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Bioactive properties of brown seaweed, *Sargassum wightii* and its nutritional, therapeutic potential and health benefits: A review

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Abstract

Seaweed, *Sargassum wightii* is a brown macroalgae (Phaeophyceae) rich in bioactive compounds such as fucoxanthin, flavonoids, sterols, sulfated polysaccharides, polyphenols, proteins and beta-carotene pigments. The purpose of the present review is to focus and discuss the usefulness of bioactive compounds of *S. wightii* to humans and animals as they exhibit diverse therapeutic activities like analgesic, anti-inflammatory, antioxidant, anti-cancer, anti-microbial, anti-tumor, immune-modulatory, anti-coagulant, hepatoprotective, anti-viral activities, etc.

The present review clarifies the nutritional, therapeutic potential and health benefits of brown seaweed algae. Nowadays, attention is being paid on the use of seaweeds for human health, food, cosmetics, energy, fertilizer and in the field of aquaculture, poultry and other industries due to their nutritive value. It is being utilized in the wastewater treatments to reduce nitrogen and phosphorus-containing compounds. This review is an attempt to highlight the nutritional and commercial value of *Sargassum wightii*, due to its bioactive compounds related to health status and disease prevention in humans and animals.

Key words: Bioactive compounds, Phaeophyceae, Seaweeds, *Sargassum wightii*

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Introduction

India is a tropical country surrounded by the Indian Ocean in the south, the Arabian Sea in the west and the Bay of Bengal in the east. More than 7500 km of Indian coastline is covered with sandy and rocky beaches, mudflats, estuaries, and lagoons. Such a suitable natural environment in India manifests the luxuriant growth of diverse seaweed flora. Seaweeds are commonly known as benthic marine macroalgae; they do not possess roots, stems and leaves, instead their body is in the form of a thallus. Macroalgae are economically, ecologically, and biologically significant and are a much-diversified group of plants. More than 10,000 species of marine algae have been reported from all over the world. According to the Food and Agriculture Organization (FAO) data, the global seaweed output (both aquaculture and wild) has increased nearly three-fold from 118,000 tonnes to 358,200 tonnes from 2000 to 2019 (FAO, 2021). In the Asian countries, 99% of seaweeds are cultured artificially. Earlier, Krishnan and Narayanakumar (2010) reported that the six states of India including Gujrat-250,000 tonnes; Tamil Nadu (250,000 tonnes); Andhra Pradesh (5,000 tonnes); Maharashtra and Andaman and Nicobar Islands (300,000 tonnes) have the total estimated of seaweed production of approximately 1,005,000 tonnes.

In India, rich seaweed beds occur around Visakhapatnam on the eastern coast, Nagapattinam, Gulf of Mannar, Thiruchendur, Tuticorin, and Kerala on the southern coast; Veraval and Gulf of Kutch on the western coast and in Andaman and Nicobar Islands, and Lakshadweep Island; Satheesh and Wesley, 2012; Jeeva *et al.,* 2012; Manilal *et al.,* 2009). The natural environment of Indian coastal regions like Tamil Nadu coast, Gujarat coast, Lakshadweep, Andaman Nicobar Islands, and Gulf of Mannar are well known for the abundant growth of seaweeds, especially brown seaweed that belong class Phaeophyceae. According to Jayaprakash *et al.* (2017), the coastal regions of India consist 844 species of red seaweeds (Rhodophyceae), 216 species of green seaweed (Chlorophyceae), and 194 species of brown seaweeds (Phaeophyceae). All these species are well known for their biological properties as they are rich in polysaccharides, phytochemical derivatives, and bioactive compounds (Pal *et al.,* 2014; Almeida *et al.,* 2020).

Sargassum, a genus of brown algae, is represented by thirty-eight species that are widely distributed in India and several other parts of Asian countries. It is used as animal feed, food ingredients and fertilizers. Among all species, *Sargassum wightii* is one of the important species of the family Sargassaceae and Order Fucales, which is a macroscopic, multicellular, photosynthetic, non-vascular, and pelagic marine species having a wide range of bioactive properties (Devi *et al.,* 2013). It grows up to 20-30 cm in height and is typically brownish in color due to the presence of fucoxanthin, beta-carotene and chlorophyll a and c pigments. It is found in shallow coastal waters (Deepak *et al.,* 2018) in the littoral and sublittoral areas of the tropical region throughout the year. They grow and develop on rocky, coral, or other suitable substrates available for their attachment (Mishra *et al.,* 2009). Brown algae, *Sargassum* and *Turbinaria* are of alginate in India. *S. wightii* contain flavonoids in large amount that promote its antioxidant activity and justify its medicinal and industrial applications (Meenakshi *et al.,* 2009; Marimuthu *et al.,* 2012; Rajivgandhi *et al.,* 2021). Based on the literature, Aquaculture and Fisheries Resources data bases *S. wightii* is a rich source of natural bioactive compounds like: antioxidants, flavonoids, polyphenols alkaloids, etc., that can be used as an alternative food components and supplements to keep humans and animals healthy (Deepika, 2017; Almeida *et al*., 2020).

Bioactive compounds of *S. wightii*: Seaweeds contain various bioactive compounds like carbohydrates, proteins, fatty acids, phenols, flavonoids, saponins, coumarins, vitamins, minerals, quinines and tannins (Prabha *et al.,* 2017; Grace *et al.,* 2021). According to Sujana and Vijay Kumar (2020), *S. wightii* is a source of maximum phytochemical constituents that include carbohydrates with higher content of polysaccharides and lower content of monosaccharides. The polysaccharides present in *S. wightii* are fucoidans and alginic acid which are strong antioxidants. Fucoidan is a water-soluble polysaccharide consisting mainly of fucose and sulphate groups with other minor components of monosaccharides such as galactose, xylose, glucuronic acid and glycosyl, etc. Beside a substantial percentage of L-fucose and sulphate esters, it contains several monosaccharides like galactose, xylose and glucuronic acids, etc. (Deepika, 2017). Fucoidan isolated from different *Sargassum* species is extensively studied due to their varied biological activities, including antioxidant, immune-modulatory, anti-inflammatory, antivirus, antitumor, anticoagulant, antithrombotic and blood lipids reducing properties as well for their therapeutic potential in surgery (Sun *et al.,* 2018).

Sargassum wightii contain high amount of polyunsaturated fatty acids (PUFA) as compared to other macroalgal species. The presence of large amount of omega 3, 6 and 9 classes of fatty acids in *S. wightii* are important precursors to other substances in the body, those involved in regulating blood pressure, oxidative injury and inflammatory responses (Prabhakar *et al.,* 2011). These fatty acids are essential nutritional components for humans because they play a major role in the prevention of cardiovascular diseases, osteoarthritis, and diabetes. (Newton, 1996; Dawczynski *et al.,* 2007).

Anti-microbial activity of *S. wightii*: Bacterial and viral infection plays a major role in spreading infectious diseases that lead to mortality and morbidity among organisms worldwide. To overcome these problems, seaweeds have received attention as herbal remedies in recent years. Studies are going on to prevent pathogenic diseases in humans and animals through the application of *S. wightii* as a potent antimicrobial herbal medicine (Sangeetha *et al.,* 2017; Magesh *et al.,* 2020). The polysaccharides content exhibited antimicrobial activity of *S. wightii* against bacterial pathogens is shown in Table 1.

Anti-oxidative property of *S. wightii*: In normal conditions, cells are able to balance the production of oxidants and anti-oxidants. Any imbalance in the natural byproduct of oxidation, *i.e.,* reactive oxygen species (ROS) causes oxidative damage of biomolecules *viz.* RNA and DNA (Moncada *et al.,* 1991; Fatima *et al*., 2007) ultimately leading to cell death. Antioxidants like thiols or ascorbic acid, *i.e.,* vitamin C inhibit oxidation of another molecule and terminate these chain reactions. Oxidative damages can be prevented by consuming natural anti-oxidants in foods (Moon and Shibamoto, 2009; Yuvaraj and Venkatesan, 2014; Ravi *et al.,* 2016). In this regard, recent studies have revealed that brown seaweed, *S. wightii* is the best natural source of phytochemicals with excellent anti-oxidant properties which improves antibacterial activity too (Rajivgandhi *et al.,* 2021). Therefore, seaweeds like *S. wightii* is an important marine algal species being rich in sulphated polysaccharides shows a wide spectrum of biological properties, such as free radical scavenging agents and a potential source of antioxidants (Josephine *et al.,* 2008). It is reported that such seaweed cells have some specific bioactive compounds and protective mechanism (Fig. 1) as they grow in harsh conditions where they are exposed to the light and high oxygen concentrations that may lead to the formation of free radicals and other strong oxidizing agents (Manivannan *et al.,* 2008).

Marine plants has proved to be a richest source of known and novel bioactive compounds as they are able to produce a great variety of secondary metabolites characterized by a broad spectrum of biological activities (Marimuthu *et al*., 2012). Extensive screening of these macroalgae has led to chemical determination of compounds, including phenolic compounds, terpenes, enzymes, fatty acids, sterols, polysaccharides, alkaloids, and flavonoids. More recent reports have revealed that bioflavonoids, polyphenolic flavonoids present in *S. wightii* in comparison to red and green algae possess rich sources of antioxidant compounds (Meenakshi *et al.,* 2009; Seenivasan et al., 2012; Bhaigyabati and Usha, 2013). Potential anti-oxidants and anti-cholinesterase activity of *S. wightii,* exclusively based on terpenoid compounds that suppress the enzymes and then reduce the activity (Syad *et al*.,2013). As shown in Fig. 1, the sulphated polysaccharides, phenolic acid, organosulfur compound, vitamins, minerals and flavonoids content of *S. wightii* are potential natural antioxidants that play a major role in combating the oxidative stress related diseases in fish and shellfish (Devi *et al.,* 2014). The cell wall of *S. wightii* are rich in fucoidan which is a fucose containing sulphated polysaccharides which act as ROS scavengers (Josephine *et al.,* 2008). Hence, the composition of polysaccharides extraction of *S. wightii* depends on the methodology, however, it can be always a prospective source of bioactive pharmacophore and can be used as supplements for humans and aquatic animals to prevent the occurrence of reactive oxygen species induced diseases, such as hypertension, diabetes and inflammatory disorders (Maneesh *et al.,* 2017).

