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New Trends for Utilization of Polysaccharides as Antimicrobial Agents

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1. Introduction

Polysaccharides are natural, non-toxic, and biodegradable biopolymers that cover the surface of most cells and play important roles in various biological mechanisms such as immune response, adhesion, infection, and signal transduction. Investigations on the alternative treatments applied by different cultures throughout the history revealed the fact that the utilized plants and fungi were rich in bioactive polysaccharides with proven immunemodulatory activity and health promoting effects in the treatment of inflammatory diseases and cancer. Hence considerable research has been directed on elucidating the biological activity mechanism of these polysaccharides by structure-function analysis [1]. Biopolymers contain monomeric units covalently bonded to form large structures. There are three main classes of biopolymers based on the monomeric units and the structure: 1) Polysaccharides; 2) Polypeptides; and 3) Polynucleotides. Polysaccharides are polymers of carbohydrates with a numerous structural diversity, from long linear repetition of the same monomer to highly branched structures of different sugars. This high structural diversity reflects the functional diversity of these molecules. Polysaccharides are produced not only by microorganisms, but also by algae, plants and animals [2]. Bacterial polysaccharides are a major component of the extracellular polymeric substance or matrix of biofilms, and mediate most of the cell-to-cell and cell-to-surface interactions required for biofilm formation and stabilization [3].

Bacterial polysaccharides represent a diverse range of macromolecules that include peptidoglycan, lipopolysaccharides, capsules and exopolysaccharides; compounds whose functions range from structural cell-wall components (e.g., peptidoglycan), and important virulence factors (e.g., Poly-N-acetyl glucosamine in S. aureus), to permitting the bacterium to survive in harsh environments (e.g., Pseudomonas aeruginosa in the human lung). Polysaccharide biosynthesis is a tightly regulated, energy intensive process and understanding the subtle interplay between the regulation and energy conservation, polymer modification and synthesis, and the external ecological functions is a huge area of research. High efficiency applications of bacterial polysaccharides in medicine, in food industry, and renewable energy production are reported. Topics include: peptidoglycan, lipopolysaccharide, arabinogalactan, capsule gene expression in Escherichia coli, immune response to polysaccharides, polysaccharides from periodontopathic bacteria, role in dental plaque, biofilms, levan, amylovoran and much more [4].

Bacterial strains that develop or acquire resistance to one or more first-line antimicrobials pose numerous challenges to healthcare, including: increased patient morbidity and mortality, increased drug costs, prolonged illness duration, and more expensive disease control measures [5]. These antimicrobial resistant (AMR) strains arise, in part, as a result of antimicrobial use that selects for resistant organisms. Inappropriate antimicrobial use therefore contributes unnecessarily to the rise in resistance. As AMR genes or plasmids can be readily transmitted between bacterial species, surveillance of AMR trends is critical for the rapid detection of new isolates and continuous monitoring of disease prevalence [6]. Antimicrobial resistance and non-susceptibility are terms used to describe an organism's ability to survive in the presence of antimicrobial agents. Organisms are tested for susceptibility to antimicrobial agents in the laboratory using the Minimum Inhibitory Concentration (MIC) breakpoints. The MIC breakpoint is the lowest concentration of the drug that will inhibit growth of the pathogen. The term non-susceptible is used for organisms with isolates that exhibit both resistant and intermediate resistance to a particular antibiotic. This review article deals with the current knowledge of the polysaccharides and importance of biologically active polysaccharides as antimicrobial agents.

