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Bioactive Compounds and Chemodiversity in Tropical Brown Macroalgae: Insights from Padina, Sargassum, and Turbinaria

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ABSTRACT

Despite the extensive efforts made to isolate and identify novel compounds with potential medicinal, health, or pharmaceutical applications, very few compounds are available to use with real potency. Seaweeds are macroscopic and multicellular marine algae that provide essential sources of bioactive metabolites in the health, pharmaceutical, and other industries. Bioactive compounds from seaweeds include sulfated polysaccharides, phlorotannins, and diterpenes. These compounds have been reported with profound anti-viral, anti-proliferative, and anti-cancer properties. The present mini review elaborates on the pharmaceutical, health, and research potentials of different bioactive compounds produced by the tropical brown seaweeds (Phaeophyta) from the genera *Padina*, *Sargassum*, and *Turbinaria*.

INTRODUCTION

The seas and oceans contain over 2.2 million plant and animal species, including more than 150,000 macroalgae species that inhabit the intertidal zones and tropical waters **(Mora *et al.*, 2011)**. Macroalgae (or seaweeds) are multicellular, floating and submerged plants of shallow marine meadows. They are lacking true stems, roots and leaves, but possess a blade, a stipe and a holdfast that resembles leaf, stem and roots of terrestrial plants **(Saavedra, 2011)**. Macroalgae are salt tolerant because their cytoplasm osmolarity has adapted to the osmolarity of the seawater thus desiccation can be avoided. They contain photosynthetic pigments and use sunlight to produce carbohydrates and oxygen from carbon dioxide and water **(Bourgougnon & Stiger-Pouvreau, 2011)**. In addition, macroalgae are well known source of natural products **(Hayes, 2011; Andrade *et al.*, 2013; Belghit *et al.*, 2017)**. Brown macroalgae (Phaeophyceae) contribute to approximately 0.2% of the total number of macroalgal population in the seas **(Anyanwu *et al.*, 2018)**. Phaeophyceae from the genus *Padina*, *Sargassum*, and *Turbinaria* are frequently found in Indonesian waters, from Aceh to Papua **(Veron *et al.*, 2009; Setyawidati *et al.*, 2018)**. *Padina* species are widely distributed in the tropical and warm waters, where they are commonly found in intertidal and subtidal zones down to 100 meters of depth **(Silberfeld *et al.*, 2013)**. *Padina* can form a large community in the coral reef area, including the outermost coral reef slope **(Geraldino *et al.*, 2005; Silberfeld *et al.*, 2013; Wichachucherd *et al.*, 2014)**. Species of the genus *Sargassum* from the family of Sargassaceae are highly diverse, with over 400 described taxa, and are widely distributed in warm and temperate waters. They are known to contain high amounts of polysaccharides and polyphenolic compounds **(Holdt & Kraan, 2011; Li *et al.*, 2017; Yang *et al.*, 2019)**. *Sargassum* species are highly diverse, with over 400 described taxa and are widely distributed in warm and temperate waters. Subsequently, macroalga species of the genus *Turbinaria* can be found in the middle of the intertidal zone down to 30 meters of depth and commonly inhabit rocky intertidal areas that are exposed to water movement **(Guiry & Guiry, 2021)**. Unlike *Sargassum* that can be found in the temperate waters, *Turbinaria* are mainly found in tropical and subtropical areas such as the West Pacific, Mid-Pacific and the Indian Ocean **(Subaryono, 2011; Zubia *et al.*, 2020)**. Several species of *Turbinaria* can be found in Hawai'i (e.g.: O‘ahu, Moloka‘i, Lana‘i, Maui and Hawai‘i) and also in the South East Asian region, where they usually grow well in eutrophic environment **(Subaryono, 2011; Handayani, 2018; Zubia *et al.*, 2020; Guiry & Guiry, 2021)**.

As the largest archipelagic state with over 17,000 islands and more than two-thirds of its area covered by seas, Indonesia is bestowed as the second mega-biodiversity country right after Brazil **(Walujo, 2008; Rohman *et al.*, 2019)**. However, many of Indonesian marine regions are currently understudied, particularly regarding its macroalgae populations. Hence, there is a high possibility to discover new macroalgal species and active compounds in Indonesia **(United Nations, 2017)**. Therefore, the current review aimed to present the chemodiversity of *Padina*, *Sargassum* and *Turbinaria* found in Indonesian waters, emphasizing on their potential applications in various fields.