Anti-inflammatory properties of *S. wightii*: Inflammation is a reaction of tissues towards infection, irritation, or foreign substances linked with the pathogenesis of many diseases such as cancer, neurodegenerative diseases, arthritis, and other metabolic disorders. The crude extracts of *Sargassum* species containing sulphated polysaccharide and purified compounds have been reported as a potential anti-inflammatory agent (Hong *et al.,* 2011; Wen *et al.,* 2016; Wu *et al.,* 2016). Raman *et al.* (2014) reported the maximum anti-inflammatory activity of *S. wightii* is that it prevents prostaglandin biosynthesis through inhibiting cyclooxygenase (COX) enzymes. Maneesh *et al.* (2017) documented the presence of electronegative groups in *S. wightii* extract that potentially coordinates with the COX active sites by ion pairing, thereby preventing the synthesis of prostaglandins and exhibiting more inhibitory effects in comparison to commercially available synthetic anti-inflammatory drugs. The anti-inflammatory agents present in macroalga can successfully reduce inflammation and preventing several diseases as shown in Fig. 2. Being a prolific source of natural analgesic and anti-inflammatory agents, polysaccharides and other compounds of *S. wightii* have recently gained special attention against indiscriminate use of commercially available analgesics and non-steroidal anti-inflammatory drugs (Ravi *et al.,* 2016). The insoluble gelatinous carbohydrate has been reported to the level of collagen metabolism concurrently reducing the inflammation and inflammatory associated disorders (Dar *et al.,* 2007; Sarithakumari *et al.,* 2013; Yuvaraj and Venkatesan, 2014).

Anti-nociceptive and anti-coagulative properties of *S. wightii*: Anti-nociceptive activity is a response against harmful or toxic substances or injuries by the sensory nervous system of the body. There is a strong link between anti-nociceptive action and inflammatory pain. Tissue injury and inflammation occurs simultaneously thereby increasing pain sensation. The free nerve endings of nociceptor sensory neurons possess terminal receptors and ion channels to detect molecular mediators released by the immune system during inflammation. In this way, neuroimmune interaction produces sensitization and pain at the centre of inflammation. The sulphated polysaccharides of *S. wightii* have the ability to block the migration of immune cells (Neutrophils) towards the centre of injury or inflammation by which these compounds reduce the intensity of pain and show the anti-nociceptive properties (Yuvaraj *et al.,* 2013; Yuvaraj and Venkatesan, 2016). Such non-steroidal herbal drugs help in relieving aches, pains, and fevers. *S. wightii* can be a substitute to reduce the oxidative stress produced by the neurotoxin and a novel drug for neurodegenerative diseases (Rajeswari and Jeyaprakash, 2018).

According to Rout *et al.* (2020), the presence of phytochemical compounds like phenols, phytosterols, flavonoids, carotenoids, fucoxanthin, fucoidan, and tannins in *S. wightii* contribute as anti-oxidant, anti-inflammatory, and neuroprotective agents. The anti-coagulant activity of brown macroalgae fucoidan depends on its molecular weight, proportion of mono sugars and level of sulphation. The most active fucoidan fractions predominantly consist sulphated fucose residues, that are known for their inhibitory activity of thrombin that is the mechanism for inhibition of coagulation (Shanmugam and Mody, 2000). Galacto-

Table 1: Anti-microbial activity of *S. wightii* against bacterial pathogens

Bacterial pathogens	Sources
Humans: *Streptococcus mutans*	Magesh *et al.* (2020)
Humans: *Staphylococcus aureus, Vibrio cholerae, Shigella dysenteriae, Shigella boydii, Salmonella paratyphi, Pseudomonas aeruginosa, Klebsiella pneumoniae.*	Vallinayagam *et al.* (2009)
Humans: *Staphylococcus aureus, Streptococcus spp., Bacillus subtilis, Micrococcus luteus, Proteus mirabilis, Pseudomonas aeruginosa, Klebsiella pneumonia, Escherichia coli.*	Christobel *et al.* (2011)
Aquatic animals: *Vibrio fischeri, Vibrio alginolyticus, Vibrio harveyi.*	
Humans: *Aeromonas hydrophila, Bacillus subtilis, Escherichia coli, Enterococcus faecalis, Klebsiella pneumoniae, Proteus vulgaris, Pseudomonas aeruginosa, Shigella flexneri, Staphylococcus aureus.*	Vijayabaskar and Shiyamala, 2011
Humans: *Pseudomonas aeruginosa, Salmonella paratyphi, Erwinia amylovora, Enterobacter aerogenes, Proteus vulgaris, Klebsiella pneumonia, Escherichia coli, Staphylococcus aureus, Bacillus subtilis, Enterococcus faecalis.*	Rosaline *et al.* (2012); Sangeetha *et al.* (2017)
Humans: *Escherichia coli, Klebsiella pneumoniae, Vibrio cholerae, Proteus proteus, Shigellasonnei, Pseudomonas aeruginosa, Salmonella typhi* and *Klebsiella* spp.	Marudhupandi and Kumar, (2013); Sangeetha *et al.* (2017)
Microorganisms: *Escherichia coli, Bacillus cereus, Bacillus subtilis, Klebsiella pneumoniae, Staphylococcus aureus, Streptococcus pyogenes, Salmonella typhimurium* and *Proteus vulgaris*	Raman *et al.* (2014)
Humans: *Bacillus cereus*	Venugopal *et al.* (2014)
Aquatic animals: *Aeromonas hydrophila, Enterobacter aerogenes, Flavobacterium* spp., *Micrococcus* spp., *Pseudomonas fluorescens, Streptococcus* spp., *Vibrio* spp., *Edwardsiella tarda* and *Proteus* spp.	Devi *et al.* (2014)
Humans: *Staphylococcus aureus, Bacillus subtilis, Enterococcus faecalis, Pseudomonas aeruginosa*, *Erwinia* spp., *Salmonella paratyphi B, Enterobacter aerogenes, Proteus vulgaris, Klebsiella pneumoniae* and *Escherichia* coli.	Rosaline *et al.* (2016)
Aquatic animals: *Aeromonas hydrophila, Pseudomonas fluorescens, Bacillus subtilis, Staphylococcus aureus, Micrococcus luteus.*	Rani *et al.* (2017)

fucoidans having 50-100,000 Da molecular are considered as potential anti-coagulants because due to high molecular weight they have high affinity for anti-thrombin, which may inhibit coagulation of blood. Eluvakkal *et al.* (2014) elucidated that due to the presence of high content of mono sugars and sulphate, the molecular weight of fucoidan increases along with alginate imparting property to *S. wightii.* Currently, heparin and its derivatives are used as anti-coagulant agents in clinical laboratories inhibiting the clotting processes by removing calcium from the blood without damaging the blood cells considering it to be advantageous, but it may also cause serious side-effects. Hence, sulphated polysaccharides-rich extracts of *S. wightii* act as anti-platelet and/or anti-thrombotic agents having anti-coagulant potential. According to Manoj *et al.* (2013) and Achary *et al.* (2014), the anti-coagulant activity of sulphated polysaccharide (SPS) in *S. wightii* encourages the development of anti-coagulant agent as an alternative drug for blood coagulation disorders. More detailed studies are required on the purification and characterization of SPS from brown algae, *S. wightii.*

Application of *S. wightii* in cancer treatment: Oncogene is a gene that gets mutated or expressed at abnormally high rate converting a normal cell into a cancerous cell. Mutated oncogenes are stimulated on exposure to chemicals, environmental or viral carcinogens which leads to change in cell and produce proteins that are either wrongly expressed within their normal cell or expressed in an inappropriate tissue causing cellular proliferation, thereby resulting in cancer formation (Fig. 3). Epidemiological studies strongly suggest that consuming cancer-preventive herbs and plants may reduce the process of carcinogen-induced risk (Kumar *et al.,* 2011) and will be a viable cancer prevention approach. Brown algae are gaining importance due to the proven anti-proliferative properties of sulphated polysaccharides and fucoidans which are abundant in these macroalgae (Gutierrez-Rodriguez *et al.,* 2018). Polysaccharides and other compounds of *S. wightii* can be a new source of anti-cancer agent along with chemotherapeutic drugs (Fig. 3). According to Manojkumar and Seema (2013), the constituents of *S. wightii* polysaccharides have an inhibitory effect during progression, promotion stage of cancer and work as chemopreventive agent. Moreover, Begum *et al.* (2017) emphasized that the alcohol, alkenes and aliphatic are functional group in the seaweed extracts which account for biological properties of *S. wightii* as these compounds interact with P13K protein, known for its contribution in promotion of proliferation and evasion of apoptosis in cancer cells. However, the presence of

