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Natural Compounds with Bioactive Properties from Marine Algae

Evrim Taşkın[1*] • Ergün Taşkın[2] • Mehmet Öztürk[2] • Jaime A. Teixeira da Silva[3]

[1] Celal Bayar University, Faculty of Arts and Sciences, Biology Department, Microbiology Section, Muradiye Campus, Manisa, 45140, Turkey
[2] Celal Bayar University, Faculty of Arts and Sciences, Biology Department, Hydrobiology Section, Muradiye Campus, Manisa, 45140, Turkey
[3] Faculty of Agriculture and Graduate School of Agriculture, Kagawa University, Miki cho, Kita gun, Ikenobe, 761-0795, Japan

Corresponding author: * **evrim.taskin@bayar.edu.tr**

ABSTRACT

Algae, mainly of marine origin, are producers of many economically important compounds. These compounds are bioactive compounds since they have different biological activities and have been used in the nutraceutical, pharmaceutical and cosmetic industries for many years. Recent trends in drug research from natural sources and several screening and clinical studies have led to the discovery and elucidation of a number of new and active compounds from macroalgae. This review covers those algae from which bioactive substances have been identified and/or synthesized with a potential impact on health and medicine.

Keywords: antibacterial, antiviral, bioactive compounds, marine pharmacology, natural products
Abbreviations: APTT, activated partial thromboplastin time; **DENV**, *Dengue virus*; **HIV**, *Human immunodeficiency virus*; **HSV**, *Herpes simplex virus*; **IC_{50}**, inhibitor concentration for the death of 50% of total cells; **IZ**, inhibition zone; **MIC**, minimum inhibitory concentration; **SP**, sulfated polysaccharide

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INTRODUCTION

The screening of marine algae for activities such as antimicrobial (antibacterial, antifungal), antitumoral, antiviral have been extensively studied over many years, and isolation of algal bioactive compounds for pharmacological purposes began recently with modern screening programmes (Harada *et al.* 2002; Vairappan 2003; Mayer and Gustafson 2003; Takamatsu *et al.* 2003; Engel *et al*. 2006). An examination of the MarinLit database reveals that *ca*. 3600 compounds have been identified from marine macro- and microalgae from a marine natural products pool of 15,000 natural products, thus representing *ca*. 24% (Bhadury and Wright 2004). These bioactive compounds are recognized as sterols, heterocyclic and phenolic compounds, carotenoids, phycocolloids, sulphated polysaccharides, lectins, mycosporine-like amino acids, halogenated compounds, terpenoids, glucans, polyketides and toxins.

In this mini-review, focus is placed on the main classes of chemically characterized compounds of marine macroalgae with bioactive properties that have medicinal and pharmaceutical value (**Tables 1, 2**). Mainly the antibacterial, antifungal, antitumoral, antiviral and anticoagulative compounds isolated from marine macroalgae are emphasized. Although there is a myriad of documents on the different bioactivities of algal extracts, only a small portion of these studies have been carried on the isolated and identified compounds. Only those articles that report on the bioactivities of partially or completely characterized marine algal chemicals are included in this mini-review. The structures and mechanims for the bioactivity of these compounds are given. The review is structured according to the bioactivities that were shown by algal compounds while related studies have been summarized.

COMPOUNDS WITH ANTIBACTERIAL ACTIVITIES

Halogenated compounds are well known in the defense mechanism of algae against marine herbivors (Hay *et al.* 1987). The red algae genus *Laurencia* (*Rhodomelaceae*, Ceramiales) is known to produce a wide range of chemically interesting secondary halogenated metabolites, two of which, elatol and iso-obtusol, were isolated and identified from *L. majuscula* collected from Sbah, Malaysia (Vairappan 2003). Both compounds inhibited a wide range of bacterial species according to the results of the disc-diffusion method as an antibacterial bioassay, while elatol exhibited equal or better activity than commercial antibiotics by inhibiting the growth of *Salmonella* sp. with a ≥ 25 mm inhibition zone (IZ) diameter and of *S. epidermidis* and *Klebsiella pneumoniae* with an IZ ≥19 mm (30 μg/disc). Using a microdilution method, both compounds were found to have a bacteriostatic mode of action.