2. General Polysaccharides

By far the majority of carbohydrate materials in Nature occur in the form of polysaccharides. Polysaccharides include not only those substances composed only of glycosidically linked sugar residues, but also molecules that contain polymeric saccharide structures linked via covalent bonds to amino acids, peptides, proteins, lipids and other structures. Polysaccharides, also called glycans, consist of monosaccharides and their derivatives. If a polysaccharide contains only one kind of monosaccharide molecule, it is known as a homo-polysaccharide, or homoglycan, whereas those containing more than one kind of monosaccharide are heteropolysaccharides. The most common constituent of polysaccharides is glucose, but fructose, galactose, mannose, arabinose, and xylose are also frequent. Polysaccharides are a structurally diverse class of macromolecules able to offer the highest capacity for carrying biological information due to a high potential for structural variability [7]. Whereas the nucleotides and amino acids in nucleic acids and proteins effectively, interconnect in only one way the monosaccharide units in polysaccharides can interconnect at several points to form a wide variety of branched or linear structures. This high potential for structural variability in polysaccharides gives the necessary flexibility to the precise regulatory mechanisms of various cell-cell interactions in higher organisms. The polysaccharides of mushrooms occur mostly as glucans. Some of which are linked by β-(1---3), (1---6) glycosidic bonds and α-(1---3)-glycosidic bonds but many are true heteroglycans. Most often there is a main chain, which is either β-(1---3), β-(1---4) or mixed β-(1---3), β-(1---4) with β-(1---6) side chains. Hetero-β-D-glucans, which are linear polymers of glucose with other D-mono-saccharides, can have anticancer activity but α-D-glucans from mushroom usually lack anticancer activity [7]. Heteroglucan side chains contain glucuronic acid, galactose, mannose, arabinose or xylose as a main component or in different combinations. The number of potential polysaccharide structures is almost limitless but in practice many such polymers are unlikely to possess useful physical properties. Even now it is difficult to relate the chemical structure elucidated for any specific polysaccharide to its physical functionality .Currently only a small number of biopolymers are produced commercially on a large scale. However, this limited group of products exhibits an extensive range of physical properties and also provides several models for study by microbiologists, carbohydrate and physical chemists and molecular biologists [8]. Polysaccharides widely exist in the plants, microorganism (fungi and bacteria), algae, and animals. Together with proteins and polynucleotides, they are essential biomacromoleules in the life activities and play important roles in cell–cell communication, cell adhesion, and molecular recognition in the immune system [9].

Polysaccharides are usually composed of various monosaccharides linked with different glucosidic bonds. Some polysaccharides have hyperbranched structures. Moreover, polysaccharides often have high molecular weights, and tend to form aggregates in solution that can mask the behavior of individual macromolecules. In consequence, to characterize the chemical structures and chain conformations of polysaccharides is not an easy task. Depending on source and chemical manipulation, polysaccharides exist in a variety of chemical compositions, architectures, molecular weights and structures. Also polysaccharides can be neutral (pullulan, dextran, cyclodextrins, chitin, starch, cellulose, etc…), positively charged (chitosan), or negatively charged (alginate, heparin, hyaluronic acid, pectin, etc…) The glycosylic polyelectrolytes bonds involved in the monomer condensation determine the conformational structure of these macromolecules which can be linear, branched, or circular (Fig.1). Polysaccharides are a large family of biopolymers constituted by sugar monomers linked together by O-glycosidic bonds that can be made to any of the hydroxyl groups. Natural polysaccharides can be obtained from different sources, namely algae (e.g., alginate), plants (e.g., pectin, guar gum), microorganisms (e.g., bacteria, fungi such as dextran, xanthan gum, pullulan), and animals (e.g., chitin, chondroitin). Instead, semi-synthetic polysaccharides have been produced bychemical or enzymatic modification of the parent macromolecules [10].

Polysaccharides can interact with living cells displaying biological properties such as antioxidant, antimicrobic, antimutant, cell differentiation, anticoagulant, immunostimulant [11]. Heparins and fucose-containing sulfated polysaccharides, for example, possess blood-anticoagulant activities [12]. Several polysaccharides and glycoproteins from seaweed have immunostimulant, antitumoral, or antiviral activity. β-glucans located in microorganisms and cereals stimulate the immune system, modulating humoral, and cellular immunity, and thereby have beneficial effect in fighting infections, i.e., bacterial, viral,