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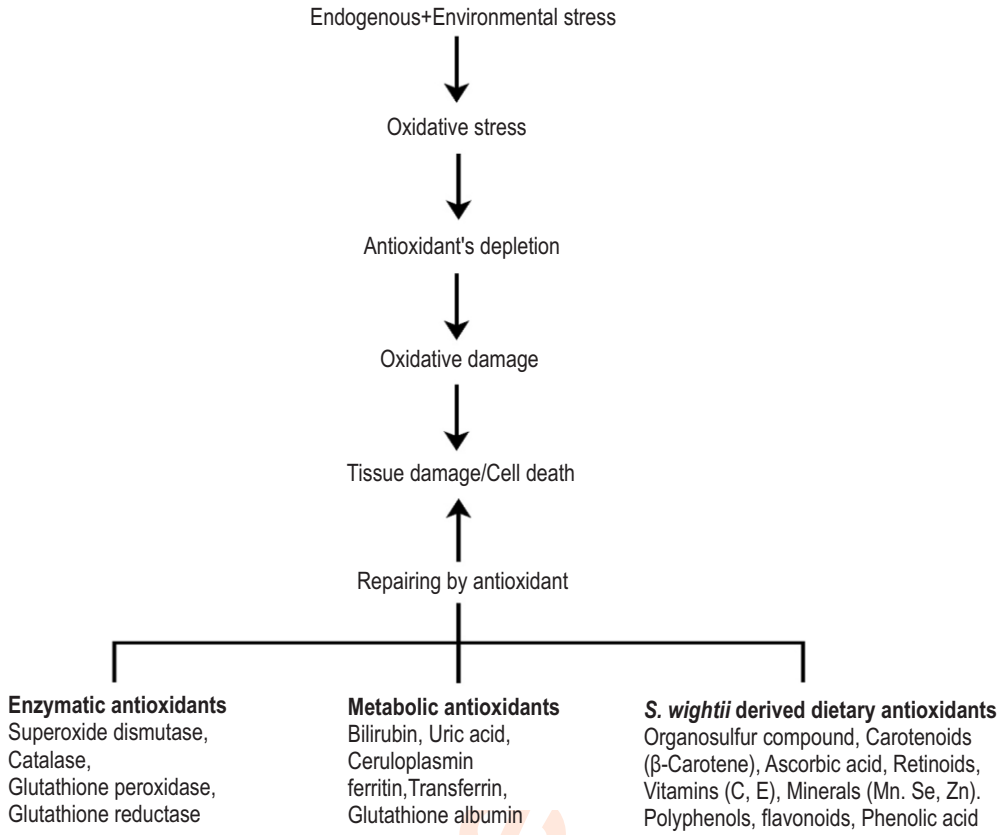

Fig. 1: Role of *S. wightii* bioactive compounds and its action mechanisms in response to stress.

such functional groups in *S. wightii* extract usually interact with P13K gene and inhibit proliferation of cancerous cells. Cell transduction is a fundamental process in the development and progression of cancer. Anti-angiogenesis and anti-tumor properties of a polysaccharide, phenol and proteins reported in *S. wightii* is a therapeutic strategy for cancer, including breast cancer (Anjana *et al*., 2014; Vaikundamoorthy *et al.,* 2018). Gunasekaran *et al.* (2017) observed an effective therapeutic role of *S. wightii* against liver cancer. Even the MgO synthesized nanoparticles from *S. wightii* also showed significant cytotoxicity against lung cancer cell lines (Pugazhendhi *et al.,* 2019). Phytochemical antioxidants are known for their protective role against carcinogens and cytotoxic damages of the normal cells during cancer therapy (Sujana and Vijay Kumar, 2020).

Anti-lithiatic activity of *S. wightii*: The formation of stone in the urinary system, *i.e.,* in the kidney, ureter, and urinary bladder or in the urethra is called urolithiasis (Vijaya *et al.,* 2013). Lithiasis is a kidney stone or urinary calculi formed when salts or minerals normally found in urine turns into crystals. Normally, these crystals are small and can pass out of the body without causing any harm, however, when urine contains more of these crystals and lack substances that prevent aggregation, these crystal's gradually increase in size, become much larger and are termed as stone. The process of lithiasis passes through urinary saturation, supersaturation, nucleation, crystal growth, aggregation of crystals, crystal retention, and finally stone formation. Such stone formation can be inhibited in initial stages by consuming herbal anti-lithiatic substances. The secondary metabolites such as phlorotannins are obtained from *S. wightii* which has the potential to reduce supersaturation of urine with divalent calcium and oxalate cations and lower their levels and aggregations (Sujatha *et al.,* 2015). The phlorotannin-rich extract of *S. wightii* can prevent stone formation and dissolve already formed stones, and may serve as natural preventive measure. (Li *et al.,* 2009; Sujatha *et al.,* 2015).

Role of *S. wightii* in diabetes: Digestion of starch in mammals occur via α-amylase and α-glucosidase present in the small intestines whereas abrupt elevation of glucose in the blood occurs due to hydrolysis of carbohydrates. α-glucosidase is a membrane-bound enzyme present in the epithelium of small intestine that yield glucose after hydrolysing maltose and isomaltose produced by action of α-amylase. Therefore, inhibition of carbohydrate hydrolytic enzymes α-amylase and α-glucosidase activities can profoundly reduce post-prandial increase of blood glucose and glucose level can be managed at borderline in diabetic patients. The bioactive compounds isolated

Fig. 2: Mechanism of inflammation and action of any anti-inflammatory agents.

from *S. wightii* have been found to significantly inhibit the activities of hydrolytic enzymes and control blood sugar level (Ravi *et al.,* 2016; Lakshmanasenthil *et al.,* 2018). Begum and Hemalatha (2017) also found the inhibiting potential of α-amylase and α-glucosidase present in the ethanolic extract of *Sargassum* spp. to control hyperglycaemia. It is clear that the excess of blood sugar causes glycation of haemoglobin, resulting in the formation of reactive oxygen species (Bailey and Day, 1989) leading to prolonged inflammation, delayed wound healing, micro and macro-vascular changes due to denaturation of proteins. The rich flavonoids and polyphenols derived from *S. wightii* are efficient free radical scavengers and antioxidants (Marimuthu *et al.,* 2012; Mohapatra *et al.,* 2016) as they may lower the chances of hypercholesterolemia and associated cardiovascular complications. In recent years, sulphate polysaccharides of microalgae are reported to have positive effect in the prevention and treatment of metabolic syndrome, and they mainly come from seaweeds. Especially, sulfated-polysaccharides viz. Fucoidans are water-soluble, highly sulfated-polysaccharides possess capacity to reduce serum cholesterol and triglyceride, low-density lipoprotein, and increase high-density lipoprotein (Preetha and Devaraj, 2010).

Role of *S. wightii* in aquaculture: Studies have reported that herbal medicines play a major role in enhancing the immune function of aquatic animals like fish, shrimp and crabs, and effectively promote anti-viral, anti-bacterial, anti-parasitic activities of immune system. For cost-effective aquaculture practices, *S. wightii* can be considered as a potential ingredient to increase the growth performance (Bindu and Sobha, 2004) and disease resistance in aquatic animals (Sivagnanavelmurugan *et al.,* 2015). Immuno-stimulators are agents that trigger non-specific immune response and enhance disease resistance. Seaweeds are rich source of immunostimulants like alginate, carrageenan, laminarin and fucoidan, etc. (Meenakshi *et al.,* 2009; Traifalgar *et al.,* 2012). *S. wightii* extract are in rich water-soluble sulphated fibrous polysaccharides. Especially, fucoidan is well known for its biological properties that include immunostimulant (Kitikiew *et al.,* 2013), disease resistance (Immanuel *et al.,* 2012b), growth stimulation in shrimps (Traifalgar *et al.,* 2012) and finfish (Tuller *et al.,* 2014; Prabu *et al.,* 2016). Since polyunsaturated fatty acids (PUFAs) of *S. wightii* are essential fatty acids for animals, they enhance the growth and development in fishes and animals (Ishwarya *et al.,* 2018; Sajina *et al.,* 2019), at the same time they may decrease the level of