Antibacterial activities of bromophenol compounds has

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Invited Mini-Review

Table 1 Some examples on antimicrobial, antiviral compounds studied from marine algae.

Algae/Class	Pharmacological activity	Name of compound	Class of compound	Mechanism of action	Reference
Rhodomela confervoides	Antibacterial	Bis (2,3 dibromo-4,5-dihydroxybenzyl)ether	Bromophenol	--	Xu *et al*. 2003
Laurencia majuscula	Antibacterial (bacteriostatic)	Elatol, iso-obtusol	Halogenated	--	Vairappan 2003
Odonthalia corymbifera	Antibacterial, antifungal	Compound 4,5,6	Bromophenol	--	Oh *et al.* 2008
Sargassum patens	Antiviral	SP-2a	SPs [a]	Adsorption inhibition	Zhu *et al*. 2006
Dictyota menstrualis	Antiviral	Da-1, AcDa-1	Diterpenes	Inhibition of RNA-dependent polymerase activity	Pereira *et al.* 2004
Stoechospermum marginatum	Antiviral	SmWE (crude fucan sulfate), F3 (fucan sulfate)	Desulfated polysaccharide	--	Adhikari *et al.* 2006
Spatoglossum schröederi	Antiviral	Fucan, alginic acid	Polysaccharide	Inhibition of RT [b]	Queiroz *et al.* 2008
Dictyota mertensii	Antiviral	Fucan A	SPs	Inhibition of RT	Queiroz *et al*. 2008
Lobophora variegata	Antiviral	Galactofucan	SPs	Inhibiton of RT	Queiroz *et al*. 2008
Meristiella gelidium	Antiviral	M3a	Carrageenan	---	Tischer *et al*. 2006

[a] sulfated polysaccharide
[b] reverse transcriptase

Table 2 Some examples on cytotoxic, antioxidative, anticoagulative compounds from marine algae.

Algae/Class	Pharmacological activity	Name and class of compound	Inhibited cell line, enzyme system	Reference
Cladophora prolifera *Sargassum filipendula* *Dictyopteris delicatula* *Dictyota menstrualis*	Cytotoxic	SPs [a]	HeLa cells	Costa *et al*. 2009
Laurencia intricata	Antitumorogenic	Laurenditerpenol/Terpenoid	Inhibition of HIF-1	Mohammed *et al*. 2004
Sargassum latifolium	Antioxidant, anticarcinogen	Compound E1 and E4	Inhibition cytP [b] 450 and induction of glutation-S-transferase	Gamal-Eldeen *et al*. 2009
Ecklonia cava	Anticoagulant	SPs	Inhibition of serin proteases	Athukorala *et al*. 2006

[a] sulfated polysaccharides
[b] cytochrome p oxidase

been shown through various studies. In particular, a family of the red algae *Rhodomelaceae* is known to be a rich source of bromophenols. *Rhodomela confervoides*, a member of this family, showed remarkable antibacterial activity against eight tested bacteria. It was subsequently chosen to study the isolated biaoctive compounds. Three bromophenols, two of which were newly isolated compounds were studied against the test bacteria. When the spectral activity of one of three newly isolated compounds was checked, compound 5 showed most potent inhibitory activity against 7/8 bacteria with a MIC value < 70 µg/ml against 4/8 bacteria tested (Xu *et al.* 2003).

The antibacterial effects of bromophenol compounds were also shown by another member of the *Rhodomelaceae*, *Odonthalia corymbifera*. *In vitro* antibacterial activities of 6 bromophenol compounds were assessed against three Gram-positive and three Gram-negative bacteria and four fungal strains. Among the isolated compounds, compound 4 was the most active against pathogenic fungi and the MIC values of these compounds were 1.56 µg/ml against *C. albicans*, *T. rubrum*, *T. mentagrophytes* and 0.78 µg/ml against *A. fumigatus*; in all cases the MIC values were lower than those obtained by the standard antibiotic Amphothericin B which was 6.25 µg/ml against *C. albicans* and 3.12 µg/ml against the three fungal species. Compounds 4, 5 and 6 showed good inhibition against Gram-positive and –negative bacteria (except for *E. coli*) and the MIC value of compound 6 against 5 tested bacteria was < 25 µg/ml. The diphenolic backbone and the presence of one or more bromines on the phenol ring were important for antimicrobial activity. To investigate the positional effects of bromines on the phenol ring on antibacterial activity, an analog was synthesized. When the position and number of hydroxyl groups and bromine were replaced by synthesis of bromophenols inactive compounds against fungi were formed (Oh *et al.* 2008).