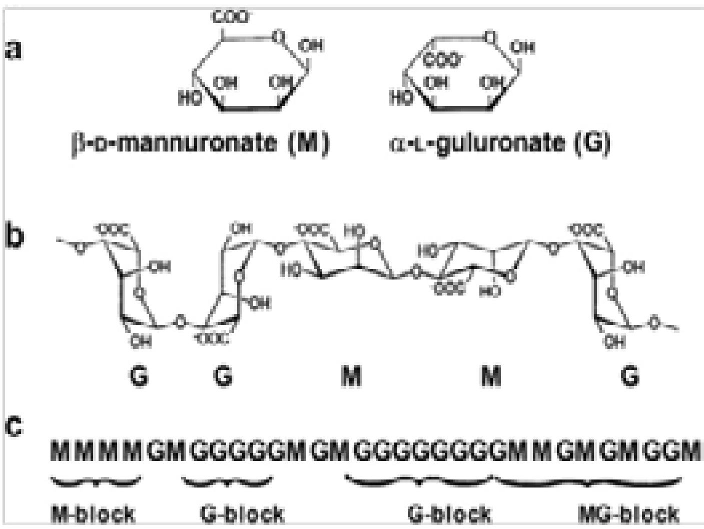

Figure 1: Structural characteristics of alginates: (a) alginate monomers, (b) chain conformation, (c) block distribution.

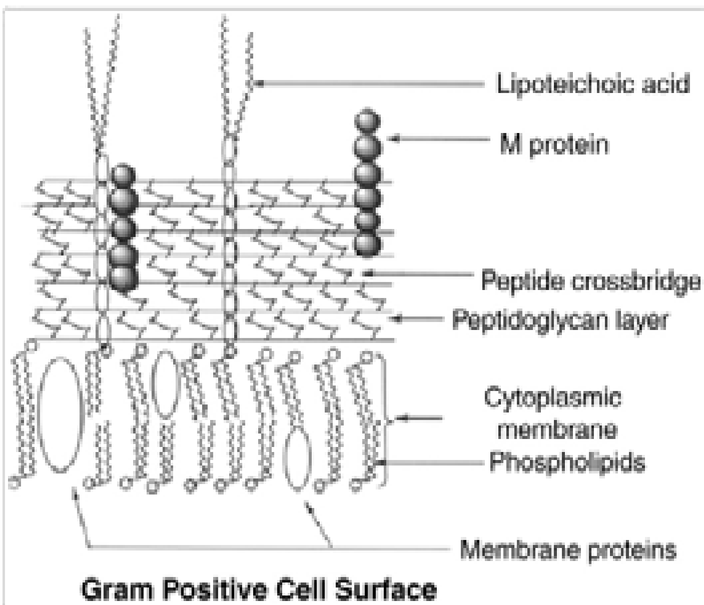

Figure 2: Schematic view of the Gram-positive bacterial cell envelope

fungal, and parasitic [13]. Hyaluronans are involved in a number of cell functions in mammalians and have a role in inflammation and cancer biogenesis. Due to their excellent biocompatibility and physicochemical properties, structural polysaccharides such as starches and celluloses have been largely used in pharmaceutical formulation. On the other side, along with the expanded knowledge of features of functional polysaccharides, these compounds have evolved from inert excipients to functional biomaterials opening new perspectives in their use for development of innovative drug-delivery systems [14]. The use of polysaccharides as soluble drug carriers in bioconjugation technology represents one of the most challenging applications of these materials. The hydroxyl, carboxyl,