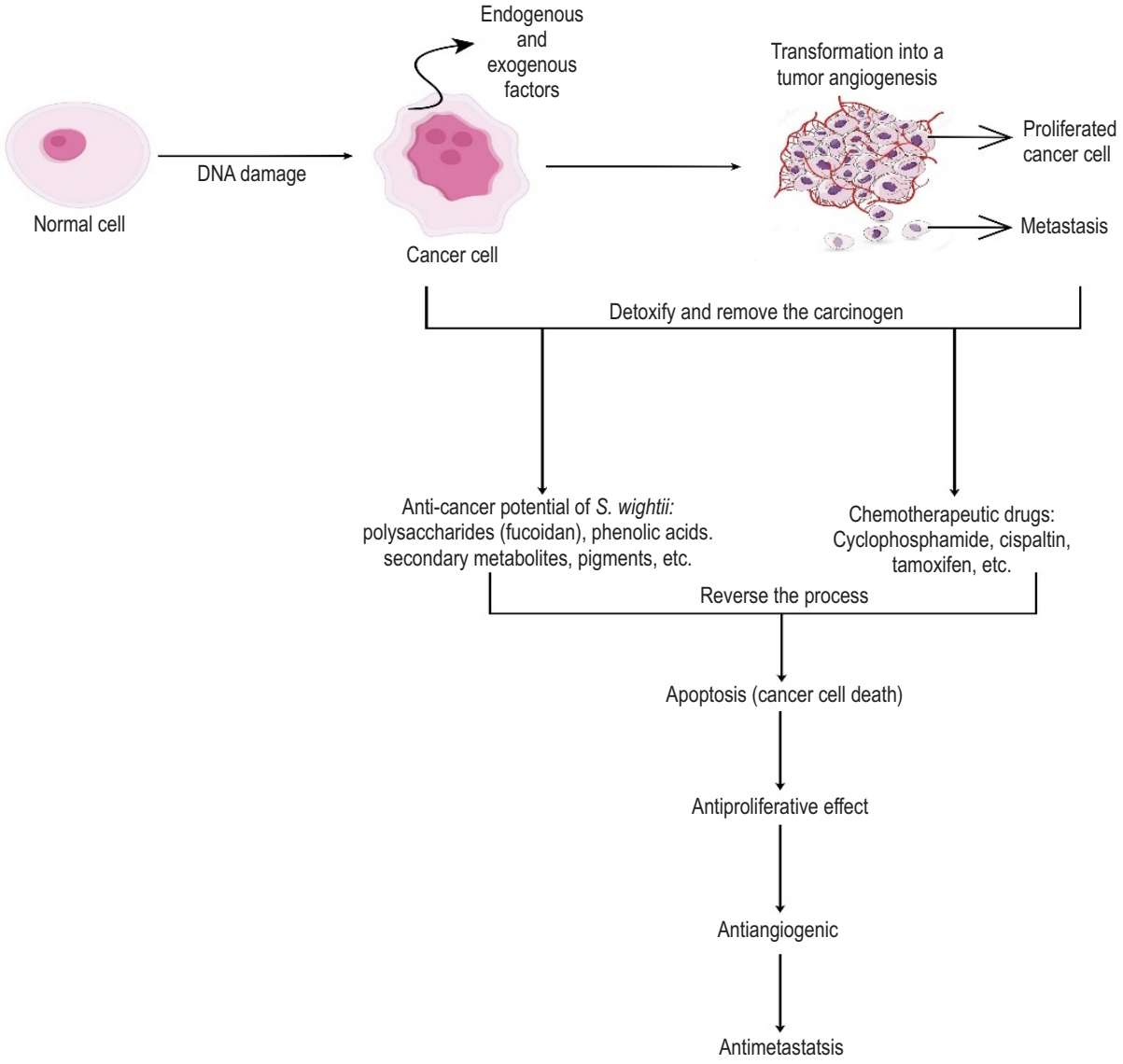

Fig. 3: Mechanism of anti-cancer drugs and seaweeds in order to block cancer progression.

cytokines, which is necessary to shift the function of lymphocytes from the cell mediated response to antibody-mediated immune response (Evans *et al.,* 2000).

The therapeutic mechanisms of S wightii bioactive compounds has been focused by many authors as a dietary supplement to enhance the immunity in fish and shellfish against the prevailing diseases in aquaculture as illustrated in Fig. 4. Dietary consumption of *S. wightii* exhibits anti-bacterial, insecticidal and immuno-stimulatory effects on tiger shrimp, *Penaeus semisulcatus* and freshwater fish like *Labeo rohita*, *Catla catla* etc. (Sivagnanavelmurugan *et al.,* 2012; 2014; Gora *et al.,* 2018). Further, it can be used in fish diet and shellfish culture as an alternative to drugs, antibiotics and immunostimulants. The environmental factors usually influence the toxicity of pollutants in vertebrates and high temperature of impoundments supress the immune function of fish (Fatima *et al.,* 2001). *S. wightii* supplemented fish diet may compensate such problems in polluted ponds because *S. wightii* are found in abundance along the Indian coastline has proved as a viable source of immunostimulant to prevent and control diseases in aquatic animals (Huxley and Lipton, 2009; Immanuel *et al.,* 2012a; Sinurat *et al.,* 2016; Ishwarya *et al.,* 2018).

According to Kanimozhi *et al.* (2013) and Sajina *et al.* (2019), fish diet supplemented with *S. wightii* for carps and mullet worked as an immunostimulant which can be used to control bacterial infections in fish and promote the health status of intensive

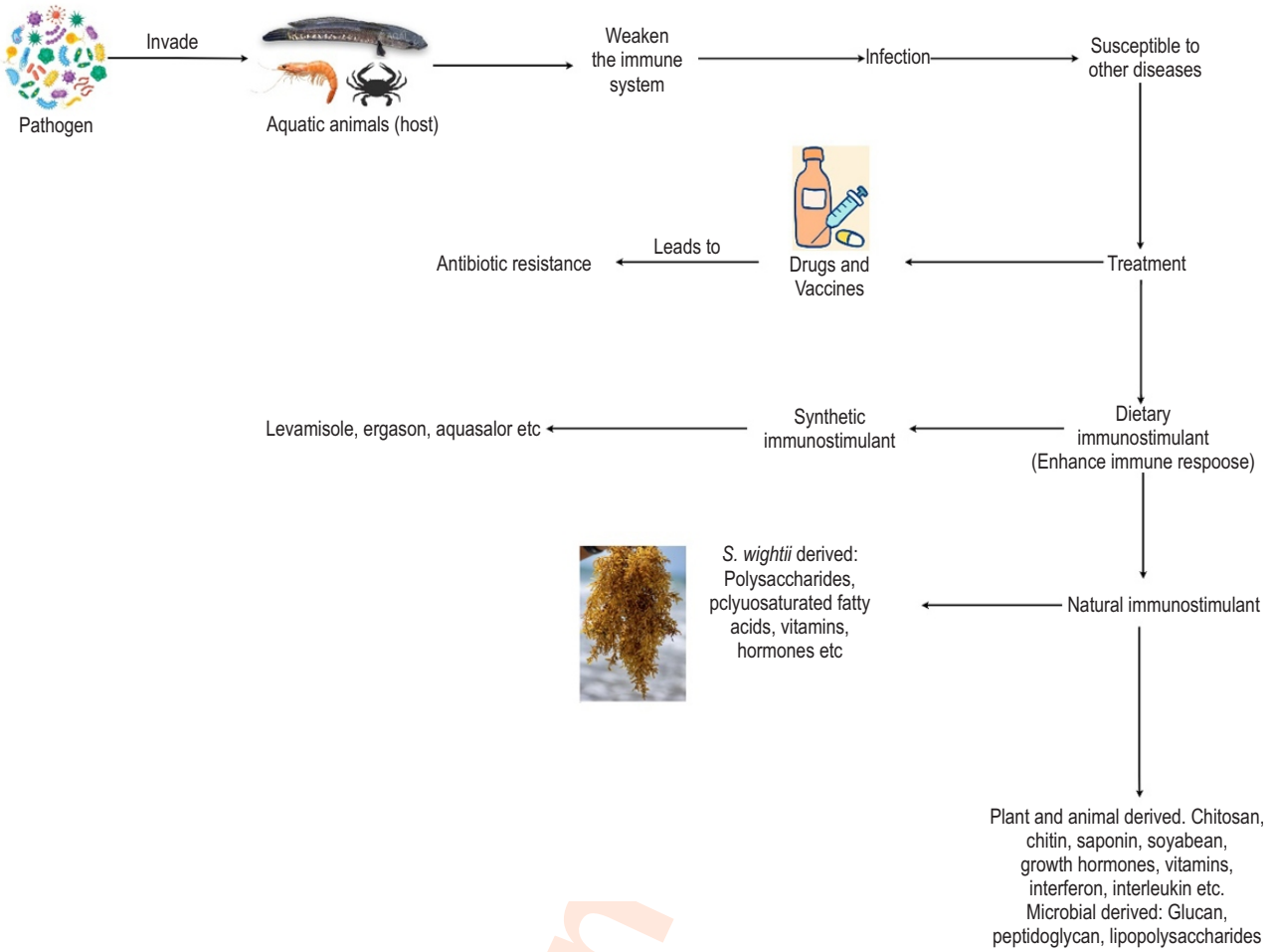

Fig. 4: Immunostimulatory compounds of *S. wightii* and their action in aquatic animals.

finfish aquaculture (Felix *et al.,* 2004). Therefore, it can be inferred that the dietary phyto-extracted or crude bioactive compounds of *S. wightii* can be supplemented with fucoidan to enhance the growth and health performance of fish by increasing their growth, immunity and resistance against oxidative stress. The use of fucoidan as immunostimulant extracted from seaweed is considered as a more environmentally friendly approach and has been proven to enhance the innate immunity of aquatic vertebrates and their resistance against pathogens. However, the mechanism of immunostimulation by fucoidan and its effect on the immune system of fish is not clearly known and needs more detailed study in this respect. Few studies have hypothesized that the immunostimulatory action of fucoidan in fish follows the same mechanism as other polysaccharides (Gora *et al.,* 2018). Keeping in view the potential antimicrobial and anti-oxidant activity of *S. wightii*, it can be used in the aquaculture industry for the procurement of bacterial infection as well for the treatment of bacterial diseases in fish and shellfish. Aquaculture industries may also be revolutionized by using the nanoparticles supplemented diet to culturable fish extracted from *S. wightii* (Shambhulingaiah *et al.,* 2021; Nirmalkar *et al.,* 2022). However, further researches have to be done on dietary intake of plant extracted nanoparticles supplemented feed for better growth and disease resistance in culturable fishes.

Industrial applications of *S. wightii*: Organic farming is production of organic food items without using conventional pesticides and synthetic fertilizers. Due to the presence of potassium chloride in seaweed, they are used as bio-fertilizers or manure in many countries for cultivating crops and for plants that require growth promoters, including potash, sulphate, trace elements and radicals (Kumar *et al.,* 2012; Muthezhilan *et al.,* 2014; Baliah *et al.,* 2017; Uthirapandi *et al.,* 2018). Liquid fertilizer extracted from *S. wightii* when used as foliar spray has been found to induce faster growth and yield in vegetables, fruits, orchards and horticulture plants (Sivasankari *et al.,* 2006; Jothinayagi and Anbazhagan, 2009; Divya *et al.,* 2015). Liquid fertilizer prepared from *S. wightii* contain auxin, cytokinin, gibberellins and minerals in high concentrations and if used in appropriate quantity can enhance crop yield (Sridhar and Rengasamy, 2010; Vijayanand

et al., 2014). Other micronutrients like iron, manganese, zinc, copper, and macronutrients like nitrogen, phosphorus, potassium, calcium, vitamins and growth promoting constituents present in liquid fertilizer accelerates chlorophyll biosynthesis as well adding organic matter, minerals, metabolites and amino acids to soil greatly influence the soil microbial dynamics and enhance soil condition (Divya *et al.,* 2015; Baliah *et al.,* 2017).