COMPOUNDS WITH ANTIVIRAL ACTIVITIES

Since 1988, the activity spectra of sulfated polysaccharides (SPs) have extended to various enveloped viruses that emerge as opportunistic pathogens (e.g., *Herpes simplex virus* (HSV), and *Cytomegalovirus*) in immunosupressed patients. As potential anti-HIV (*Human immunodeficiency virus*) drug candidates, SPs offer a number of promising features (Witvrouw and de Clercq 1997). Carrageenan, a common cell wall polysaccharide from red algae, is co-internalized into infected cells with the HSV inhibiting the virus. Carrageenan also interferes with fusion (syncytium formation) between cells infected with the HIV and inhibits the specific retroviral enzyme reverse transcriptase (Neushul 1990). Many species of marine algae contain significant quantitites of complex structural SPs, thus the marine algae are among the richest sources of known and novel bioactive SPs (Harden *et al.* 2009). Recent observations have accumulated evidence about the *in vitro* activities of SPs against animal viruses including HSV-1 and HSV-2, *Human cytomegalovirus* (HCMV), HIV-1, *Respiratory syncytial virus* (RSV) and *Influenza virus* by inhibiting replication of the virus. SPs are able to block HIV replication in cell culture at concentrations as low as 0.1 to 0.01 µg/ml (Witvrouw and de Clerq 1997; Adhikari *et al*. 2006). Thus, the potential of polysaccharides extracted from seaweed as antiviral agents has become of considerable interest. The biological activities of these high molecular weight molecules are determined by their chemical structure, including the degree of sulfation, molecular weight, constituent sugars, conformation and stereochemistry (Harden *et al*. 2009). To determine the structure-activity relationship of SPs from natural sources, they are modified by carboxyreduction and desulfation. These modified conditions reduced the inhibitory activities of chemically modified fucan fractions (Queiroz *et al.* 2008). Antiviral activities of the SPs reportedly result from interference with early steps in the viral replication process, including virus adsorption (Witvrouw and de Clerq 1997). The mechanism of action can be attributed to inhibition of the initial attachment of the virus to host cells, and is thought to be mediated by interactions of SPs with positively charged domains of the viral envelope glycoproteins involved in the attachment of the virus to heparan sulfate proteoglycans on the surface of host cells. Both the degree of sulfation and the distribution of sulfate groups

on the constituent polysaccharides play an important role in the antiviral activity of these SPs. Many SPs have been shown to have antiviral activity *in vitro*, including fucans, galactans and xylomannans that presumably act by similar mechanisms (Harden *et al.* 2009). An antiviral agent Carraguard®, whose active material is obtained from carrageenan, is used as a microbicidal vaginal gel in South Africa and Thailand.

Sulfated galactans are the major extracellular polysaccharides produced by red seaweeds, some of which such as kappa (κ)-, iota (ι)- and lambda (λ) carrageenans show commercial interest. Red seaweeds of the family Gigartinales are known to be carrageenophytes producing κ/ι and λ carrageenans (Tischer *et al.* 2006). The polysaccharides from the red algae tested were also active, particularly the λ type carrageenan isolated from the tetrasporophyte form of *G. atropurpurea*, which had the best activity of the samples.

Isolated sulfated polysaccharides of some red and brown algae from New Zealand (*Undaria pinnatifida*, *Splachnidium rugosum*, *Gigartina atropurpurea*, *Plocamium cartilagineum*) have been reported as effective against HSV-1 and HSV-2 at concentrations of about 1.0 μg/ml. Each of the extracts examined also exhibited virucidal activity (Harden *et al*. 2009).