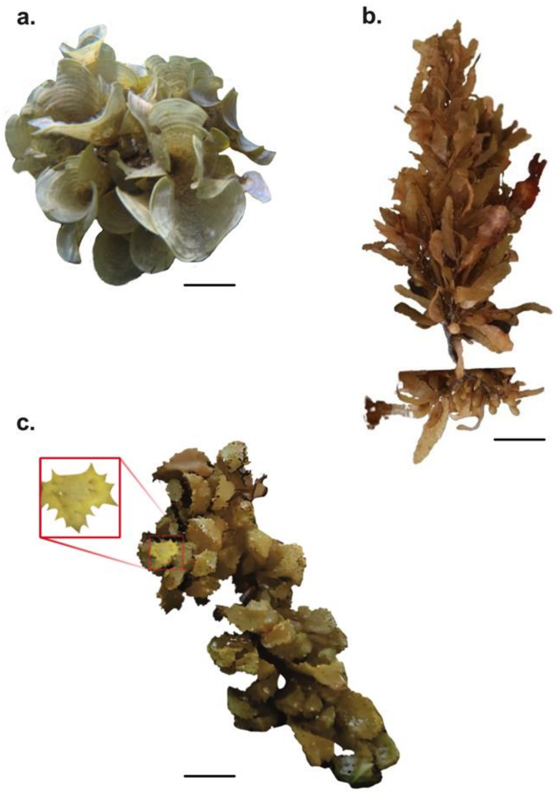

Fig. 1. Representative specimens of brown macroalgae (Phaeophyceae) from Indonesian waters. (a) Genus *Padina*, characterized by its fan-shaped thallus with concentric growth bands. (b) Genus *Sargassum* , featuring a bushy thallus with distinctive air bladders. (c) Genus *Turbinaria*, displaying a rigid and serrated thallus structure, with an inset showing a close-up of the spiny blade morphology (indicated by the red box). Scale bars represent 5cm.

DIVERSITY AND MORPHOLOGICAL TRAITS OF *PADINA*, *SARGASSUM* AND *TURBINARIA*

Macroalgae from the genus *Padina* is characterized by its "ear-like" blades with apical and circular boundaries, wherein a row of meristematic cells produces a parenchymal thallus (Fig. 1a). The thallus usually consists of two or more layers of cells, while the stipe (stem) consists of four layers or more. Calcification occurs on the upper surface of the thallus, and reproductive structures are visible in the bands above and, occasionally, on the lower surface of the thallus. Phaeophycean hairbands may also appear in several species **(Geraldino *et al.*, 2005; Win *et al.*, 2013)**. Recent classification system revealed that the genus *Padina* belongs to the order and family of Dictyotales and Dictyotaceae, respectively **(Guiry & Guiry, 2021)**. To date, there are 37 species recognized within the genus *Padina*, of which 24 species are distributed in the Pacific Ocean, whereas about 17 were recorded from the Indian Ocean **(Silberfeld *et al.*, 2013;**

Win *et al.*, 2013; Guiry & Guiry, 2021).

Species of the genus *Sargassum* are characterized by a holdfast attached to the substrate. Most *Sargassum* species possess numerous lateral leave-like blades (Fig. 1b). One of the most characteristic features of *Sargassum* is the presence of gas-filled bladders (pneumatocysts). These bladders are spherical or oval-shaped and provide buoyancy, allowing the algae to float in the water column. They also have vesicles that play an essential role in assisting the reproduction process that occurs laterally. The morphological characteristics of the genus *Sargassum* varies greatly depending on the respective aquatic environment **(Noiraksar & Ajisaka, 2009; Kim *et al.*, 2018)**, thus the identification through morphological traits should be confirmed by molecular methods **(Mattio & Payri, 2009; Mattio *et al.*, 2009; Tanniou *et al.*, 2014; Camacho *et al.*, 2015)**. There are currently more than 300 *Sargassum* species described globally. Among them, *S. muticum* is a native *Sargassum* species from Southeast Asia that can also be found in Indonesian waters **(Subaryono, 2011; Titlyanov *et al.*, 2017)**.