S. wightii extracts can be used as biocides against plant and animal pathogens (Kumar *et al.,* 2012; Asaraja and Sahayaraj, 2013; Suganya *et al.,* 2019; Niroja and Kannan, 2020). *S. wightii* has a unique ability to act as a bio sorbent, since the cell wall structure shows biosorbent properties as it can bind with the ions, metals and toxic substances present in sewage and, therefore, can be used in the biosorption-based bioremediation techniques. (Vijayaraghavan and Prabu, 2006; Vijayaraghavan *et al.,* 2006; Tamilselvan *et al.,* 2012; Kumar *et al.,* 2014). Besides, bioremediation and biocidal effect, *S. wightii* components showed a wide range of possible applications in food and dye industries due to decreasing number of legally permitted food additives as they are suspected to be carcinogenic promoters. Therefore, more and more innovations are coming through to find the solutions and the researchers are focusing on natural and plant-based dyes. This has increased the market demand for natural pigments including seaweed's pigments. Seaweed's bioactive compounds are applied as nutritional supplements, food coatings and foods additives in functional food products. *S. wightii* extracted dye caused no stress to aquatic animals (Vigneshpriya *et al*., 2020) and its polysaccharides contain highest prebiotic activity in comparison to other algal species and exhibited enhanced inhibitory potential against gut pathogens (Praveen *et al*., 2019). Hence, it has been traditionally used in food and animal feed due to their color properties. This is the reason; *S. wightii*-derived carotenoids are extensively used in food and beverages industries (Pangestuti and Siahaan, 2018). In addition, the high mineral content of this macroalgae fulfill the nutritive requirements of cattle and simultaneously enhances the milk production (Singh *et al*., 2017). There are many dyes which have been developed from mother-nature but one which still needs to be researched on is brown seaweed.

The use of *S. wightii* in bioenergy plants may overcome high fuel prices (Dubey *et al.,* 2015) and it has been observed that photosynthetic pigments-chlorophyll, carotenoids and fucoxanthin perform as a sensitizer in the solar cell, which is a low-cost and eco-friendly alternative to metal complexes (Anand and Suresh, 2015). *S. wightii* is a good source of nutrients like crude protein, crude fibre calcium, iron, and sulphur, etc. Moreover, water and oil holding capacity of *S. wightii* is directly related to its protein, fibre, and flavonoid contents that increase its antioxidant potential and provide a genuine reason to use it as a fibre rich ingredient in food products and nutraceuticals (Kumar *et al.,* 2021). For health benefits, *S. wightii* can be infused for better flavour in coffee-based beverages (Kumar *et al.,* 2019) and as a spice in the diet to improve the taste and nutritive value of food (Sumayaa and Kavitha, 2015). *S. wightii* supplemented feed to poultry has been found to promote growth and meat scoring due to essential amino acids, minerals, and long chain fatty acids (Kumar, 2018) present in it.

There are number of research work have been done on seaweed and concluded with special reference to its nutritive value, medicinal property, pharmaceutical, pharmacology and industrial uses. Seaweeds are being studied due to its biologically active compounds and concluded with its nutritional, therapeutic, pharmacological and industrial values. This review is an attempt to provide information in all fields related to the uses and application of especially brown seaweed, *S. wightii* both in past and present scenario.

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References

Achary, A., K. Muthalagu and M.S. Guru: Identification of phytochemicals from *Sargassum wightii* against *Aedes aegypti*. *Int. J. Pharm. Sci. Rev. Res.,* **29**, 314-319 (2014).

Almeida, A., M. Sole, A.M. Soares and R. Freitas: Anti-inflammatory drugs in the marine environment: Bioconcentration, metabolism and sub-lethal effects in marine bivalves. *Environ. Pollut.,* **263**, 114442 (2020).

Anand, M. and S. Suresh: Marine seaweed *Sargassum wightii* extract as a low-cost sensitizer for ZnO photoanode based dye-sensitized solar cell. *Adv. Nat. Sci. Nanosci. Nanotechnol.,* **6**, 035008 (2015). https://doi.org/10.1088/2043-6262/6/3/035008

Anjana, A., K.F.H.N. Ahamed, V. Ravichandiran and M.A. Sumithra: Anticancer activity of *Sargassum wightii* Greville on Dalton's ascitic lymphoma. *Chin. J. Nat. Med.,* **12**, 114-120 (2014).

Asaraja, A. and K. Sahayaraj: Screening of insecticidal activity of brown macroalgal extracts against *Dysdercus cingulatus* (Fab.) (Hemiptera: Pyrrhocoridae). *J. Biopestic.,* **6**, 93-203 (2013).

Bailey, C.J. and C. Day: Traditional plant medicines as treatments for diabetes. *Diabe. Care,* **12**, 553-564 (1989).

Baliah, N.T., S.L. Priyatharsini, C.P. Sheeba and V. Raja: Effect of seaweed liquid fertilizer of *Sargassum wightii* on the yield characters of *Abelmoschus esculentus* (L.) Moench. *Int. J. Adv. Res. Sci. Eng. Technol.,* **4**, 4511-4518 (2017).

Begum, S.M.F.M. and S. Hemalatha: Characterization, *in silico* and *in vitro* determination of antidiabetic and anti-inflammatory potential of ethanolic extract of *Sargassum wightii*. *Asian. J. Pharm. Clin. Res.,* **10**, 297-301 (2017).

Begum, S.M.F.M., S. Priya, R. Sundararajan and S. Hemalatha: Novel anticancerous compounds from *Sargassum wighti*: *In silico* and *in vitro* approaches to test the antiproliferative efficacy. *J. Adv. Pharm. Res.,* **7**, 272-277 (2017).

Bhaigyabati, T. and K. Usha: Preliminary phytochemical screening and antioxidant activity of various extracts of *Sargassum wightii* Greville. *Int J. Pharma. Bio. Sci.,* **2**, 60-69 (2013).

Bindu, M.S. and V. Sobha: Conversion efficiency and nutrient digestibility of certain seaweed diets by laboratory reared *Labeo rohita* (Hamilton). *Indian J. Exp. Biol.,* **42**,1239-1244 (2004).

Christobel, G.J., A.P. Lipton, M.S. Aishwarya, A.R. Sarika and A. Udayakumar: Antibacterial activity of aqueous extract from selected macroalgae of southwest coast of India. *Seaw. Res. Utiln.,* **33**, 67-75 (2011).

Dar, A., H.S. Baig, S.M. Saifullah, V.U. Ahmad, S. Yasmeen and M. Nizamuddin: Effect of seasonal variation on the anti-inflammatory activity of *Sargassum wightii* growing on the N. Arabian Sea coast of Pakistan. *J. Exp. Mar. Biol. Ecol.,* **351**, 1-9 (2007).

Dawczynski, C., R. Schubert and G. Jahreis: Amino acids, fatty acids, and dietary fibre in edible seaweed products. *Food Chem.,* **103**, 891-899 (2007).

Deepak, P., V. Amutha, R. Birundha, R. Sowmiya, C. Kamaraj, V. Balasubramanian, G. Balasubramani, D. Aiswarya, D. Arul and P. Perumal: Facile green synthesis of nanoparticles from brown seaweed *Sargassum wightii* and its biological application potential. *Adv. Nat. Sci. Nanosci. Nanotechnol.,* **9**, 1-10 (2018).

Deepika, R.C.: Fucose-containing sulfated polysaccharides from *Sargassum wightii*: Extraction technology and anticancer activity assessment. I*nt. J. Pharm.Chem. Biol. Sci.,* **7**, 279-284 (2017).

Devi, J.A.I., G.S. Balan and K. Periyanayagam: Pharmacognostical study and phytochemical evaluation of brown seaweed *Sargassum wightii*. *J. Coast. Life Med.,* **1**, 178-183 (2013).

Devi, K.N., T.T.A. Kumar and T. Balasubramanian: Antibacterial and antioxidant effects from seaweed, *Sargassum wightii* (Greville, 1848) against marine ornamental fish pathogens. *J. Coast. Life Med.,* **2**, 773-783 (2014).

Divya, K., N.M. Roja and S.B. Padal: Effect of seaweed liquid fertilizer of *Sargassum wightii* on germination, growth and productivity of brinjal. *Int. J. Adv. Res. Sci. Eng. Technol.,* **2**, 868-871 (2015).

Dubey, K.K., A.K. Dhingra and S. Rana: Optimisation of process parameters for enhanced biobutanol production from *Sargassum wightii* hydrolysate. *Int. J. Energy Technol. Policy,* **11**, 303-311 (2015).

Eluvakkal, T., N. Shanthi, M. Murugan and A. Kumar: Extraction of antibacterial substances, galactofucoidan and alginate successively from Gulf of Mannar brown seaweed *Sargassum wightii* Greville ex. *J. Agardh. Indian J. Nat. Prod. Resour.,* **5**, 249-257 (2014).

Evans, R.P., P. Zhu, C.C. Parrish and J.A. Brown: Lipid and amino acid metabolism during the early development of marine fish. In: Seafood in Health and Nutrition-Transformation in Fisheries and Aquaculture: Global Perspectives (Ed.: F. Shahidi). Science Tech Publishing Company, St. John's, New-Foundland, pp. 477-493 (2000).