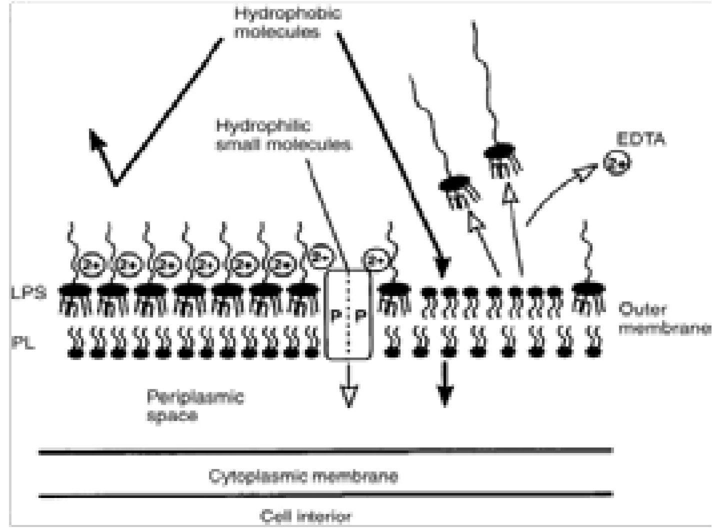

Figure 3: Schematic view of the Gram-negative bacterial cell envelope

and amino groups naturally present or artificially introduced in the polymer backbone can, in fact, be exploited for direct or spacer mediated drug conjugation yielding macromolecules bearing high number of drug units. The conversion of drugs into macromolecular prodrugs can improve their poor physicochemical and biopharmaceutical properties thus enhancing their therapeutic value. As a major class of biomolecules, carbohydrates are the most complex and least appreciated for their bioactivity. In the past three decades, an increasing number of reports describing the isolation and bioactivity of polysaccharide glucans and proteoglucans from plant and other sources highlight the potential role of this class of molecules in cancer therapy as a result of its immunostimulatory properties. In nature, polysaccharides work as defense system against environmental influences and bacteriophage attack, aid for attachment to surfaces, nutrient availability, and antigenicity. Polysaccharide categorization are complex but can be divided into four groups; α-D-glucans, β-D-glucans, fructans, and polygalactan, this grouping is based on linkage bonds and nature of monomeric units. Bonds between monomeric units at the backbone of the polymers are β-(1---4)- or β-(1---3)- linkages and α-(1---2)- or α-(1---6)-linkages. The differences between homo- and hetero-polysaccharide are not only reflected in the chemical nature and linkage bonds but in synthetic enzymes and site of synthesis [15].

3. Bioactive Polysaccharides

Natural polysaccharides with clearly elucidated compositions/structures, identified cellular activities, as well as desirable physical properties have shown the potential to serve as therapeutic tools for tissue regeneration [16]. There are an enormous variety of polysaccharides that can be synthesized and/or released by marine algae. Both these marine organisms are excellent sources of PSs, most of them sulfated (S-PSs). Although some similarities may be found between the PSs from each group of organisms, they can be very heterogeneous and structurally different [17]. Bacteria are a rich source of biologically active polysaccharides. On the base of structural properties, bacterial polysaccharides can be defined into five major classes: Exopolysaccharides (EPSs), capsular polysaccharides (CPSs), lipopolysaccharides (LPSs), peptidoglycans, and teichoic acids. Veronique [18]. The complex carbohydrates of terrestrial and marine biomass represent a rich nutrient source for free-living and mutualistic microbes alike. The enzymatic saccharification of these diverse substrates is of critical importance for fueling a variety of complex microbial communities, including marine, soil, ruminant, and monogastric microbiota [19]. Known bioactive polysaccharides are found in fungi, lichens, higher plants, marine as well as animal sources throughout the world, but some of the most well characterized and clinically relevant polysaccharides are found in Traditional Chinese Medicine [20], especially those herbs from the TCM materia medica classically characterized as tonic in nature or having 'Fu-Zhen' properties [21]. Many such tonic Chinese herbs have been found to possess immunomodulatory and other anti-tumor bioactivities and are potentially useful in cancer therapy. As such, the search and characterization of novel, safe and effective natural compounds from Chinese herbs is a significant goal for anti-cancer research.

4. Polysaccharides as Antimicrobial Agents

The main functions of polysaccharides are thought to be protective, either as a general physical barrier preventing access of harmful substances, or more specific as a way of binding and neutralizing bacteriophage. In appropriate environments they may prevent dehydration. In recent years; some bioactive polysaccharides isolated from natural sources have attracted much attention in the field of biochemistry and pharmacology. They exhibit various biological activities affected by different chemical structures [22]. Owing to its intrinsic antibacterial and film-forming properties, chitosan can be directly used to create antibacterial materials [23].