The sulfated galactans from red seaweed *Grateloupia indica* represent very potent antiherpetic properties and they also showed a higher inhibitory effect when compared with reference SPs such as dextran sulfate 8000 and heparin (Chattopadhyay *et al.* 2007). The crude fraction (GiWE) and purified native sulfated galactan (F3) of *G. indica* may be considered potent inhibitors of HSV-1 and HSV-2 with values of IC_{50} ranging from 0.25 to 0.31 μg/ml. On the other hand the desulfated derivatives GiWED and F3D were inactive against these viruses up to a concentration of 50 μg/ml. The conclusion the can be drawn is that the antiviral activity of these polysaccharides is linked to the anionic features of the molecules, given mainly by the high amount of sulfate groups. The inhibitory effect of these SPs appears to be based mainly on their ability to interfere with the replication cycle of HSV-1.

KCI-precipitated carrageenans from *M. gelidium* are constituted by ι- (88-90%), μ- (6-8%) and κ (4%) disaccharide repeating units. All the compounds obtained from *M. gelidium* (M1, M3, M3a, G3, G3d) exhibited antiherpetic activity with IC_{50} values in the range of 0.04-0.06 μg/ml and showed higher antiviral action and selectivity index than the reference substances heparin and DS8000. In general, the inhibitory action against Dengue virus (DENV-2) was lower than that against HSV-2. The range of IC_{50} against DENV-2 was 0.14-1.6 μg/ml. For M3a, the most active fraction, the selectivity index against HSV-2 was 25.000, a value high enough to consider this carrageenan as a promising agent to be evaluated for the treatment of genital HSV-2 infections (Tischer *et al.* 2006).

A sulfated polysaccharide (SP-2a) was isolated from the marine algae *S. patens* (*Sargassaceae*) collected in Hong Kong waters. Vero cells were used as the host for HSV-1. SP-2a inhibited the adsorption of HSV-1 to host cells. The infectivity of the virus was inhibited by SP-2a in a dose-dependent manner, with EC_{50} values of 4.3 and 3.5 μg/ml for the standard, the clinical and DM2.1 strains of HSV-1, respectively (Zhu *et al.* 2006).

The meroditerpenes (plastoquinones, chromanols and chromenes) consisting of a polyprenyl chain attached to a hydroquinone ring moiety are present in many marine organisms, including algae (Jang *et al.* 2005). Brown algae produce a myriad of secondary metabolites of this class, including meroditerpenes such as sargaquinone, sargaquinoic acid, sargahydroquinoic acid. Also new meroditerpenes were described from *Sargassum fallax* collected from Port Philip Bay, Victoria, Australia as fallahydroquinone, fallaquinone, fallachromenoic acid (Reddy and Urban 2008).

The antiviral effect of the CH_2CI_2/MeOH soluble fraction from the alga *D. menstrualis* on HIV-1 replication was evaluated *in vitro*. The antiretroviral activity was attributed to two diterpenes, Da-1 and AcDa-1, which affected an early step of the virus replication cycle. Da-1 and AcDa-1 inhibited the RNA-dependent polymerase activity of HIV-1 RT in a dose-dependent manner. At 100 mM, Da-1 inhibited 97% of the virus produced while AcDa-1 inhibited nearly 70% (Pereira *et al.* 2004). Two isolated diterpenes that denominated, namely hydroxidictiodial and dictiodial, showed inhibitory effect against HIV-RT activity and had been previously isolated from the brown algae *D. dichotoma* (EC_{50} = 4.3 and 9.2 μg/ml, respectively).

The antiviral activity of fucan sulfates isolated from *Stoechospermum marginatum*, i.e. SmWE (crude fucan sulfate) and purified fucan sulfate (F3) were found to be very active against both serotypes of HSV, SmWE being more active than F3 for HSV-1 (EC_{50} = 1.15 and 3.55 μg/ml, respectively) and equally active for HSV-2 (EC_{50} = 0.78 μg/ml for SmWE and 0.63 μg/ml for F3). On the contrary, the desulfated polysaccharides SmWE-D and F3-D showed significantly reduced antiviral activity. No cytotoxicity was observed with the water extract SmWE and the fraction F3 when cell viability was evaluated in preformed monolayers of Vero cells in the presence of concentrations up to 1000 μg/ml (Adhikari *et al.* 2006).