FAO: FAO Yearbook. Fishery and Aquaculture Statistics 2019/FAO annuaire. Statistiques des pêches et de l'aquaculture 2019/FAO anuario. Estadísticas de pesca y acuicultura 2019. Rome/Roma (2021).

Fatima, M., I. Ahmad, R. Siddiqui and S. Raisuddin: Paper and pulp mill effluent-induced immunotoxicity in freshwater fish *Channa punctatus* (Bloch). *Arch. Environ. Contam. Toxicol.,* **40**, 271-276 (2001).

Fatima, M., S. N. M.Mandiki, J. Douxfils, F. Silvestre, P. Coppe and P. Kestemont: Combined effects of herbicides on biomarkers reflecting immune–endocrine interactions in goldfish: Immune and antioxidant effects. *Aquat. Toxicol.,* **81**, 159-167 (2007).

Felix, S., P.H. Robins and A. Rajeev: Immune enhancement assessment of dietry incorporated marine alga *Sargassum wightii* (Phaeophyceae/Punctariales) in tiger shrimp *Penaeus monodon* (Crustacea/Penaeidae) through prophenoloxidase (proPO) systems. *Indian J. Mar. Sci.,* **33**, 361-364 (2004).

Gora, A.H., N.P. Sahu, S. Sahoo, S. Rehman, S.A. Dar, I. Ahmad and D. Agarwal: Effect of dietary *Sargassum wightii* and its fucoidan-rich extract on growth, immunity, disease resistance and antimicrobial peptide gene expression in *Labeo rohita*. *Int. Aquat. Res.,* **10**, 115-131 (2018).

Grace, M.P., R.M. Rajithra, V. Ilakkiya and B. Dhanalakshmi: Qualitative analysis of phytochemical studies on *Sargassum wightii* and *Padina gymnospora*. *EPRA Int. J. Res. Dev.,* **6**, 161-175 (2021).

Gunasekaran, S., V.K. Thirumalairaj, L.S. Pitchai, S. Shanmugasokan, R. Yesudas and A. Chacko: Screening of *in vitro* cytotoxic activity of brown seaweeds against hepatocellular carcinoma. *J. Appl. Pharm. Sci.,* **7**, 51-55 (2017).

Gutierrez-Rodriguez, A.G., C. Juarez-Portilla, T. Olivares-Banuelos and R.C. Zepeda: Anticancer activity of seaweeds. *Drug. Discov.,* **23**, 434-447 (2018).

Hong, D.D., H.M. Hien and H.T.L. Anh: Studies on the analgesic and anti-inflammatory activities of *Sargassum swartzii* (Turner) C. Agardh (Phaeophyta) and *Ulva reticulata* Forsskal (Chlorophyta) in experiment animal models. *Afr. J. Biotechnol.,* **10**, 2308-2314 (2011).

Huxley, V.A.J. and A.P. Lipton: Immunomodulatory effect of *Sargassum wightii* on *Penaeus monodon* (Fab.). *Asian J. Anim. Sci.,* **4**, 192-196 (2009).

Immanuel, G., M. Sivagnanavelmurugan, V. Balasubramanian and A. Palavesam: Sodium alginate from *Sargassum wightii* retards mortalities in *Penaeus monodon* postlarvae challenged with white spot syndrome virus. *Dis. Aquat. Org.,* **99**, 187-196 (2012a).

Immanuel, G., M. Sivagnanavelmurugan, T. Marudhupandi, S. Radhakrishnan and A. Palavesam: The effect of fucoidan from brown seaweed *Sargassum wightii* on WSSV resistance and immune activity in shrimp *Penaeus monodon* (Fab). *Fish Shellfish Immunol.,* **32**, 551-564 (2012b).

Ishwarya, R., B. Vaseeharan, S. Subbaiah, A.K. Nazar, M. Govindarajan, N.S. Alharbi, S. Kadaikunnan, J.M. Khaled and M.N. Al-Anbr: *Sargassum wightii*-synthesized ZnO nanoparticles-

from antibacterial and insecticidal activity to immunostimulatory effects on the green tiger shrimp *Penaeus semisulcatus*. *J. Photochem. Photobiol. B, Biol.,* **183**, 318-330 (2018).

Jayaprakash, K., N. Sri Kumaran and Swarnakala: Seaweed research in India - a novel domain in marine biotechnology. *Int. J. Pharm. Sci. Res.,* **8**, 3231-3241 (2017).

Jeeva, S., J. M. Antonisamy, C. Domettila, B. Anantham and M. Mahesh: Preliminary phytochemical studies on some selected seaweeds from Gulf of Mannar, India. *Asian Pac. J. Trop. Biomed.,* **2**, 30-33 (2012).

Josephine, A., K. Nithya, G. Amudha, C.K. Veena, S.P. Preetha and P. Varalakshmi: Role of sulphated polysaccharides from *Sargassum wightii* in Cyclosporine A-induced oxidative liver injury in rats. *BMC Pharmacol.,* **8**, 1-9 (2008).

Jothinayagi, N. and C. Anbazhagan: Effect of seaweed liquid fertilizer of *Sargassum wightii* on the growth and biochemical characteristics of a *Abelmoschus esculentus* (L) medikus. *Rec. Res. Sci. Technol.,* **1**, 155-158 (2009).

Kanimozhi, S., M. Krishnaveni, B. Deivasigmani, T. Rajasekar and P. Priyadarshni: Immunomostimulation effects of *Sargassum wightii* on *Mugil cephalus* against *Pseudomonas fluorescence*. *Int. J. Curr. Microbiol.,* **2**, 93-103 (2013).

Kitikiew, S., J.C. Chen, D.F. Putra, Y.C. Lin, S.T. Yeh and C.H. Liou: Fucoidan effectively provokes the innate immunity of white shrimp *Litopenaeus vannamei* and its resistance against experimental *Vibrio alginolyticus* infection. *Fish Shellfish Immunol.,* **34**, 280-290 (2013).

Krishnan, M. and R. Narayanakumar: Socio-economic dimensions of seaweed farming in India. Central Marine Fisheries Research Institute, India. Special Bulletin No. **104**, 1-78 (2010).

Kumar, A.P., H. Graham, C. Robson, K. Garapati and R. Ghosh: An overview of anticancer herbal medicines. In: Evidence-based Anticancer Complementary and Alternative Medicine-Herbal Medicine (Ed.: W.C.S. Cho). Springer Science+Business Media B.V., pp.1-45 (2011).

Kumar, K.A.: Effect of *Sargassum wightii* on growth, carcass and serum qualities of broiler chickens. *Open Access J. Vet. Sci. Res.,* **3**, 1-10 (2018).

Kumar, K.P., K. Murugan, K. Kovendan, A.N. Kumar, J.S. Hwang and D.R. Barnard: Combined effect of seaweed (*Sargassum wightii*) and *Bacillus thuringiensis* var. israelensis on the coastal mosquito, *Anopheles sundaicus*, in Tamil Nadu, India. *Sci. Asia,* **38**, 141-146 (2012).

Kumar, P.S., J. Pavithra, S. Suriya, M. Ramesh and K. Anish Kumar: *Sargassum wightii*, a marine alga is the source for the production of algal oil, bio-oil, and application in the dye wastewater treatment. *Desalin. Water Treat.,* **55**, 1-17 (2014).

Kumar, Y., A.Tarafdar, D. Kumar and P.C. Badgujar: Effect of Indian brown seaweed *Sargassum wightii* as a functional ingredient on the phytochemical content and antioxidant activity of coffee beverage. *J. Food Sci.Technol.,* **56**, 4516-4525 (2019).

Kumar, Y., A. Tarafdar, D. Kumar, K. Verma, M. Aggarwal and P.C. Badgujar: Evaluation of chemical, functional, spectral, and thermal characteristics of *Sargassum wightii* and *Ulva rigida* from Indian coast. *J. Food Qual.,* **2021**, 1-9 (2021).

Lakshmanasenthil, S., T.V. Kumar, D. Geetharamani and S.S. Priya: α-Amylase and α-glucosidase inhibitory activity of tetradecanoic acid (TDA) from *Sargassum wightii* with relevance to type 2 diabetes mellitus. *J. Biol. Act. Prod. Nat.,* **8**, 180-191 (2018).

Li, Y., Z.J. Qian, B. Ryu, S.H. Lee M.M. Kim and S.K. Kim: Chemical components and its antioxidant properties *in-vitro*: An edible marine brown algae, *Ecklonia cava*. *Bioorg. Med. Chem.,* **17**, 1963-1973 (2009).

Magesh, K.T., R. Aravindhan, M.S. Kumar and A. Sivachandran: Antibacterial efficacy of the extract of *Sargassum wightii* against oral pathogen-an *in vitro* study. *J. Orofac. Sci.,* **12**, 96-100 (2020).

Maneesh, A., K. Chakraborty and F. Makkar: Pharmacological activities of brown seaweed *Sargassum wightii* (Family Sargassaceae) using different *in-vitro* models. *Int. J. Food Prop.,* **20**, 931-945 (2017).

Manilal, A., S. Sujith, G.S. Kiran, J. Selvin, C. Shakir, R. Gandhimathi and A.P. Lipton: Antimicrobial potential and seasonality of red algae collected from the southwest coast of India tested against shrimp, human and phytopathogens. *Ann. Microbiol.,* **59**, 207-219 (2009).

Manivannan, K., G.K. Devi, G. Thirumaran and P. Anantharaman: Mineral composition of marine macroalge from Mandapam coastal regions; Southeast coast of India. *J. Bot.,* **1**, 58-67 (2008).

