Diversity of bioactive polysaccharide originated from marine sources: A review

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A multitude of marine organisms, including shellfish, sponge, seaweed, marine fungi, microalgae, and corals, are very efficient sources of polysaccharides with number of interesting functional properties. Marine-based polysaccharides as the counterparts of terrestrial animals have great potential to be used for food processing, long-term storage, and fortification, as well as in medicine industry as carriers of drugs and as nutraceuticals. This review will encounter the recent findings on the different mechanisms of anti-viral actions of marine polysaccharides. Their potential for therapeutic application is also summarized to a certain level. The potential food applications of marine polysaccharides along with their chemical nature is discussed in later half. This review covers a significant amount of vital information on the chemistry and biological potential of the bioactive brominated compounds, heterocyclics (nitrogen and nitrogen-sulphur) and sulfated polysaccharides isolated from marine algae, fungi and bacteria.

[Keywords: Marine polysaccharides; Antimicrobial activity; Antiviral activity; Anticoagulant activities]

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Introduction

Habitats from marine have been found to provide various interesting polysaccharides including β-glucan, laminarin, alginic acid, galactan, carrageenan and chitin¹. Polysaccharides belong to a major class of biologically active compounds which can be isolated from marine creatures. Polysaccharides possess significant importance in extending the shelf-life or processed foods and enhance their quality and acceptability at consumer level¹. Carbohydrates, mostly found in cell walls as structural compounds and the essential composition of polysaccharides reflect a remarkable ability by constituting about 75% of dry weight of plant community belonging to both land and marine resources¹.

Since marine microorganisms inhabit in critical aquatic conditions, they produce a vast majority of biologically active chemical compounds with diverse range of novel functions and therapeutic uses². Researches on new drug discovery from marine resources have given an extra credit on the discovery of noble type of polysaccharides from marine aquatic environment³⁴.

In drug discovery, an enormous variety belongs to marine polysaccharides which are chemically complex in structures and are considered novel sources of compounds for therapeutic applications⁵. In addition, based on the different sources, marine polysaccharides can be categorized in different types including the marine animal polysaccharide, plant polysaccharide and microbial polysaccharide⁶. Polysaccharides derived from marine resources have been found to display variety of important roles in medicinal purposes as well as their various reported biological activities including antioxidant, immunoinflammatory, antitumor, antiviral, and anticoagulant effects. Nowadays marine polysaccharides are paving a way for new trends in anti-viral therapy, since marine polysaccharides and their oligosaccharide derivatives are being investigated to certain extended levels for their anti-viral mode of actions⁷.

This review provides an overview of recent progress and research on the marine polysaccharides, relating to their structural features and biological and therapeutic efficacy. It consists information on their potent applications in food industry along with major diversity of polysaccharide producers in marine
environment. In later half, the chemical nature of polysaccharide and their various biological potentials is also discussed. Present study also consists substantial information on marine polysaccharides and recent developments on their anti-viral mechanisms in regard to marine environment.

