhibitory activity on tyrosinase, an enzyme related to melanin hyperpigmentation of the skin. These compounds showed higher inhibitory activity than commercial inhibitors such as arbutin and kojic acid [57, 58]. Tyrosinase inhibition plays an important role in skin-related diseases and has been considered a whitening agent in cosmetics and clinical skin treatments [61].

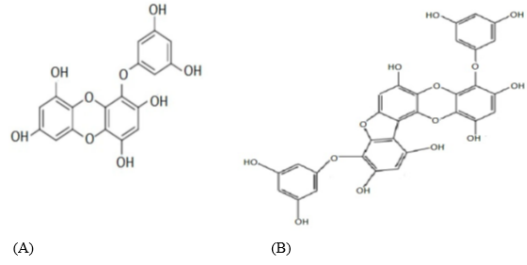

Fig. 2: Chemical structures of eckol (A) and plorofucofuroeckol (B), phlorotannins extracted from *Ecklonia cava* [37]

V. CONCLUSIONS

Brown algae offer a valuable source of bioactive compounds that can be explored for the development of natural agents with therapeutic applications. Among the compounds, fucoidans and phlorotannins are notable, although other substances are equally important such as vitamins and fucoxanthin. These compounds have attracted much interest from researchers in recent years due to their many medicinal properties. These bioactive compounds share common characteristics, including potent antioxidant effects achieved through the scavenging of reactive oxygen species (ROS) or the enhancement of intracellular antioxidant defenses. They also exhibit anticancer properties by inducing apoptosis in cancer cells, inhibiting metastasis and angiogenesis, and have anti-inflammatory effects by suppressing specific inflammatory mediators. Additionally, they demonstrate various other biological activities such as anti-obesity, anti-diabetic, anti-bacterial, anti-aging, and even anticoagulant/antithrombotic effects in the case of fucoidan. However, this type of algae can have many other applications, specifically in the fields of developing nutritional, cosmetic, and pharmaceutical products. With this review, the authors hope to increase awareness about the applications of algae-derived products, as well as contribute to promoting their commercial value.

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