Manoj, S.G.M., K.P.S. Mahesh, M. Vasanthi and A. Achary: Anticoagulant property of sulphated polysaccharides extracted from marine brown algae collected from Mandapam Island, India. *Afr. J. Biotechnol.,* **12**, 1937-1945 (2013).

Manojkumar, K. and Seema: *In vitro* cancer chemopreventive properties of polysaccharide extract from the brown alga, *Sargassum wightii*. *IOSR J. Pharm. Biol. Sci.,* **8**, 6-11 (2013).

Marimuthu, J., P. Essakimuthu, J. Narayanan, B. Anantham, R.J.J.M. Tharmaraj and S. Arumugam: Phytochemical characterization of brown seaweed *Sargassum wightii. Asian Pac. J. Trop. Dis.,* **2**, 109-113 (2012).

Marudhupandi, T. and T.T.A. Kumar: Antibacterial effect of fucoidan from *Sargassum wightii* against the chosen human bacterial pathogens. *Int. Curr. Pharm. J.,* **2**, 156-158 (2013).

Meenakshi, S., D.M. Gnanambigai, S.T. Mozhi, M. Arumugam and T. Balasubramanian: Total flavanoid and in vitro antioxidant activity of two seaweeds of Rameshwaram Coast. *Glob. J. Pharmacol.,* **3**, 59-62 (2009).

Mishra, V.K., F. Temelli, B. Ooraikul, P.F. Shacklock and J.S. Craigie: Lipids of the red alga, *Palmaria palmata*. *Bot. Mar.,* **36**, 169-174 (2009).

Mohapatra, L., S.K. Bhattamishra, R. Panigrahy, S. Parida and P. Pati: Antidiabetic effect of *Sargassum wightii* and *Ulva fasciata* in high fat diet and multi low dose streptozotocin induced type 2 diabetic mice. *Int. J. Pharma. Bio. Sci.,* **4**, 13-23 (2016).

Moncada, S., R.M. Palmer and E.A. Higgs: Nitric oxide: Physiology, pathophysiology and pharmacology. *Pharmacol. Rev.,* **43**, 109-142 (1991).

Moon, J.K. and T. Shibamoto: Antioxidant assays for plant and food components. *J. Agric. Food Chem.,* **57**, 1655-1666 (2009).

Muthezhilan, R., V. Ravikumar, R. Karthik and A.J. Hussain: Development of seaweed liquid fertilizer (SLF) consortium for the enhancement of agriculturally important crop plants. *Biosci. Biotechnol. Res. Asia*, **11**, 253-261 (2014).

Newton, I.S.: Long chain fatty acids in health and nutrition. *J. Food Lipids.,* **3**, 233-249 (1996).

Niroja, D. and R. Kannan: Anti-insect properties of a potential marine algae *Sargassum wightii* against *S. Litura* (Fab.). *Plant Arch.,* **20**, 3343-3346 (2020).

Nirmalkar R., E. Suresh, N. Felix, A. Kathirvelpandian, M.I. Nazir and A. Ranjan: Synthesis of iron nanoparticles using *Sargassum wightii* extract and its impact on serum biochemical profile and growth response of *Etroplus suratensis* juveniles. *Biol. Trace. Elem. Res.,* **2022**, 1-8 (2022).

Pal, A., M.C. Kamthania and A. Kumar: Bioactive compounds and properties of seaweeds-A review. *OALib J.,* **1**, 1-17 (2014).

Pangestuti, R. and A.E. Siajhaan: Seaweed derived carotenoids. In:

Bioactive Seaweed for Food Application (Eds.: Yimin qin). Academic press, pp.95-107(2018).

Prabha, V., K. Shoba, B. Hebsibah Elsie and G. Nithya: Qualitative and quantitative analysis of *Sargassum wightii* and *Kappaphycus alvarezii. Int. J. Novel Trends Pharm. Sci.,* **7**, 36-48 (2017).

Prabhakar, V., R. Anandan, T.P. Aneesh, N.B. Jayasree, S.V. Nair and O.A. Halima: Fatty acid composition of *Sargassum wightii* and *Amphiroa anceps* collected from the Mandapam coast Tamil Nadu, India. *J. Chem. Pharm. Res.,* **3**, 210-216 (2011).

Prabu, D.L., N.P. Sahu, A.K. Pal, S. Dasgupta and A. Narendra: Immunomodulation and interferon gamma gene expression in sutchi cat fish, *Pangasianodon hypophthalmus*: Effect of dietary fucoidan rich seaweed extract (FRSE) on pre and post challenge period. *Aquac. Res.,* **47**, 199-218 (2016).

Praveen, M.A., K.R.K. Parvathy, R. Jayabalan and P. Balasubramanian: Dietary fibre from Indian edible seaweeds and its *in-vitro* prebiotic effect on the gut microbiota. *Food Hydrocoll.,* **96**, 343-353 (2019).

Preetha, S.P. and H. Devaraj: Role of sulphated polysaccharides from *Sargassum wightii* in the control of diet-induced hyperlipidemia and associated inflammatory complications in rats. *Eur. J. Inflamm.,* **8**, 23-30 (2010).

Pugazhendhi, A., R. Prabhu, K. Muruganantham, R. Shanmuganathan and S. Natarajan: Anticancer, antimicrobial and photocatalytic activities of green synthesized magnesium oxide nanoparticles (MgONPs) using aqueous extract of *Sargassum wightii. J. Photochem. Photobiol. B, Biol.,* **190**, 86-97 (2019).

Rajeswari, R. and K. Jeyaprakash: Neuro protective activity of *Sargassum wightii* against neurotoxicity induced cell death on an *in vitro* human neuro blastoma model. *Int. J. Pharm. Res.,* **10**, 780-784 (2018).

Rajivgandhi, G.N., C.C. Kanisha, G. Ramachandran, N. Manoharan, R.A. N.A. Mothana, Siddiqui, A.J. Al-Rehaily, R. Ullah and O.M. Almarfad: Phytochemical screening and anti-oxidant activity of *Sargassum wightii* enhances the anti-bacterial activity against *Pseudomonas aeruginosa*. *Saudi J. Biol. Sci.,* **28**, 1763-1769 (2021).

Raman, R., S. Parthiban, S. Karthikeyan, M.S. Muthuraman and A. Sivasubramanian: Antimicrobial and anti-inflammatory studies on *Sargassum wightii* extracts. *Int. J. Pharm. Pharm. Sci.,* **6**, 611-614 (2014).

Rani, V., R.J. Shakila, P. Jawahar and A. Srinivasan: Influence of species, geographic location, seasonal variation and extraction method on the fucoidan yield of the brown seaweeds of Gulf of Mannar, India. *Indian J. Pharm. Sci.,* **79**, 65-71 (2017).

Ravi, C., R. Muthamil and A. Karthiga: Biomedical potential and preliminary phytochemistry of the brown seaweed *Sargassum wightii* Greville ex J. Agardh 1848. *Asian Fish. Sci.,* **29**, 43-56 (2016).

Rosaline, X.D., S. Sakthivelkumar, K. Rajendran and S. Janarthanan: Screening of selected marine algae from the coastal Tamil Nadu, South India for antibacterial activity. *Asian Pac. J. Trop. Biomed.,* **2**, 140-146 (2012).

Rosaline, X.D., S. Sakthivelkumar, K. Rajendran and S. Janarthanan: Detection of antibacterial activity and its characterization from the marine macro-algae *Sargassum wightii* (Greville ex J.Agardh 1848). *Indian J. Geo-Mar. Sci.,* **45**, 1365-1371 (2016).

Rout, S., B. Rath, S.K. Bhattamisra, A. Kumar and S. Rath: Neuroprotective effect of methanolic extract of *Sargassum wightii* on haloperidol induced catalepsy and tardive dyskinesia in Albino rats. *Int. J. Pharm. Pharm. Sci.,* **12**, 1-6 (2020).

Sajina, K.A., N.P. Sahu, T. Varghese and K.K. Jain: Fucoidan-rich *Sargassum wightii* extract supplemented with α-amylase improve growth and immune responses of *Labeo rohita* (Hamilton, 1822) fingerlings. *J. Appl. Phycol.,* **31**, 2469-2480 (2019).

Sangeetha, J., S. Gayathri and S. Rajeshkumar: Antimicrobial assessment of marine brown algae *Sargassum wightti* against UTI pathogens and its phytochemical analysis. *Res. J. Pharm. Technol.,* **10**, 1905-1910 (2017).

Sarithakumari, C.H., G.L. Renju and G.M. Kurup: Anti-inflammatory and antioxidant potential of alginic acid isolated from the marine algae, *Sargassum wightii* on adjuvant-induced arthritic rats. *Inflammopharmacology*, **21**, 261-268 (2013).

Satheesh, S. and S.G. Wesley: Diversity and distribution of seaweeds in the Kudankulam coastal waters, South-Eastern coast of India. *Biodivers. J.,* **3**, 79-84 (2012).

Seenivasan, R., M. Rekha, H. Indu and S. Geetha: Antibacterial activity and phytochemical analysis of selected seaweeds from Mandapam Coast, India. *J. Appl. Pharm. Sci.,* **2**, 159-169 (2012).

Shanmugam, M. and K.H. Mody: Heparinoid-active sulphated polysaccharides from marine algae as potential blood anticoagulant agents. *Curr. Sci.,* **79**, 1672-1683 (2000).