Chitosan as an example of antimicrobial polysaccharide is a polysaccharide consists of a biopolymer of glucosamine and N-acetyl glucosamine units linked by β-(1---4)-glycosidic bonds. Today, chitosan is mostly prepared commercially by the alkaline deacetylation of chitin. Chitin, composed of β (1---4)-N-acetyl-D-glucosamine units, is synthesized by a number of living organisms in the lower plant and animal kingdoms, serving many functions where reinforcement and strength are required [24]. Chitin is the major structural component in the exoskeleton of arthropods and the cell walls of fungi and yeast. The main commercial sources of chitin are crab and shrimp shells, which are abundantly supplied as waste products of the seafood industry. Chitin is an extremely insoluble material. More important than chitipolysaccharides are natural, non-toxic, and biodegradable biopolymers that cover the surface of most cells and play important roles in various biological mechanisms such as immune response, adhesion, infection, and signal transduction. Investigations on the alternative treatments applied by different cultures throughout the history revealed the fact that the utilized plants and fungi were rich in bioactive polysaccharides with proven immunomodulatory activity and health promoting effects in the treatment of inflammatory diseases and cancer. Hence considerable research has been directed on elucidating the biological activity mechanism of these polysaccharides by structure-function analysis [25].

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Bacterial polysaccharides represent a diverse range of macromolecules that include peptidoglycan, lipopolysaccharides, capsules and exopolysaccharides; compounds whose functions range from structural cell-wall components (e.g., peptidoglycan), and important virulence factors, to permitting the bacterium to survive in harsh environments. Polysaccharide biosynthesis is a tightly regulated, energy intensive process and understanding the subtle interplay between the regulation and energy conservation, polymer modification and synthesis, and the external ecological functions is a huge area of research. High efficiency applications of bacterial polysaccharides in medicine, in food industry, and renewable energy production are reported. Topics include: peptidoglycan, lipopolysaccharide, arabinogalactan, capsule

Table 1: Application of antimicrobial property of chitosan

Support(Perparation method)	Appliction	Tested microorganism
Chitosan acetates	Food Preservative[a]	Escherichia coli
		Staphylococcus aureus
Chitosan and its maillard reaction products	Food Preservative[a]	Bacillus subtilis CCRC 10258
Chitosan-hydroxy propyl methyl cellulose film	Packaging materials[a]	Listeria Monocytogenes
Chitosan/pdyet hulene oxide film	Packaging materials[a]	Escherichia coli
Chitosan-nylon-6/Ag blended membranes	Packaging materials[a]	Escherichia coli
		Staphylococcus aureus
Polypropylene/chitosan/pectin films	Packaging materials[a]	Bacteria:
		Clavibacter michiganensis
		Pseudomonas solanacearum
		Fungi:
		Fusarium oxysporum
		Verticillium albo-atrum
		Alternaria solani
Chitosan-hydroxy propyl methyl cellulose film	Edible films and coatings[a]	Aspergillus niger
Chitosan	Food additive[a]	Streptococcus
Alginate/chitosan fibers	Wound dressing materials[b]	Staphylococcus aureus
Quatemised chitosan nano-fibers	Wound-healing application[b]	Escherichia coli 3588
		Staphylococcus aureus 749
Quatemized chitosan derivative/poly(vinyl pyrolidone) fibers	Wound dressing materials[b]	Escherichia coli
		Staphylococcus aureus
Alginate/carboxmethyl chitosan blend fibers	Wound dressing materials[b]	Staphylococcus aureus
Polyp ropylene-g-acrylic acid-g-N-isopropylacrylamide-chitosan fabric	Wound dressing materials[b]	Pseudomonas aeruginosa
		Staphylococcus aureus
Chitosan/cellulose blends memberane	Wound dressing materials[b]	Escherichia coli
		Staphylococcus aureus
Chistosan-$Ca_3V_{10}O_{28}$ complex membrane	Wound dressing materials[b]	Escherichia coli
		Staphylococcus aureus
Porous chitosan/poly(N-isopropylacrylamide) gel/polypropylene sponge	Wound dressing materials[b]	Escherichia coli
		Staphylococcus aureus
Chitosan-gelatin sponge	Wound dressing materials[b]	Escherichia coli K88
		Streptococcus
Photocrosslinkable chitosan hydrogel	Wound dressing and tissue adhesion[b]	Escherichia coli
Poly(vinyl alcohol)/water-soluble-chitosan hydrogels	Wound dressing materials[b]	Escherichia coli
Chitosan/poly(vinyl alcohol) blended hydrogel membranes	Haemodialysis[b]	Aurococcus
Polyacrylonitrile.chitosan/heparin	Haemodialysis[b]	Pseudomonas aeruginosa Atcc10145
6-0-carboxymethylchitsaon/waterbome polyurethanes semi-interpenetrating polymer network memnranes	Biomaterial for blood-contracting devices[b]	Escherichia coli
Chitosan/hepanin multiayer films	Tissue engineening[b]	Escherichia coli
Trimethyl chitosan and N-diethylmethyl chitosan nanoparticles loaded with insulin	Delivery system[b]	Staphylococcus aureus ATCC 29737
N-carboxymethylchitosan N)-sulfate	Drugs for AIDS[b]	HIV-1
Water soluble carboxymethyl chitosan	Cotton Fabric[c]	Escherichia coli
		Staphylococcus aureus
Poly(n-butyl acrylate) cores and chitosan shells core-shell particles	Cotton Fabric[c]	Staphylococcus aureus