**Major marine sources of interest**

**Algae**

Algae constitute a long fossil history and belong to a group of heterogeneous plants. Algae are identified based on their two major types which include the macro-algae (seaweeds) such as green algae, brown algae and red algae, occupying the littoral zone, and the micro-algae of bentheic and littoral habitats as phytoplankton all over the marine area such as diatoms (bacillariophyta), dinoflagellates (dinophyta), green and yellow-brown flagellates, and blue-green algae (cyanobacteria). Different marine algae produce different and various kinds of algal metabolites which have been found to exert a number of biological properties including anti-infective, anti-inflammatory, and anti-proliferative activities with a potential industrial significance. Secondary metabolites produced by algae represent a wide variety of chemical structures from simple acyclic entities with a linear chain to complex polycyclic molecules. Marine algae are also considered good producers of biologically active compounds which include terpenoids, phenolics, alkaloids, and polysaccharides as well as composition of various fatty acids. Since decades, these marine algal metabolites have been used practically in several therapeutic efficacy of medical and pharmaceutical significance. Special significance has been given to macro-algae (seaweeds) which are considered as foods in Asian countries including Korea, China and Japan. Crude formulations of seaweeds as traditional therapy have also been used to treat various common diseases such as iodine deficiency, goiter, and hyperthyroidism. A number of seaweeds have been reported to be the reservoirs of vitamins and are used to treat stomach disorders as effective vermifuges, hypcholesterolaemic and hypoglycaemic drugs. Although marine micro-algae are significant sources of beneficial secondary metabolites, not much relevance has been given on the search of novel drugs from marine algae such as anti-infective molecules. The cyanobacteria or blue-green algae have several common structural features present in bacteria. The main unique feature of blue-green algae make them different from bacteria is the presence of chlorophyll in them, considered to be in class of algae. Due to presence of chlorophyll, cyanobacteria are known as photosynthetic prokaryotes with an ability to produce various biologically active complexly structured compounds including cyclic polyethers and nitrogenous compounds. Reports have revealed the practical uses of most of the polysaccharides including agars, carrageenans, algacines and their derivatives along with fucoids and laminarin in food industry derived from macro-algae. Nowadays, a red alga *Porphyridium cruentum* and *Spirulina* have shown great industrial potential due to the production of sulphated expopolysaccharides. In addition, sulphated galactans derived from macro-algae have gained significant importance as value added food ingredients due to their gelling and binding characteristics as well as higher biological efficacy.

**Fungi**

A majority of fungal species belonging to marine environment are considered to be the most potential producers of biologically active secondary metabolites. Several reports have been published on the isolation, and development of marine fungal metabolites. Marine world provides a huge and versatile treasure of filamentous fungi with significant sources of novel fungal metabolites, resulting in the immergence of new area of multidisciplinary research. Nowadays marine derived fungal metabolites have multiple applications in medical and therapeutic purposes with diverse range of biological efficacy to serve as novel biomolecules in the treatment of chronic and severe diseases including AIDS, Cancer, Alzheimer’s disease and arthritis which are very critical to cure. Hence, study on marine fungi and their potential bioactive compounds are gaining significant importance. Since scarce information is available on marine filamentous fungi, this review will provide some insights on reviewing marine filamentous fungi and their secondary metabolites with special interest focusing on their biological potential.

**Sponge**

Since decades, marine sponges have showed great potential of chemical diversity. A number of published reports have been reported on the isolation
and characterization of various biologically active molecules from sponges including nucleosides, bioactive terpenoids, sterols, peptides, alkaloids, fatty acids, peroxides and amino acid derivatives. In evaluation of sponges, their primitive appearance has given them a prolonged time to develop them to a stable form and to give them a firm identity leading to the diverse chemical defence ability to survive in a crucial marine environment. A vital phenomenon is that regulation of secondary metabolite biosynthesis is correlated with marine sponges as they experience similar conditions in marine environment. A number of marine sponge based secondary metabolites complex in their chemical structures and their biosynthetic pathways are the important indicators of their immense survival ability. A number of infectious diseases caused by deleterious microorganisms which are also getting developed resistance to commercially available drugs has open a new way to explore lead molecules from marine sponges to combat against these serious concerns\cite{19,20}.

**Marine environment to produce polysaccharides**

Micro-flora such as bacteria, actinobacteria, cyanobacteria and fungi along with macro-flora (seaweeds) including marine flowering plants such as mangroves and other halophytes make a diverse marine flora. The marine world, occupying 71% of marine area is a rich source of microbial biodiversity where marine flora constitutes a 90% oceanic biomass\cite{21}. This diverse range of marine flora offers a great scope for drug discovery and for developing new and novel types of biomolecules of marine origin. Marine environment has offered a large number of natural products as novel antibiotics of diverse and complex chemical structures with unique biomedical properties that may play a significant role in the treatment of various chronic and specific human diseases with greater efficacy in future therapeutic applications\cite{22}. A long history of the existence of marine flora from 3.5 billion years and biosynthesis of numerous marine natural products has remained unchanged and given a continued contribution as the best sources of chemical compounds. These marine floras surviving in very critical marine environment such as extreme pressure variations, salinity, and temperature produce diverse range of unique chemical compounds which are outstanding in their diversity, chemical structures and functional properties\cite{23}.