Turbinaria species are characterized by their robust and leathery thallus, which grows upright and forms dense clusters. The thallus is typically branched, often exhibiting a bushy or conical shape that resembles a small shrub or tree **(Alka *et al.*, 2017; Guiry & Guiry, 2021)**. Additionally, the fronds of *Turbinaria* are flattened and commonly arranged in a spiral or whorled pattern. These fronds can vary from lanceolate to ovate in shape and usually possess a tough, coriaceous texture, with edges that may be either serrated or smooth (Fig. 1c). Unlike some other genera of brown algae, *Turbinaria* lacks gas-filled bladders (pneumatocysts) for buoyancy and instead relies on its sturdy structure to remain upright.

Turbinaria species can reach a height of 2-20cm. The holdfast is upright, while the bottom is conical and irregular and bears a circular cross-section. The branched holdfasts are located in the main stipe area. Species of *Turbinaria* are usually yellowish-brown or dark brown and decorated with small black spots. *Turbinaria* species can withstand extreme environmental conditions by removing their thallus to recolonize during changing seasons **(Stiger & Payri, 1999; Zubia *et al.*, 2020; Guiry & Guiry, 2021)**. The thallus is strong and can survive extreme hydrodynamic conditions in the intertidal area by holding strongly/firmly to the substrate. *Turbinaria* is considered invasive in coral reef areas inhabited by *Sargassum* **(Guiry & Guiry, 2021)**. According to the database of AlgaeBase (www.algaebase.org), there are 21 currently listed *Turbinaria* species, which are taxonomically accepted and 11 of which can be found in Indonesian waters **(Handayani, 2018; Guiry & Guiry, 2021)**.

THE BIOACTIVE COMPOUNDS OF *PADINA* MACROALGA

Bioactive compounds extracted from *Padina* are widely used for various pharmaceutical applications, such as anticancer, antioxidant, antimitotic, and analgesic

(Jose *et al.*, 2015; Isnansetyo *et al.*, 2017; Ruslin *et al.*, 2018). Table (1) summarizes the compounds produced by several species of *Padina* and their bioactivities. Bioactive compounds from *Padina* species include flavonoids, a large group of phenolic compounds that possess chromophores with the ability to absorb UV radiation. This explains why some species of the genus *Padina* (e.g. *P. australis*) could potentially be utilized in the production of sunscreen cream in the cosmetic industry **(Svobodová *et al.*, 2003; Choquenet *et al.*, 2009; Saewan & Jimtaisong, 2013; Monsalve-Bustamante *et al.*, 2020; Nurjanah *et al.*, 2020)**. Furthermore, bioactive compounds from *P. australis* extract also exhibit antioxidant activity with IC_{50} value of approximately 87μmol L^{-1} **(Maharany *et al.*, 2017)**. Previous study by **Setha *et al.* (2013)** revealed that the antioxidant activity from *P. australis* could be influenced by the solvent used during the extraction process. The authors reported that the highest IC_{50} value (900mg L^{-1}) was obtained when the sample was extracted using hexane in contrast to those obtained using ethyl acetate and methanol (IC_{50} value: 483 and 201mg L^{-1}, respectively). Another *in vitro* experiment from **Djamaludin *et al.* (2019)** demonstrated that the extract derived from *P. australis* could present free radical scavenging with an IC_{50} value of 113.37mg L^{-1}. It was also reported that the extract of *P. australis* could inhibit the growth of cancer cell lines (MCM-B2 and K562), which further supports the potentiality of this genus as a source of potent natural anticancer drugs. Elucidation of new compounds and their activity in *Padina* therefore merits further investigation.