The antiviral activity of metabolites of newly isolated and identified diterpenes isopachydictyolal from *D. dichotoma* and 4α-acetyldictyodial from *D. linearis* were evaluated in laboratory assays against HSV I and polymyelitis virus I using Vero cells as host. However, they showed antiviral activity in concentrations lower than their maximal non-toxic dose and proved to be toxic for Vero cells in different dilutions.

Fucans and fucoidans are a family of high molecular weight sulfated polysaccharides, widely dispersed in the cell walls of brown seaweed. The activities of the fucans from *S. schröederi*, *D. mertensii* and *L. variegata* as inhibitors of HIV reverse transcriptase (RT) were investigated (Queiroz *et al.* 2008). The polysaccharide isolated from *L. variegata* was denominated as a galactofucan and the inhibitory activity of the galactofucan fraction at 1 μg/ml showed marked inhibitory effect on RT with 94% inhibition of synthetic polynucleotides. This inhibitory effect decreased to 60.5% in the presence of activated DNA. An SP isolated from *S. schröederi*, a xylofucoglucuronan, inhibited RT enzyme activity by 99.03%. However, fucan B from the same species of algae showed inhibitory activity of 53.9% at 1.0 μg/ml. In contrast, fucan A from *D. mertensii* had a high inhibitory effect at 0.5 and 1.0 μg/ml equaling 99.1 and 99.3%, respectively. Altough the fucan B fraction had more sulfates than the other fucans studied, it had a lower inhibitory effect. It was suggested that not only the charges, but also the spatial disposition of the sulfate groups is important for the biological response. The presence of the sulfate group is necessary for anti-HIV activity, and potency increases with the degree of sulfation (Witvrouw and de Clercq 1997). Queiroz *et al.* hypothesized that anionic charges on the sulfate groups may be effective in inhibiting RT activity.

COMPOUNDS WITH ANTIOXIDATIVE AND ANTITUMORAL ACTIVITIES

In oxidative stress and inflammation, excessive production of reactive oxygen and nitrogen species (ROS, RNS) results in DNA damage and contributes to tumor initiation and promotion, which might ultimately lead to carcinogenesis (Kanai 2008). Consequently, scavenging of radicals represents an effective strategy in preventing tumor initiation and promotion (Gamal-Eldeen *et al*. 2009).

Metabolites produced by *Sargassum* spp. have been reported to display a range of biological activities. A cancer chemopreventive activity of different fractions of a water-soluble polysaccharide extract derived from *S. latifolium* was shown (Gamal-Eldeen *et al*. 2009). Plastoquinones isolated from the brown algae *S. microcanthum* have been shown to contribute towards the diversity and selectivity of

bioactive properties of this genus. Compound 4 displayed significant antioxidant activity, which was attributed to the hydroquinone moiety. Compound 4 also displayed potent cytotoxic activity against colon 26-C5 cells; however, the structure-activity relationship and pharmacophore remain unknown (Reddy and Urban 2009).

In the evaluation of the bioactivities of isolated meroditerpenoids, sargaquinoic and sargahydroquinoic acids were found to display moderate antitumor activity (IC_{50} = 17 and 14 μM, respectively). Both acids were evaluated for their antimicrobial activity and displayed only weak activity against *Bacillus subtilis* (Reddy and Urban 2009).

In order to explore the cancer chemopreventive activity of *Sargassum latifolium*, different fractions of water-soluble polysaccharide extracts were studied (Gamal-Eldeen *et al*. 2009). Estimation of cancer chemopreventive activity, specifically anti-initiation, including the modulation of carcinogen metabolism and antioxidant capacity, revealed that compounds E1 and E4 were potent anti-initiators, where they not only inhibited the carcinogen activator cytochrome P4501A (IC_{50} 2.54 and 10.30 μg/ml, respectively) but also induced the carcinogen detoxification enzymes, glutathione-*S*-transferases (144 and 225% of control, respectively). E1 and E4 inhibited 59 and 63% of induced DNA damage, as measured by the comet assay. Since inhibition of COX-2, TNF-α and NO is one of the most important strategies in cancer chemoprevention (Ma and Kinner 2002), E1 and E4 were considered promising cancer preventive and anti-inflammatory agents.