Fig. 1-Schematic representation on various roles of exopolysaccharides (EPS) in marine environment. Each number indicates the different processes involving EPS. 1, production of EPS by bacteria and phytoplankton; 2, production of TEP from EPS; 3, microbial loop; 4, form action of particles; 5, chelation of dissolved metals and 6, EPS as a carbon source for benthic community.

Phytoplanktons are considered good sources of polysaccharides production from their cells in the external medium. Nutrient deficiency during the stationary growth phase may result in the maximum polysaccharide production\cite{24}. The n-ernalization of algal materials which occurs by extracellular algal products may stimulate bacterial growth and activity during the natural bloom of phytoplanktons\cite{25}. It has been hypothesized that exudates of phytoplanktons evolve a diverse mechanism in order to establish a bacterial mutualism\cite{26}. This mutualism helps to dissolve organic nitrogen and phosphorus components leading to the formation of an algal polysaccharide layer whereas bacteria hydrolyze the polymers on the algal cell surface due to the presence of hydrolytic enzymes\cite{26}. Although nutrient stress to algal flora may result in the higher production of polysaccharides, which helps to maintain the mutualism but resulting in aggregation and sinkage, their metabolism becomes heterotrophic and most cells die. However, mucus is colonized by the bacteria rendering it even stickier\cite{27}. A schematic representation on various roles of exopolysaccharides in marine environment has been summarized in Fig. 1.
Major food application of polysaccharides

Due to various functional properties of polysaccharides, they can be used as good sources of food additives making them to be used as emulsifiers, ingredientbinders, viscosity modifiers, foam stabilizers, thickening agents, stabilizers and water-retention compounds. Use of polysaccharides can stop the crystal growth in ice creams, and they also improve satiety in the products containing fluid and mixed gel. Due to the natural origin of weak gels of biopolymers, they are commonly used in food products as safe food additives as compared to synthetic food additives. In food commodity, polysaccharides in combination with sugars, corn syrup, and dextrose represent 90% of additive use due to their interesting functional properties.

Due to the desired consumer demand and stability of products, polysaccharides have been used in food industry as thickeners and stabilizers in various foods and food products even at very low concentrations. Use of polysaccharides has significant importance in food industry due to their various functional properties including thickening and viscosity which mainly depend on the following features including concentration of substrate polysaccharides, molar mass, solvent characteristics, stiffness of the polymer, temperature, and shear rate. Applications of polysaccharide use have significant impact on the improvement of food stability, control of syneresis, flavor enhancement, fat replacement, and improvement in the fiber contents of food products. Polysaccharides on interaction with water may also influence the quality and stability of various foods of everyday meal including frozen desserts, confectioneries, salad dressings, puddings, gravies, and cheese.

Polysaccharides have also given a significant contribution in bakery products. For example, polysaccharides in combination with hydrocolloids are commercially used in baking to facilitate processing, compensate in variations for raw materials, assurance of quality maintenance and to prolong and maintain the functional food properties and freshness of food products. Inclusion of polysaccharides as additives enhance the stability and dough handling properties of food products along with viscoelasticity and other quality assurance parameters including water absorption ability and specific loaf volume which may be a possibility of replacing wheat protein gluten. Dietary fibers play a significant role in human by reducing absorption of nutrients in the intestine, colonic luminal toxicity, systemic effects, and by the changes in colonic microflora along with a direct effect on colonic mucosa. Increased amount of fiber intake decrease food transit time and adds bulk to the stool. Intestinal microflora metabolize dietary compounds mainly carbohydrates which are not hydrolyzed or absorbed in upper gastrointestinal tract. Polysaccharides significantly influence intestinal micro-flora, resulting in the release of energy through the microbial fermentation. A few selected bacteria such as Lactobacillus casei, L. acidophilus, L. plantarum, L. crispatus and Bifidobacterium longum have been found to exert health promoting effects especially with respect to their influence on mucosal and systemic immune responses to disease. Such health beneficial effects can be modulated by substrate polysaccharides, supporting the growth, survival and the development of bacteria.