THE BIOACTIVE COMPOUNDS OF *SARGASSUM* MACROALGA

Macroalgae from the genus *Sargassum* are commonly consumed in many Asian countries such as Indonesia, China, the Philippines, South Korea, North Korea, and Malaysia. Due to their high content of vitamins, minerals, unsaturated fatty acids, protein, and dietary fiber; species of *Sargassum* have also recently been used for culinary industry in Japan and China **(Raghavendran *et al.*, 2005; Khaled *et al.*, 2012; Dore *et al.*, 2013; Shao *et al.*, 2015; Fan *et al.*, 2017; Usoltseva *et al.*, 2017; Yang *et al.*, 2019)**. Apart from being a food ingredient, *Sargassum* is also beneficial for pharmaceutical applications. The bioactive compounds in *Sargassum* are often used as natural antioxidants, anticancer, anti-inflammatory, anti-obesity, anti-angiogenic, anti-viral and neuroprotective agents **(Holdt & Kraan, 2011; Vieira *et al.*, 2017; Vieira *et al.*, 2018; Sun *et al.*, 2019)**. Findings from previous studies emphasize the potential applications of *Sargassum* not only in food and pharmacological industries, but also in the field of aquaculture **(Bazes *et al.*, 2009; Pangestuti & Kim, 2011; Plouguerné *et al.*, 2012; Jose *et al.*, 2015; Isnansetyo *et al.*, 2017; Ruslin *et al.*, 2018; Pinteus *et al.*, 2021)**. The bioactive compounds produced by the macroalgae of the genus *Sargassum* have been widely studied. Numerous *Sargassum* species display bioactivity effects such as antioxidant and antibacterial activities. Concerning antioxidant activity, some *Sargassum* species contains phenolic compounds, such as phlorotannins. These compounds are widely distributed in the brown algae (Phaeophyta) lineages and are known to show very strong antioxidant properties, even stronger than those of the red (Rhodophyta) and green algae (Chlorophyta) **(Raghavendran *et al.*, 2005; Holdt & Kraan, 2011; Khaled *et al.*, 2012; Gany *et al.*, 2015; Li *et al.*, 2017; Kim *et al.*, 2018; Gager *et al.*, 2020)**.

Table 1. Chemodiversity of bioactive compounds from *Padina* spp. and their bioactivities

No.	Species	Compound	Bioactivity	Reference
1	*P. australis*	Phlorotannins, flavonoids	Anti-radiation	**(Maharany *et al.*, 2017)**
2	*P. tetrastromatica*	Alginate acids,	Anticoagulant, antiviral, antibacterial	**(Ponnanikajamideen *et al.*, 2014)**
3	*P. australis*	Polyphenol, carotene, polysaccharide sulfate, omega-3 fatty acids, and anthocyanin	Anticancer	**(Djamaludin *et al.*, 2019)**
4	*Padina* sp.	Fatty acids and anthocyanin.	Antibacterial, anticancer, antioxidant and in overcoming the gland disorder and decreasing high blood pressure	**(Setha *et al.*, 2013, El Maghraby and Fakhry, 2015, Gany *et al.*, 2015)**
5	*Padina* sp.	Alkaloids, phenols, terpenoids, steroids	Antibacterial (*S. aures, E. Coli, C. albicans*)	**(Handayani *et al.*, 2019)**
6	*Padina* sp.	Fucoidan	Anticancer	**(Isnansetyo *et al.*, 2017)**
7	*P. australis*	Fucoidan, fucoxanthin (carotenoids), pheophytin A and pheophorbide A	Anti-neuroinflammatory, antioxidant, Anticholinesterase	**(Gany *et al.*, 2015)**
8	*P. tetrastromatica*	Sulfated polysaccharides (SPS), Ethanolic sulfated polysaccharides (ESPS), Ethanolic sulfated polysaccharides – column purified (ESPS-CP), flavonoid, tannin, glycosides, steroid, terpenoid.	Antioxidant, antimitotic	**(Jose *et al.*, 2015)**
9	*Padina* sp.	Flavonoid	Analgesic effect	**(Ruslin *et al.*, 2018)**
10	*P. boergesenii*	Triterpenoids, phenols	Antioxidant, anti-angiogenesis, anti-inflammatory	**(Rajamani *et al.*, 2018, Nurjanah *et al.*, 2020)**
11	*P. pavonica*	Phenolic acids, flavonoids, triterpenoids, glycosides, amino acids, tannins, coumarin	Antibacterial, antioxidant, anticancer, antifungal	**(Khaled *et al.*, 2012, Sahayaraj *et al.*, 2012, El Maghraby and Fakhry, 2015, Al-Enazi *et al.*, 2018, Benita *et al.*, 2018)**
12	*P. tetrastromatica*	Sulphated polysaccharide ascophyllan, polysaccharide	Anti-inflammatory, antiviral	**(Karmakar *et al.*, 2010, Mohsin and Kurup, 2011, Nair *et al.*, 2019)**

		phlorotannin		
13	*P. boryana*	Sulfated polysaccharides, phenols, flavonoids, fucoidan, fucose, galactose, mannose, glucose and uronic acid residues.	Anticancer, antibacterial, antiviral, antioxidant	**(Setha *et al.*, 2013, Sameeh *et al.*, 2016, Usoltseva *et al.*, 2018, Jayawardena *et al.*, 2020)**