Costa *et al*. (2009) investigated the antioxidative and antiproliferative effects of SPs isolated from tropical macroalgae belonging to 3 classes of algae (1 Rhodophyta, 6 Phaeophyta and 4 Chlorophyta) collected from Northeast Brazil. All species collected had reported antioxidative activities, four of which had great antioxidant potential: *Caulerpa sertularioide*, *Dictyota cervicornis*, *Sargassum filipendula* and *Dictyopteris delicatula*. Among the Chlorophyta, the antiproliferative effect of SPs against HeLa cells was obtained with *C. prolifera* (57.1% inhibition at 0.1 mg/ml). SPs from *S. filipendula* were the most active (61.1% cell inhibition at 0.1 mg/ml) while SPs from *D. delicatula* and *D. menstrualis* also presented an excellent antiproliferative activity at a high concentration (2.0 mg/ml), 61.0 and 58.4% inhibition, respectively.

Another interesting study was carried on the antitumoral activity of a new diterpene, laurenditerpenol, from the marine algae *Laurencia intricata* (Mohammed *et al*. 2004). In that study, the inhibition of hypoxia inducible factor-1 (HIF-1) production was studied. HIF-1 is a transcription factor that promotes tumor cell adaptation and survival under hypoxic conditions Since HIF-1 activates the expression of genes that promote hypoxic tumor cell survival under hypoxic conditions, HIF-1 inhibitors represent potential anticancer drug leads that target tumor hypoxia and an important new class of potential tumor-selective therapeutic agents. Bioassay guided fractionation of the lipid extract of *L. intricata* yielded a structurally novel diterpene, Laurenditerpenol (compound 1) potently inhibited HIF-1 activation by hypoxia (79% inhibition at 1 μg/ml). The isolated new compound potently inhibited the hypoxia-activated HIF-1 (IC_{50}: 0.4 μM) and hypoxia-induced VEGF (a potent angiogenic factor) in T47D cells. This compound inhibited HIF-1 by blocking the induction of the oxygen regulated HIF-α protein.

ANTICOAGULATIVE, IMMUNOMODULATORY, SPASMOGENIC AND SOME RELATED ACTIVITIES

As reported by Athukorala *et al*. (2006), scientists investigated blood anticoagulant properties from marine brown algae in 1913. There is a greater incidence of anticoagulant activity in the extracts of marine brown algae than those from red and green algae. Like many other SPs, fucans possess a wide spectrum of activity in biological systems. They play an important role in the anticoagulant and antithrombic activity, act on the immune system and in the inflammatory process, have antiproliferative and antiadhesive effects on cells, interfere with mechanisms involved in fertilization and protect cells from viral infection (Boisson-Vidal *et al*. 1995). Fucoidans isolated from brown algae have been extensively studied. Algal anticoagulant polysaccharides exert their activity through potentiating antithrombin III (ATIII) and/or heparin cofactor II, (HCII) which are important endogeneous inhibitors, called SERPIN. On the other hand, some algal anticoagulant polysaccharides exert anticoagulant activity by directly inhibiting fibrin polymerization and/or thrombin activity without potentiating ATIII and HCII. Algal anticoagulant polysaccharides activate the fibrinolysis system and modulate endothelial cell functions (Matsubara 2004). The anticoagulant properties are assessed by the activated partial thromboplastin time (APTT) assay, prothrombin time (PT) and thrombin time (TT) using normal human plasma. As reported in Matsubara *et al*. (2000) some *Codium* species such as *C. fragile* subsp. *atlanticum*, *C. latum* and *C. pugniformis* were investigated for their anticoagulative properties and anticoagulants isolated from *Codium* spp. include glucuronoxylorhmannans, glucuronoxylorhamnogalactans, xyloarabinogalactans, xylogalactoarabinans and galactoarabinan. The composition of *C. pugniformis* was mainly glucose with minor amounts of arabinose, highly sulfated, and contained a small amount of pro-tein, so it was a proteoglycan. However, according to the APTT assay, the anticoagulant activity of proteoglycan from *C. pugniformis* was weaker than that of heparin at 1.5 μg/ml (64.3 and >300 s, respectively).