Molecular level studies on polysaccharides and their interactions with food ingredients may provide great insights on the practical applications of such polymers in food industries. A detailed description on the interaction of polysaccharides among the food ingredients and effect of different processing conditions has been summarized in Table 1.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Affects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing parameters</td>
<td>Temperature and shear rate significantly influence the rheological properties resulting in the change of food texture</td>
</tr>
<tr>
<td>Salt</td>
<td>Salt incorporation can influence the behavior of hydrocolloids; such as cations including as Na⁺, K⁺, and Ca²⁺; influence the gelation of alginate and κα-carrageenan.</td>
</tr>
<tr>
<td>Sugar</td>
<td>The texture of ice cream and desserts is significantly influenced by the presence of sugar. Sugar reactivity of some hydrocolloids also influences Gelation. The molecular diversity of a simple hydrocolloid influences textural properties through its effect on gelation, oil emulsification, and foam stability.</td>
</tr>
</tbody>
</table>

Chemical composition of marine polysaccharides

Polymers of simple sugars such as monosaccharides linked together by glycosidic bonds are called polysaccharides. Polysaccharides have various applications in food industry serving as
stabilizers, thickeners, emulsifiers, food, feed, and beverages. The marine macro-flora (seaweeds) represents an interesting concentration range of polysaccharides from 4-76% of the dry weight. Although marine species Ascophyllum, Porphyra and Palmaria have been reported to possess highest contents of polysaccharides, green seaweed Ulva has shown polysaccharide contents up to 65% of dry weight. The polysaccharides, main components of algal cell wall, mainly consist of cellulose and hemicelluloses, neutral polysaccharides, supporting physical strength of algal thallus during water streaming. These polysaccharides serve as building blocks to the marine macro-flora during movement or motility of thallus in the water which are comparatively less strong than terrestrial plants or trees. Recently Stepfan in his excellent review on algal polysaccharides reported that cellulose and hemicellulose contents of macro-flora (seaweeds) of great interest ranging from 2-10% of dry weight.

Most of the marine microorganisms produce hetero-polysaccharides which are composed of complex carbohydrate molecules supported with repeating units of different monosaccharides joined by glycosidic bonds in them. Hexose (glucose, galactose and mannose), pentose (arabinose, xylose and ribose) and deoxy sugars (fucose and rhamnose) represent most common monosaccharides of marine polysaccharides. In marine biotechnology, neutral monosaccharides or neutral sugars terminologies have also been used to define the monomers of marine polysaccharides especially during the application of chromatographic techniques for the chemical composition analysis of monosaccharides.

Marine algal species produce alginates, agar, and carrageenans types of polysaccharides. Some selected genera of marine world belonging to red-algae such as Gelidium and Gracilaria produce unbranched polysaccharide agar which is chemically synthesized by galactose sugar molecules. Agar polysaccharide provides structural support to the cell wall of algal species.

Carrageenans polysaccharides have significant importance in filling the space between cellulosic plant structures of seaweeds which are derived by the alteration in 1,3- and 1,4-linked galactose residues. The contents of different monomers in the total polysaccharides differ relatively based on the sources of specific micro- or macro-flora. For instance, bacterial polysaccharides are usually rich sources of glucose and galactose, whereas phytoplankton polysaccharides possess relatively higher contents of rhamnose, xylose and mannose. It has been reported that during the bloom of phytoplankton large amount of dissolved polysaccharides is released with variations in their chemical composition profile.