Shambhulingaiah, T.C., E. Krishnamoorthy, L. R. Gopakumar, S. Ebeneezar, A.K. Kasim, S.K. Kannaiyan, G. Vaidhyanathan and S. Mathew: Valorisation of brown seaweed (*Sargassum wightii*) waste as a feed ingredient in rohu (*Labeo rohita*): Effects on growth and metabolism. *Aquac. Nutr.,* **27**, 2662-2672 (2021).

Singh, B.K., R.C. Chopra, S.N. Rai, M.P. Verma and R.K. Mohanta: Nutritional evaluation of seaweed on nutrient digestibility, nitrogen balance, milk production and composition in Sahiwal cows. *Proc. Natl. Acad. Sci. India. Sect. B. Biol. Sci.,* **87**, 437-443 (2017).

Sinurat, E., E. Saepudin, R. Peranginangin and S. Hudiyono: Immunostimulatory activity of brownseaweed-derived fucoidans at different molecular weights and purity levels towards white spot syndrome virus (WSSV) in shrimp *Litopenaeus vannamei. J. Appl. Pharm. Sci.,* **6**, 82-91 (2016).

Sivagnanavelmurugan, M., T. Marudhupandi, A. Palavesam and G. Immanuel: Antiviral effect of fucoidan extracted from the brown seaweed, *Sargassum wightii* on shrimp *Penaeus monodon* postlarvae against white spot syndrome virus. *J. World. Aquac. Soc.,* **43**, 697-706 (2012).

Sivagnanavelmurugan, M., B.J. Thaddaeus, A. Palavesam and G. Immanuel: Dietary effect of *Sargassum wightii* fucoidan to enhance growth, prophenoloxidase gene expression of *Penaeus monodon* and immune resistance to *Vibrio parahaemolyticus. Fish. Shellfish. Immunol.,* **39**, 439-449 (2014).

Sivagnanavelmurugan, M., G. Karthik Ramnath, B. Jude Thaddaeus, A. Palavesam and G. Immanuel: Effect of *Sargassum wightii* fucoidan on growth and disease resistance to *Vibrio parahaemolyticus* in *Penaeus monodon* post-larvae. *Aquac. Nutr.*, **21**, 960-969 (2015).

Sivasankari, S., V. Venkatesalu, M. Anantharaj and M. Chandrasekaran: Effect of seaweed extracts on the growth and biochemical constituents of *Vigna sinensis. Bioresour. Technol.,* **97**, 1745-1751 (2006).

Sridhar, S. and R. Rengasamy: Studies on the effect of seaweed liquid fertilizer on the flowering plant, *Tagetes erecta* in field trial. *Adv. Biores.,* **1**, 29-34 (2010).

Suganya, S., R. Ishwarya, R. Jayakumar, M. Govindarajan, N.S. Alharbi, S. Kadaikunnan, J.M. Khaled, M.N. Al-anbr and B. Vaseeharan: New insecticides and antimicrobials derived from *Sargassum wightii* and *Halimeda gracillis* seaweeds: Toxicity against mosquito vectors and antibiofilm activity against microbial pathogens. *S. Afr. J. Bot.,* **125**, 466-480 (2019).

Sujana, M. and P.P.N. Vijay Kumar: Phytochemical screening and high-performance thin-layer chromatography profile of *Sargassum*

wightii and its antioxidant activity. *Int. J. Green Pharm.,* **14**, 355-359 (2020).

Sujatha, D., K. Singh, M. Vohra, K.V. Kumar and S. Sunitha: Antilithiatic activity of phlorotannin rich extract of *Sarghassum wightii* on calcium oxalate urolithiais-*in vitro* and *in vivo* evaluation. *Int. Braz. J. Urol.,* **41**, 511-520 (2015).

Sumayaa, S. and K. Kavitha: Preparation of novel seaweed recipes and standardisation for the human consumption. *Int. J. Adv. Res. Publ.,* **3**, 159-167 (2015).

Sun, Z., Z. Dai, W. Zhang, S. Fan, H. Liu, R. Liu and T. Zhao: Antiobesity, antidiabetic, antioxidative, and antihyperlipidemic activities of bioactive seaweed substances. In: Bioactive Seaweeds for Food Applications: Natural Ingredients for Healthy Diets (Ed.: Y. Qin). Elsevier Science Publishing Company Inc, San Diego, United State, pp. 239-253 (2018).

Syad, A.N., K.P. Shunmugiah and P.D. Kasi: Antioxidant and anti-cholinesterase activity of *Sargassum wightii. Pharm. Biol.,* **51**, 1401-1410 (2013).

Tamilselvan, N., K. Saurav and K. Kannabiran: Biosorption of Cr (VI), Cr (III), Pb (II) and Cd (II) from aqueous solutions by *Sargassum wightii* and *Caulerpa racemosa* algal biomass. *J. Ocean. Univ. China.,* **11**, 52-58 (2012).

Traifalgar, R.F.M., S. Koshio, M. Ishikawa, A.E. Serrano and V.L. Corre: Fucoidan supplementation improves metamorphic survival and enhances Vibriosis resistance of *Penaeus japonicus. J. Fish. Aquacul.,* **3**, 33-36 (2012).

Tuller, J., C. De Santis and D.R. Jerry: Dietary influence of Fucoidan supplementation on growth of *Lates calcarifer* (Bloch). *Aquac. Res.,* **45**, 749-754 (2014).

Uthirapandi, V., S. Suriya, P. Boomibalagan, S. Eswaran, S.S Ramya, N. Vijayanand and D. Kathiresan: Bio-fertilizer potential of seaweed liquid extracts of marine macroalgae on growth and biochemical parameters of *Ocimum sanctum. J. Pharmacogn. Phytochem.,* **7**, 3528-3532 (2018).

Vaikundamoorthy, R., V. Krishnamoorthy, R. Vilwanathan and R. Rajendran: Structural characterization and anticancer activity (MCF7 and MDA-MB-231) of polysaccharides fractionated from brown seaweed *Sargassum wightii. Int. J. Biol. Macromol.,* **111**, 1229-1237 (2018).

Vallinayagam, K., R. Arumugam, R.R.R. Kannan, G. Thirumaran and P. Anantharaman: Antibacterial activity of some selected seaweeds from Pudumadam coastal regions. *Glob. J. Pharmacol.,* **3**, 50-52 (2009).

Venugopal, A.K.B., V.K. Thirumalairaj, G. Durairaj, M.P. Vijayan, N. Lazar, K.K. Sathyan, A. Chacko, R. Yesudas, S. Kadheeja, I.K.J. David and S.J. Damascene: Microbicidal activity of crude extracts from *Sargassum wightii* against *Bacillus cereus*. *Int. Curr. Pharm. J.,* **3**, 326-327 (2014).

Vigneshpriya, D., N. Krishnaveni, S. Renganathan and R. S.S. Priyadarshini: Impact of untreated and *Sargassum wightii*-treated brilliant green dye exposure on Indian major carp, *Labeo rohita* Ham.: Hematology, biochemistry, enzymology and histopathology. *Int. J. Phytoremedia.,* **22**, 819-826 (2020).

Vijaya, T., M. Sathish Kumar, N.V. Ramarao, A. Naredra Babu and N. Ramarao: Urolithiasis and its causes- short review. *J. Phytopharmacol.,* **2**, 1-6 (2013).

Vijayabaskar, P. and V. Shiyamala: Antibacterial activities of brown marine algae (*Sargassum wightii* and *Turbinaria ornata*) from the Gulf of Mannar biosphere reserve. *Adv. Biol. Res.,* **5**, 99-102 (2011).

Vijayanand N., S.S. Ramya and S. Rathinavel: Potential of liquid extracts of *Sargassum wightii* on growth, biochemical and yield parameters of cluster bean plant. *Asian Pac. J. Reprod.,* **3**, 150-155 (2014).

Vijayaraghavan, K. and D. Prabu: Potential of *Sargassum wightii* biomass for copper (II) removal from aqueous solutions: application of different mathematical models to batch and continuous biosorption data. *J. Hazard. Mater.,* **137**, 558-564 (2006).

Vijayaraghavan, K., T.V.N. Padmesh, K. Palanivelub and M. Velan: Biosorption of nickel (II) ions onto *Sargassum wightii*: application of two-parameter and three-parameter isotherm models. *J. Hazard. Mater.,* **133**, 304-308 (2006).

Wen, Z.S., X.W. Xiang, H.X. Jin, X.Y. Guo, L.J. Liu, Y.N. Huang, X.K. Ou Yang and Y.L. Qu: Composition and anti-inflammatory effect of polysaccharides from *Sargassum horneri* in RAW264. 7 macrophages. *Int. J. Biol. Macromol.,* **88**, 403-413 (2016).

Wu, G.J., S.M. Shiu, M.C. Hsieh and G.J. Tsai: Anti-inflammatory activity of a sulfated polysaccharide from the brown alga *Sargassum cristaefolium*. *Food Hydrocoll.,* **53**, 16-23 (2016).

Yuvaraj, N. and A. Venkatesan: *In vitro* anti-tumour, anti-inflammatory, antioxidant and antibacterial activities of marine brown alga *Sargassum wightii* collected from the Gulf of Mannar. *Glob. J. Pharmacol.,* **8**, 566-577 (2014).

Yuvaraj, N. and A. Venkatesan: Antinociceptive and anti-inflammatory effect of sulfated polysaccharide fractions from *Sargassum wightii* and *Halophila ovalis* in male Wistar rats. *Indian J. Pharmacol.,* **48**, 562-570 (2016).

Yuvaraj, N.,P. Kanmani, R. Satishkumar, A. Paari, V. Pattukumar and V. Arul: Antinociceptive and anti-inflammatory activities of *Sargassum wightii* and *Halophila ovalis* sulfated polysaccharides in experimental animal models. *J. Med. Food.,* **16**, 740-748 (2013).

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