Among seven enzymatically hydrolyzed brown algal species (*Ecklonia cava*, *Ishige okumurae*, *Sargassum fulvellum*, *S. hornei*, *S. coreanum*, *S. thunbergii* and *Scytosiphon lomentaria*), *E. cava* had the highest anticoagulant activity according to the APTT assay (Athukorala *et al*. 2006). An active component was purified from the enzymatic extract of this alga. It was determined to be highly sulfated and mainly composed of fucose and a small amount of galactose. At 0.7 μg/ml pure SPs from *E. cava* showed better anticoagulant activity (APTT, 60 s) than heparin (78 s). According to the results of the activated coagulation factor assay, the purified compound strongly interferes with the coagulation cascade by inhibiting biological activity of serine proteases.

The fucoidan from brown seaweeds can beneficially impact an immune system's health by stimulating immunoreactions of the humoral and cellular types, and by enhancing macrophage phagocytosis (Patankar 1993).

Stoechospermum marginatum (Ag.) Kutz. is a brown algae rich in sulfated fucans and known to possess spasmogenic activity. Sulfated fucan from water extract of *S. marginatum* was isolated, purified and analyzed for its chemical and biological properties (Adhikari *et al*. 2006).

CONCLUSIONS

In conclusion, different polysaccharides as bioactive compounds obtained from mainly three classes of algae, especially Phaeophyta, Rhodophyta and partially Chlorophyta, are being extensively investigated for their potential benefits in medicine and pharmacology. These polysaccharides show differences in their composition (e.g. sugar content, methyllation and degree of sulfation, etc.). The differences in these polysaccharides contribute to the biological activities such as antimicrobial, antiviral, antitumoral, etc.

REFERENCES

Adhikari U, Mateu CG, Chattopadhyay K, Pujol CA, Damonte EB, Ray B (2006) Structure and antiviral activity of sulfated fucans from *Stoechospermum marginatum*. *Phytochemistry* **67 (22)**, 2474-2482

Athukorala Y, Jung W-K, Vasanthan T, Jeon Y-J (2006) An anticoagulative polysaccharide from an enzymatic hydrolysate of *Ecklonia cava*. *Carbohydrate Polymers* **66**, 184-191

Bhadury P, Wright PC (2004) Exploitation of marine algae: biogenic compounds for potential antifouling applications. *Planta* **219**, 5611-578

Boisson-Vidal C, Haroun F, Ellouali M, Blondin C, Fischer AM, de Agostino A, Jozefonvicz J (1995) Biological activities of polysaccharides from marine algae. *Drugs of the Future* **20**, 1237-1249

Chattopadhyay K, Mateu CG, Mandal P, Pujol CA, Damonte EB, Ray B (2007) Galactan sulfate of *Grateloupia indica*: Isolation, structural features and antiviral activity. *Phytochemistry* **68 (10)**, 1428-1435

Costa LS, Fidelis GP, Cordeiro SL, Oliveira RM, Sabry DA, Câmara RBG, Nobre LTDB, Costa MSSP, Almeida-Lima J, Farias EHC, Leite EL, Rocha HAO (2010) Biological activities of sulfated polysaccharides from tropical seaweeds. *Biomedicine and Pharmacotheraphy* **64 (1)**, 21-28

Engel S, Puglisi PM, Jensen PR, Fenical W (2006) Antimicrobial activities of extracts from tropical Atlantic marine plants against marine pathogens and saprophytes. *Marine Biology* **149**, 991-1002

Gamal-Eldeen AM, Ahmed EF, Abo-Zaied MA (2009) *In vitro* cancer chemopreventive properties of polysaccharide extract from the brown alga, *Sargassum latifolium. Food and Chemical Toxicology* **47 (6)**, 1378-1384

Harada H, Yamashita U, Kurihara H, Fukushi E, Kawabata J, Kamei Y (2002) Antitumor activity of palmitic acid found as a selective cytotoxic substance in a marine red algae. *Anticancer Research* **22**, 2587-2590

Harden EA, Falshaw R, Carnachan SM, Kern ER, Prichard MN (2009) Virucidal activity of extracts from four algal species against herpes simplex virus. *Antiviral Research* **83 (3)**, 282-289