In addition, a marine bacterium Alteromonas infernus produces very acidic and highly branched heteropolysaccharide, an exo-polysaccharide of high molecular weight with low sulfate contents. The monosaccharide units in this expolysaccharide are composed of uronic acid (galacturonic and glucuronic acid) and neutral monosaccharides including galactose and glucose, with one reduced group of sulfate molecule. Conclusively, the polysaccharides derived from marine microbial flora with novel chemical composition profile and diverse structural features have shown great potential of
practical applicability for their uses in food, pharmaceutical and medicine industries. A brief description of chemical structures with preponderant repeating units of few selected polysaccharides has been given in Fig. 2, and Fig. 3.

**Potential health benefits of polysaccharides from diversity of marine sources**

The marine world as a rich source of microbial diversity represents significant contribution in health benefits. Polysaccharides derived from marine world demonstrate various biological and pharmaceutical potentials including antioxidant, anti-proliferative, anti-tumor, anti-complementary, anti-inflammatory, anti-viral, anti-peptic, anti-adhesive and anti-coagulant potential. Although literature survey has provided a significant amount of information on marine polysaccharides, studies on relationship between structural and their biological and therapeutic potential have not been studied in great detail.[47. However, it is most likely to say that specific structural features of polysaccharides are certainly needed for demonstrating the biological or therapeutic efficacy as in case of sulfate clusters, which are needed to ascertain the interactions with cationic proteins.[48]

As reported in previous section that polysaccharides are polymers of monosaccharides linked together with glycosidic bonds, which demonstrate a structurally diverse class of biologically active macromolecules of marine diversity. Polysaccharide structural diversity originates from number of different sugars and sugar derivatives found in polysaccharides, since each sugar molecule is linked to other sugar molecule on sugar ring at different positions covalently. A number of reported studies have been demonstrated significant biological and therapeutic potential of marine polysaccharides with multiple health benefits. The marine polysaccharides have been used extensively in food and pharmaceutical industries. The chemical structures of few selected polysaccharides including fucoidan, carrageenan, ulvan, chitosan, galactan and γ-carrageenan have been reported here which have shown significant efficacy on human health (Fig. 4).

**Antioxidant activities of marine polysaccharides**

Nowadays research on natural antioxidants from marine resources has gained significant importance due the potential effect on reducing free radicals responsible for several chronic and degenerative diseases caused by oxidative stress. Antioxidants play a vital role against number of chronic human diseases such as cardiovascular diseases, cancer, inflammatory disorders, and neurodegenerative disorders such as Alzheimer’s diseases as well as in ageing.[50]

![Chemical structures of the repeating dimeric units of sulfated polysaccharides derived from major marine sources: (a) fucoidan; (b) carrageenan; (c) ulvan; (d) chitosan; (e) galactan; and (f) γ-carrageenan.](image)

Recently Wang et al.[50] reported that polysaccharide isolated from phaeophyta has played an important role as a potential source of free radical scavenger with significant antioxidant activity leading to prevention of oxidative damage in living cells. These findings have sustained the demand on the isolation of various polysaccharides from marine resources since marine environment is a rich source of microbial diversity. In addition, the polysaccharide-like products isolated from seaweed *Ecklonia kava* have been found to exert potential antioxidant effect as a scavenger of superoxide radicals.[51] Sulfated polysaccharides, fucoidans and ulvans isolated from seaweeds *Laminaria japonica* and *Ulva pertusa* have been found to work as highly effective antioxidants as compared to standard antioxidant ascorbic acid and showed potential efficacy against superoxide radicals.[50,52] Marine based sulfated polysaccharides have shown highly effective antioxidant potential against different free radicals even in some test assays their activity was quite lower than other standard antioxidant molecules.[53] Since there is not much information is available between the antioxidant mode of action of marine polysaccharides and their...
structural relationship, marine seaweeds have become significantly important sources to isolate and characterize highly purified polysaccharides from marine seaweeds with confirmed antioxidant mechanism of action. On the other hand, marine fungi have also gained a considerable amount of significance due to their great contribution in natural product research of therapeutic importance. Marine fungi are diverse in range which may provide a stable platform on the discovery of extra-cellular polysaccharides of marine origin with novel functions and complex chemical structures. Recently Wang et al. reported isolation of YSS extra-polysaccharide, a galactofuranose-containing branched galactomannan from a marine fungus A. terreus composed of mannopranose residues with extra branches consisting of galactofuranose residues and disaccharide units with mannopyranose. Upon testing, although YSS exhibited significant amount of free radical scavenging capacity against DPPH and hydroxyl radicals in vitro, its precise mode of action in vivo antioxidant model may further give insights on its practical applications in food and pharmaceutical industries. In addition, an extra-polysaccharide isolated from a marine fungus Penicillium sp. F23-2 found to serve as a good source of antioxidant agent.