Terpenoids, particularly the carotenoid group, also possess antioxidant properties. Carotenoid are the second most abundant pigment in brown algae after chlorophyll. Carotenoids found in brown algae are β-carotene and xanthophylls (e.g. fucoxanthin, zeaxanthin, and lutein) **(Peng *et al.*, 2011; Vieira *et al.*, 2017; Vieira *et al.*, 2018)**. Carotenoids play a significant role in protecting photosynthetic cells against photooxidative effects by scavenging singlet oxygen molecules and peroxyl radicals **(Balasubramaniam *et al.*, 2020; Nie *et al.*, 2021)**.

Phenolic compounds from *Sargassum* generally contain at least one hydroxyl (i.e.-OH) group, although most of them are polyphenols. The role of phenolic compounds as antioxidants is associated with the conjugative bonds in the benzene aromatic ring and the number of -OH functional groups **(Tierney *et al.*, 2010; Tanniou *et al.*, 2014; Sari *et al.*, 2019)**. There are two mechanisms for the radical scavenging of phenolic compounds, namely the H atom donor and electron transfers. Phenolic compounds such as α-tocopherol, hydroxytyrosol, caffeic acid, and the gallic acid could act as H donors, while kaempferol and resveratrol are the examples of electron donors **(Chew *et al.*, 2008; Maadane *et al.*, 2015; Gan *et al.*, 2017)**.

Carotenoids are known to dampen singlet oxygen (singlet oxygen quenching) through the C=C conjugative bonds in the polyene-base skeleton carbon chain. Carotenoid pigments can also react with peroxyl radical scavenging, forming peroxyl carotenoid radicals, and turning them into carotenoid peroxides, which are less reactive and easier to decompose, thus greatly reduces their harmful effects to the living cells **(Chew *et al.*, 2008; Maadane *et al.*, 2015; Gan *et al.*, 2017)**. *Sargassum* extracts also display anticancer properties **(Usoltseva *et al.*, 2017; Usoltseva *et al.*, 2018)**. Anti-cancer agents can have several mechanisms of action, targeting cell growth, cell cycle, cell death, DNA repair, cell migration and invasion, as well as angiogenesis. They are commonly used as cytotoxic or cytostatic drugs that terminate or inhibit the proliferation of cancer cells. However, such drugs are not only toxic to the cancer cells but also to regular cells that rapidly proliferate within the body, such those found in the spinal cord, gastrointestinal epithelium, and hair follicles. It is also worth noting that several bioactive compounds from *Sargassum* species (e.g. sodium alginate and some sulfated compounds) can inhibit the growth of Hep-2 and MCF-7-bound cancer **(Mary *et al.*, 2012)**. Furthermore, **Méresse *et al.* (2020)** reviewed that the xanthophyll fucoxanthin also displays several anticancer activities. The chemodiversity and biological activities of bioactive compounds reported from the genus *Sargassum* are summarized in Table (2).

Apart from exhibiting prospective antioxidant effects, bioactive compounds from the genus *Sargassum* could also be used as antimicrobial and antifungal agents. Indeed, there is a growing body of evidence showing that the phenolic compounds from *Sargassum* species have antibacterial activity against Gram-positive and Gram-negative bacteria **(Vijayabaskar & Shiyamala, 2011; Khaled *et al.*, 2012)**. Moreover, several studies revealed that the extract from *Sargassum* can control or prevent bacterial growth and reproduction, especially pathogenic bacteria **(Vijayabaskar & Shiyamala, 2011; Khaled *et al.*, 2012; Mayer *et al.*, 2013; Tanniou *et al.*, 2014; Vatsos & Rebours, 2015)**. The phenolic compounds could impact the bacterial cells by damaging their membrane, inhibit the virulence factors (e.g. the production of enzymes and toxins), and suppress the formation of bacterial biofilm. The bioactive compounds from this genus, especially the phenolic compounds, are usually available in high quantity, thus highlighting the potentiality of *Sargassum* as a source for producing valuable antibacterial agents **(Selma *et al.*, 2009; Taskin *et al.*, 2010; Stengel *et al.*, 2011; Chojnacka *et al.*, 2012; Tanniou *et al.*, 2014; Vatsos & Rebours, 2015)**.