Hay ME, Fencail W, Gustafson K (1987) Chemical defense against diverse coral reef herbivores. *Ecology* **68**, 1581-1591

Kanai Y (2008) Alterations of DNA methylation and clinicopathological diversity of human cancers. *Pathology International* **58**, 544-558

Matsubara K, Matsuura Y, Hori K, Miyazawa K (2000) An anticoagulant proteoglycan from the marine green alga, *Codium pugniformis*. *Journal of Applied Phycology* **12**, 9-14

Matsubara K (2004) Recent advances in marine algal anticoagulants. *Cardiovascular and Haematological Agents* **2 (1)**, 13-19

Mayer AM, Gustafson KR (2003) Marine pharmacology in 2000: antitumor and cytotoxic compounds. *International Journal of Cancer* **105**, 291-299

Mohammed KA, Hossain CF, Zhang L, Bruick RK, Zhou Y-D, Nagle DG (2004) Laurenditerpenol, a new diterpene from the tropical marine alga *Laurencia intricata* that potently inhibits HIF-1 mediated hypoxic signaling in breast tumor cells. *Journal of Natural Products* **67**, 2002-2007

Neushul M (1990) Antiviral carbohydrates from marine red algae. *Hydrobiologia* **204/205**, 99-104

Oh KB, Lee JH, Chung SC, Shin J, Shin HJ, Kim HK, Lee HS (2008) Antimicrobial activities of the bromophenols from the red algae *Odonthalia corymbifera* and some synthetic derivatives. *Bioorganic and Medicinal Chemistry Letters* **18 (1)**, 104-108

Patankar MS, Oehninger L, Barnett T, Williams RL, Clark GF (1993) A revised structure for fucoidan a explain some of its biological activities. *Journal of Biological Chemistry* **68**, 21770-21776

Pereira HS, Leão-Ferreira LR, Moussatché N, Teixeira VL, Cavalcanti DN, Costa LJ, Diaz R, Frugulhetti ICPP (2004) Antiviral activity of diterpenes isolated from the Brazilian marine algae *D. menstrualis* against human immunodeficiency virus type 1 (HIV-1). *Antiviral Research* **64**, 69-76

Queiroz KCS, Medeiros VP, Queiroz LS, Abreu LRD, Rocha HAO, Ferreira CV, Jucá MB, Aoyama H, Leite EL (2008) Inhibition of reverse transcriptase activity of HIV by polysaccharides of brown algae. *Biomedicine and Pharmacotheraphy* **62**, 303-307

Reddy P, Urban S (2009) Meroditerpenoids from the Southern Australian marine brown algae *Sargassum fallax*. *Phytochemistry* **70**, 250-255

Takamatsu S, Hodges TW, Rajbhandari I, Gerwick WH, Hamann MT, Nagle DG (2003) Marine natural products as novel antioxidant prototypes. *Journal of Natural Products* **66**, 605-608

Tischer de PC, Talarico LB, Noseda MD, Guimarães SMPB, Damonte EB, Duarte MER (2006) Chemical structure and antiviral activity of carrageenans from *Meristrella gelidium* against herpes simplex and dengue virus. *Carbohydrate Polymers* **63 (4)**, 459-465

Vairappan CS (2003) Potent antibacterial activity of halogenated compounds from Malaysia red algae, *Laurencia majuscula* (Rhodomelaceae, Ceramiales). *Biomolecular Engineering* **20 (4-6)**, 255-259

Witvrouw M, de Clercq E (1997) Sulfated polysaccharides extracted from sea algae as potential antiviral drugs. *General Pharmacology* **29 (4)**, 497-511

Xu N, Fan X, Yan X, Li X, Niu R, Tseng CK (2003) Antibacterial bromophenols from the marine red algae *Rhodomela confervoides. Phytochemistry* **62**, 1221-1224

Zhu W, Chiu LC, Ooi VEC, Chan PKS, Ang Jr. PO (2006) Antiviral property and mechanism of sulfated polysaccharides from the brown alga *Sargassum patens* against *Herpes simplex virus* type I. *Phytomedicine* **13**, 695-701