A number of marine based sulfated polysaccharides isolated from marine algal species have been found to exert antioxidant activity in phosphatidylcholine-liposomal suspension and organic solvents. Kim et al. reported that sulfated polysaccharides isolated from marine algae Sargassum fulvellum shown more potential efficacy while scavenging NO radicals as compared to standard antioxidant molecules α-tocopherol and BHA. Moreover, fucan polysaccharides isolated from Fucus vesiculosus have also been found to display significant superoxide radical scavenging ability. A positive co-relation has also been reported for sulfate content, superoxide and hydroxyl radical assays in sulfated polysaccharide fraction of fucoidan isolated from brown alga Laminaria japonica. In addition, a number of sulfated polysaccharides isolated from marine seaweeds have shown appreciable antioxidant and free radical scavenging efficacy. A sulfated polysaccharide isolated from brown alga Sargassum tenerrimum can also be considered a significant sourced of antioxidant molecule. Guo et al. reported the isolation of two water soluble extra-cellular polysaccharides from a marine bacterium Edwardsiellatarda by ion-exchange and size-exclusion chromatography with potential antioxidant ability. The antioxidant efficacy of marine polysaccharides mainly associated with their monosaccharide contents, molecular mass and their complex structural diversity. Variations in molecular mass of different marine polysaccharides may cause a difference in the antioxidant activity since molecular mass of polysaccharides is one of the most important structural factors for their antioxidant activity. Recently Zhao et al. reported sulfated polysaccharides porphyrans of different molecular weights from red algae which showed great variations in their antioxidant activity, and a low molecular weight porphyran showed higher scavenging ability as compared to high molecular weight compounds, which was directly related to its hydrogen donating ability in DPPH radical scavenging assay. Although numbers of reported incidences of marine polysaccharides to serve as natural antioxidants are available in the literature, antioxidant mechanisms of marine polysaccharides are still complex and have not been fully characterized.