Table 2. Chemodiversity of bioactive compounds from *Sargassum* spp. and their bioactivities

No.	Species	Compound	Bioactivity	Reference
1.	*S. fusiforme*	Sulfated polysaccharides (fucoidan)	Antiviral	**(Sun *et al.*, 2019)**
2.	*S. confusum*	Oligosaccharides	Anti-diabetic	**(Yang *et al.*, 2019)**
3.	*S. polycystum*	Alginate, fucoidan	Antioxidant	**(Raghavendran *et al.*, 2005)**
4.	*S. latifolium*	Crude extract	Antibacterial	**(Dashtiannasab *et al.*, 2012)**
5.	*S. thunbergii*	Polysaccharides	Anti-tumor	**(Jin *et al.*, 2017)**
6.	*S. fusiforme*	Polysaccharides	Anti-tumor	**(Fan *et al.*, 2017)**
7.	*S. horneri*	Polysaccharides	Antioxidant	**(Shao *et al.*, 2015)**
8.	*S. angustifolium*	Polysaccharides	Anti-inflammatory	**(Borazjani *et al.*, 2018)**
9.	*S. vulgare*	Fucan (SV1) sulfated polysaccharides	Antioxidant	**(Dore *et al.*, 2013)**
10	*S. duplicatum*	Fucoidan	Anti-cancer	**(Usoltseva *et al.*, 2017)**

BIOACTIVE COMPOUNDS OF *TURBINARIA* MACROALGA

Macroalgae species from the genus *Turbinaria* produce several bioactive compounds with potential applications in the food and pharmaceutical industries **(Alka *et al.*, 2017)**. *Turbinaria conoides*, *T. decurens*, and *T. ornata* are traditionally consumed by population of the Eastern region of Indonesia **(Anggadiredja, 2009)**. In food industries, these macroalgae can be used to formulate healthy diets due to relatively high content of iron (893.7 ± 210.5μg g^{-1} dry weight) and many valuable bioactive compounds (alginic acid, fucoidan, mannitol, and laminarin) **(Zubia *et al.*, 2003; Stiger-Pouvreau *et al.*, 2016)**. Furthermore, silver- and gold-nanoparticles can be prepared using extracts from this genus for further application in biomedical applications, for instance, as antitumor and antipathogen agents **(Kayalvizhi *et al.*, 2014; Alka *et al.*, 2017)**. Additionally, phenolic compounds from *T. ornata* could be utilized as natural antibiotic and antimicrobial agents **(Vijayabaskar & Shiyamala, 2011; Alka *et al.*, 2017; Rajkumar & Bhavan, 2017)**. Moreover, *T. ornata* exhibits interesting utilization potential as a source of natural pesticide for mosquito larval due to its ability to synthesize silver nanoparticles (AgNPs) with bioactive compounds. These compounds can interfere with the functioning of cellular proteins and can induce subsequent changes in cellular chemistry **(Deepak *et al.*, 2017)**.

The macroalgae from the genus *Turbinaria* display a variety of bioactivities that could be beneficial for the pharmaceutical industries, for instance, as raw materials for developing antibacterial, antioxidant, anticoagulant, anti-elastase, anti-tyrosinase, and anticancer products **(Subaryono, 2011; Vijayabaskar & Shiyamala, 2011; Rajeshkumar *et al.*, 2013; Kayalvizhi *et al.*, 2014; Marudhupandi *et al.*, 2015; Alka *et al.*, 2017; Isnansetyo *et al.*, 2017; Nurrochmad *et al.*, 2018)**. The presence of phenols, tannins, and fucoxanthin in *Turbinaria* supports the potential utilization of this genus as a prospective source of antioxidants. Indeed, tannins are primarily known as potent antioxidants or free radical scavengers **(Tierney *et al.*, 2010; Gupta & Abu-Ghannam, 2011; Gager *et al.*, 2020)**, while also containing antibacterial activities **(Taskin *et al.*, 2010; Vijayabaskar & Shiyamala, 2011; Vatsos & Rebours, 2015; Ponnan *et al.*, 2017)**. The fucoxanthin of the genus *Turbinaria* could also serve an important role as antioxidant due to the reactivity of the oxygen atoms in fucoxanthin to radicals **(Peng *et al.*, 2011, Méresse *et al.*, 2020)**. For instance, the fucoxanthin derived from *T. decurrens* has shown promising results as a natural antioxidant **(Nurrochmad *et al.*, 2018)**. Table (3) shows the chemodiversity of bioactive compounds from several *Turbinaria* species and their biological activities.