**Antiviral activities of marine polysaccharides**

Recent trends on anti-viral efficacy of marine based products, especially marine polysaccharides have gained significant importance world-wise due to their natural origin and beneficial health effects in human beings. Wang et al. reported anti-viral efficacy of marine polysaccharides and their low molecular weight derivatives, especially oligosaccharides which showed potential anti-viral activity. In addition, an acidic polysaccharide nostoflan isolated from an edible blue-green alga Nostoc flagelliforme has been found to exert significant anti-viral effect, and has been considered to an anti-HSV-1 component against herpes simplex virus type 1. During the study, it was observed that this nostoflan polysaccharide exhibits the viral propagation during early stages of viral binding and penetration process. To observe this phenomenon, the outcomes of viral binding and viral penetration assays confirmed that nostoflan induced anti-viral effect against herpes virus via inhibition of viral binding but not by penetration into the host cells. Also Sato et al. reported that a marine polysaccharide lectin isolated from filamentous cyanobacterium Oscillatoria agardhii NIES-204 showed potent anti-viral effect.
against HIV in MT-4 cell assay. Recently anti-herpes polysaccharides have shown great applicability as heparinoid polysaccharides, these cell surface heparinoid sulfate proteoglycans serve as initial receptors to human herpes viruses HSV-1, HSV-2 and bovine herpes virus for initial viral infection process which can interact with positively charge cell surface regions of glycoproteins, resulting in the shielding effect, thereby protecting viral binding on host cell surface. It has been also reported that dextran sulfate polysaccharide has ability to inhibit influenza virus especially showing its in vivo mode of action on cell membrane fusion. A number of sulfated fucans isolated from different seaweeds such as Lobophora variegata, Dictyota mertensii, Fucus vesiculosus and Spatoglossum Schroedleri have been found to exhibit inhibitory effect on HIV reverse transcriptase. A marine polysaccharide fucan isolated from Cladosiphon Kamuranus has been found to inhibit dengue virus type 2 in BHK-21 cells, along with a mild inhibitory effect against three other serotypes of dengue virus. Liquid proportions of carrageenan polysaccharide have been found to prohibit the infection caused by HSV type 2 virus,72. Similarly, liquid inocula of carrageenanin polysaccharide showed inhibitory effect against influenza virus A infection in mice model.73,74 Several studies on the mode of action of marine based sulfated polysaccharides have been reported in the literature against virus HIV type 1. These polysaccharides block the entry of virus in host cell by modulating its attaching ability to cell surface receptors. In addition, sulfated polysaccharides also display their anti-viral action against HIV-1 via shielding off the positively charged amino acids present in the viral envelope composed of glycoprotein gp120. These glycoproteins with highly V3 loop region interact with poly-anionic regions of host cell surface molecules. These findings were in accordance with previous report of Bourgougnon et al. who reported anti-HIV potential of sulfated glucurono-galactan isolated from Schizymenia dubyi. It was observed that sulfated galactan inhibited formation of syncytial and suppressed HIV-associated reverse transcriptase at very low concentration. Hence, it was determined that mode of action of sulfated galactan polysaccharide was correlated to its inhibitory action at early stage of viral infection and inhibition of viral host cell attachment.

Moreover, sulfated galactan polysaccharides isolated from Grateloupia filicina and Grateloupia longifolia have also been found to exert anti-viral effects in human peripheral blood cells and HIV type 1 virus. Recently, a marine sulfated polysaccharide p-KG03 isolated from marine a micro-alga Gyrodinium Impudium has also shown anti-viral effect against influenza virusin conjugation with uronic acid. Kim et al. based on the data obtained through fluorescence microscopy and viral binding assay confirmed direct effect of p-KG03 on virus particles. The p-KG03 exhibited better anti-viral activity as compared to other sulfated and commercially available polysaccharides. These findings confirm that sulfated polysaccharide p-KG03 of marine origin can be a new drug target for developing anti-viral drugs specifically against influenza A virus.

**Antimicrobial activities of marine polysaccharides**

A number of biologically active polysaccharides have been isolated from marine micro- and macro-flora such as bacteria, fungi, cyanobacteria, sponges, algae and seaweeds and gradually being evaluated for their biological and therapeutic efficacy including antimicrobial spectrum. It has been found that marine-based polysaccharides have shown great potential to act as effective antimicrobials. A versatile example of marine-based polysaccharide is chitinase, isolated from Streptomyces sp. associated with marine sponge Craniella australiensis which has shown broad spectrum of antifungal activity against some very important fungal pathogens including Aspergillus niger and Candida albicans. It is thought that sponge symbiosis may lead to chitin degradation resulting in effective antifungal defence mechanism. Intact physical state of chitosan supports it.
antibacterial activity, however, a liquid state of chitosan exhibits significantly higher antibacterial activity leading to in vivo shelf-life extension of food products. Ye et al. found that although chitosan display remarkable antibacterial efficacy in aqueous system, it has shown very less antibacterial activity against *L. monocytogenes* when tested on salmon fish food model in its natural physical state. There were no significant differences observed in control and treatment when chitosan was coated on antibacterial film in its intact form, this might be due to its inability to diffuse through a complex salmon matrix.

Moreover, a number of sulfated polysaccharides isolated from marine algal species such as *P. gymnospora* and *Dictyota dichotoma* have been found to exert antibacterial effect only against Gram+ bacteria in crude form. In contrast, a crude sulfated polysaccharide from *Hypneaus ciformis* displayed antibacterial activity against Gram-bacteria. However, a crude polysaccharide isolated from *Sargassum muticum* exhibited antibacterial activity against both Gram+ and Gram-bacteria. In addition, polysaccharides capisterones A and B, isolated from a green alga *Penicillus capitatus* revealed antifungal activity against fungal pathogens resistant to azole treatment. A phenolic compound isolated from marine sponge *Dysidea herbacea* exhibited strong antifungal efficacy against human fungal pathogens including *C. albicans* and *Aspergillus fumigatus* and its inhibitor effect was higher than commercial antifungal and/or antimycotic standard drug amphotericin B, leading to significant loss of potassium ions and caused deformity in fungal cell morphology, showing its effect on membrane integrity.

**Anticoagulant activities of marine polysaccharides**

Nowadays marine based sulfated polysaccharides have gained great deal of attention due to their important anticoagulant potential. Although especially low molecular weight heparin sulfated polysaccharides are currently used as potential anticoagulant agents, a few adverse effects have increased the demand of more and effective anticoagulant agents as safer anticoagulant agents from marine resources. Marine sulfated polysaccharides isolated from algal species have shown great potential of anticoagulant activity. In addition, broypsidales, dicotyotales and fucales orders belonging to chlorphyta and phaeophyta divisions are also considered significant producers of sulfated polysaccharides. The mode of action of sulfated polysaccharides as anticoagulants correlated to their inhibitory action on Xa and IIa factors mediated by antithrombin and heparin cofactor II. Pharmacological studies on fucoidan polysaccharides isolated from marine algae *Fucus evanescens* and *Laminaria cichorioides* have also confirmed the potent anticoagulant effect of fucoidans. Recently a low molecular weight polysaccharide was isolated from Italian mollusk *Callista chione* and characterized as sulfated heparin which was found to exert thrombo-plastin activity and suppressed anti-
factor Xa. Besides, sulfated galactan polysaccharides isolated from a red marine alga Gelidium crinale showed anticoagulant effect associated with 2,3-disulfated α-galactose units along the galactan chain which played a major role in anticoagulant activity of sulfated galactans, since galactan chains modulate polysaccharide interactions with target proteases and coagulation inhibitors. A detailed description of various biological activities of marine polysaccharides has been summarized in Table 2.

Conclusion
This mini review reports a brief survey of recent advances and applications of polysaccharides of marine origin in the food, pharmaceutical and medicine industries. Previous studies have provided scientific evidences that marine environment rich in microbial diversity plays a vital role in human health and nutrition with multitude of functional products. Moreover, induction of cancer cells in human body by free radicals and development of natural chemopreventive anticancer drugs from marine resources have gained significant importance in medicine industry. Among the available sources of polysaccharides, algal polysaccharides such as fucoidans and their derivatives may play an important role in cancer cell therapy and can be used potentially effective biomedical tools to cure degenerative diseases in future. In addition, polysaccharides of bacterial origin also represent real potential in cell therapy and tissue engineering with an advantage over the polysaccharides from eukaryotes, since they can be produced totally under controlled conditions in bioreactors. It is significantly necessary to make a proper use of the differences in the structural and functional relationship of different polysaccharides. Since polysaccharides are considered low toxic and less irritants, they might have better applications in human health concerns. However, continued efforts with a multidisciplinary approach are imperative in order to develop novel types of polymers useful as drugs or for human healthcare system.

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