Table 3. Chemodiversity of bioactive compounds from the *Turbinaria* genus and their bioactivities

No.	Species	Compound	Bioactivity	Reference
1	*T. conoides*	Fucoidan, fucosterols, laminaran, polysaccharides, sulfated polyscchares, phloroglucinol	Antibacterial, antioxidant, anti-proliferative, anti-angiogenic, and anti-tyrosynase	**(Sheu *et al.*, 1999, Chattopadhyay *et al.*, 2010, Marudhupandi *et al.*, 2015, Ponnan *et al.*, 2017, Sari *et al.*, 2019)**
2	*T. ornata*	Sulphated polysaccharide	anti-inflammatory and anti-arthritic	**(Zubia *et al.*, 2003, Ananthi *et al.*, 2017)**
		Carbohydrates, fucoidan, alkaloids, saponin, phenolics, flavonoids, tannins, cumarin,	Antioxidant, anti-haemolysis, anti-inflammatory, antibacterial	**(Holdt and Kraan, 2011, Rajkumar and Bhavan, 2017,**

		steroids, and terpenoids, sulfoquinovosyl-monoacyl-glycerols		**Jayawardena *et al.*, 2019, Lee *et al.*, 2020)**
		Silver nanoparticles	Larvicidal	**(Deepak *et al.*, 2017)**
3	*T. decurrens*	Fucoxanthin	Antioxidant, Anti-colagenase, Anti-elastase, Anti-tyrosinase	**(Nurrochmad *et al.*, 2018)**

Antibacterial activity from the extracts of *T. ornata* showed strong antibacterial activity when tested against eight pathogens, *Aeromonas hydrophila*, *Bacillus subtilis*, *Enterococcus faecalis*, *Escherichia coli*, *Klebsiella pneumoniae*, *Proteus vulgaris*, *Pseudomonas aeruginosa*, and *Shigella flexusus* Stugine **(Vijayabaskar & Shiyamala, 2011)**. This antibacterial activity is probably related to the active compounds present in the extract, which are derived from various secondary metabolisms, such as tannins, saponins, terpenoids, phenols, flavonoids, and coumarin. For example, the polyphenols from methanolic extract of *T. ornata* have a strong antibacterial activity with a larger spectrum than that of the reference compound ampicillin **(Vijayabaskar & Shiyamala, 2011)**. Indeed, in another study, it has been shown that the presence of polyphenols was detected in the extracts of *T. ornata* **(Rajkumar & Bhavan, 2017)**, such as saponin and flavonoids. Saponin has various medicinal properties including hypo-cholesterolemic, anti-carcinogenic, anti-inflammatory, anti-microbial and antioxidant properties. The latter, flavonoids, are polyphenol compounds that also have anti-inflammatory, antiviral, antioxidant, anti-cancer, and scavenger of reactive oxygen species (ROS) activities **(Ren *et al.*, 2003; Svobodová *et al.*, 2003; Kim *et al.*, 2005; Gul *et al.*, 2017; Ruslin *et al.*, 2018)**. In depigmentation activity, flavonoids can directly inhibit tyrosinase activity in the melanogenic pathway. The functional structure analysis of flavonoids shows that these molecules consist of α-keto groups with a promising activity in inhibiting tyrosinase, due to the similarity between the dihydroxy phenyl groups in DOPA and α-keto content.

It is also worth noting that phenolic compounds, polyphenols, and tannins are relatively abundant and diverse across algae species, and relatively easy to identify. Therefore, they can be used as chemical markers in taxonomic classification of different algal groups **(Chojnacka *et al.*, 2012; Mayer *et al.*, 2013; Rajeshkumar *et al.*, 2013; Alka *et al.*, 2017)**.

CONCLUSION

The present review summarized the potential exploitation of bioactive compounds extracted from the brown macroalgae *Padina*, *Sargassum*, and *Turbinaria*, frequently found in Indonesian waters. The bioactive compounds are known, yet more prospection should be done to isolate a high-producing species. Furthermore, this review could be useful for future work considering the potential application of these three genera of

Phaeophyceae in various fields, such as biotechnology, biomedicine, pharmaceuticals, neutraceticals, and aquaculture.

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