gene expression in Escherichia coli, immune response to polysaccharides, polysaccharides from periodontopathic bacteria, role in dental plaque, biofilms, levan, amylovoran and much more (Matthias 2009). Bacterial strains that develop or acquire resistance to one or more first-line antimicrobials pose numerous challenges to healthcare, including: increased patient morbidity and mortality, increased drug costs, prolonged illness duration, and more expensive disease control measures [5]. These antimicrobial resistant (AMR) strains arise, in part, as a result of antimicrobial use that selects for resistant organisms. Inappropriate antimicrobial use therefore contributes unnecessarily to the rise in resistance. As AMR genes or plasmids can be readily transmitted between bacterial species, surveillance of AMR trends is critical for the rapid detection of new isolates and continuous monitoring of disease prevalence [6]. Antimicrobial resistance and non-susceptibility are terms used to describe an organism's ability to survive in the presence of antimicrobial agents. Organisms are tested for susceptibility to antimicrobial agents in the laboratory using the Minimum Inhibitory Concentration (MIC) breakpoints. The MIC breakpoint is the lowest concentration of the drug that will inhibit growth of the pathogen. The term non-susceptible is used for organisms with isolates that exhibit both resistant and intermediate resistance to a particular antibiotic. This review article deals with the current knowledge of the polysaccharides and importance of biologically active polysaccharides as antimicrobial agents.

Antimicrobial properties of chitosan have been a long journey of scientific exploration and technological development. The journey began two decades ago, with studies on the biological phenomena arising from food borne and soil borne pathogenic fungi in the food and agriculture industries [28]. In light of their intimate relationship with human activities, bacteria rightly began to receive more attention in the search for efficacious antimicrobials. The studies at that time were typically carried out via chemical, biochemical, microbiological and medical assays of chitosan and its derivatives. In some cases, but rarely so, molecular and cell approaches were utilized. The outcomes obtained through this period suggested that antimicrobial activities of chitosan and its derivatives relied on numerous intrinsic and extrinsic factors, such as pH, microorganism species, presence or absence of metal cations, pKa, Molecular weight (Mw) and degree of deacetylation (DD) of chitosan, etc. Some basic hypotheses about underlying antimicrobial mechanisms were also proposed (Zivanovicet al., 2004). Based on the outcomes, various antimicrobial agents based on chitosan or its derivatives emerged. At the same time, since biocide resistant bacteria and fungi, growing public health awareness of pathogenic microorganism raised demands for safe and efficacious agents that were less prone to stimulating development of resistance. In addition to tremendous advancements in molecular biological, pharmaceutical, cell biological technologies and detecting methods, nanotechnology emerged and began playing an extraordinary role, carrying the potential to extend antimicrobial treatment to the atomic level. The many approaches that have been used in studying antimicrobial activities of chitosan and its derivatives have given rise to various physical forms of chitosan in differing methods, from the original solution applied in agriculture, to film structure in food sector and to ubiquitous pharmaceutical nanostructure materials. Different physical states of chitosan, as a crucial factor influencing antimicrobial activity, are supposed to have strongly considered but always being underestimated. Chitosan's water-solubility casts important impact on its particular antimicrobial activities, and the relevant researches have accordingly attracted understandable attention in the water solution. In contrast, solid state research has been confining to the application of antimicrobial properties such as beads, films, fibers, and hydrogels, mostly aimed at biomedical applications (Kong et al., 2008). Little attention has been paid to systemic investigations of the inhibitory effect in solid state, needless to its mode of action. Based on the current situation of research and progress in corresponding areas, this review attempts to sum up the general developments in the study of antimicrobial properties of chitosan (Figure 2&3). Comparison of the antimicrobial activity between different physical states of chitosan is made, especially the solid form. Differences among influencing factors and corresponding modes of action are discussed in detail. Finally, present and potential future applications are discussed. Variations in chitosan's bactericidal efficacy arise from various factors. According to roles playing, these factors can be classified into four categories as follow:

(1) Microbial factors, related to microorganism species and cell age.

(2) Intrinsic factors of chitosan, including positive charge density, Mw, concentration, hydrophilic/hydrophobic characteristic and chelating capacity.

(3) Physical state, namely water-soluble and solid state of chitosan

4) Environmental factors, involving ionic strength in medium, pH, temperature and reactive time.

Chitosan is mostly applied as a food additive or preservative, and as a component of packaging material, not only to retard microorganism growth in food, also to improve the quality and shelf life of food (Table 1).

5. Sulfated polysaccharides

Among marine organisms, marine algae are rich sources of structurally diverse bioactive compounds with various biological activities. Recently, their importance as a source of novel bioactive substances is growing rapidly and researchers have revealed that marine algal originated compounds exhibit various biological activities [29, 30]. Edible marine algae, sometimes referred as seaweeds, have attracted a special interest as good sources of nutrients and one particular interesting feature is their richness in sulfated polysaccharides (SPs), the uses of which span from food, cosmetic and pharmaceutical industries to microbiology and biotechnology [31]. These chemically anionic SPs polymers are widespread not only in marine algae but also occur in animals such as mammals and invertebrates [32, 33]. Marine algae are the most important source of non-animal SPs and the chemical structure of these polymers varies according to the algal species [34]. The amount of SPs present is found to be differing according to the three major divisions of marine algae, Chlorophyceae (green algae), Rhodophyceae (red algae) and Phaeophyceae (brown algae). The major SPs found in marine algae include fucoidan and laminarans of brown algae, carrageenan of red algae and ulvan of green algae. In recent years, various SPs isolated from marine algae have attracted much attention in the fields of food, cosmetic and pharmacology. Carrageenans, a family of SPs isolated from marine red algae, are widely used as food additives, such as emulsifiers, stabilizers, or thickeners [35, 36]. Ulvan displays several physiochemical and biological features of potential interest for food, pharmaceutical, agricultural and chemical applications [37]. Compared with other SPs, fucoidans are widely available commercially from various cheap sources; hence, more and more fucoidans have been. Chemical structure of the repeating units of ulvan investigated in recent years to develop novel drugs and functional foods [38]. Novel extraction and separation techniques, such as supercritical CO_2 extraction, ultrasonic-aided extraction and membrane separation technology have recently been applied in development of bioactive SPs from marine algae [39, 40]. Biological activities of SPs depend on chemical structure, molecular weight and chain conformations [41]. Therefore, for the efficient recovery of bioactive SPs with desired molecular size and functional property, a suitable method is the use of an ultrafiltration membrane system. The cell walls of seaweeds are rich in matrix SPs and they exhibited beneficial biological activities such as anticoagulant [42], antiviral [43], antioxidative [44], anticancer [45] and anti-inflammation [46](Na et al., 2010). This review focuses on SPs derived from marine algae and presents an overview of their biological activities with potential health benefits

6. Future prospects for polysaccharides

With the recent increase in ecological awareness associated with the dramatic decrease in fossil resources, research has turned towards the elaboration of more natural materials. New trends for using active packaging is one of the responses to the recent food-borne microbial outbreaks and to the consumer's demand for high quality food and for high-quality packaging that is more advanced and creative than what is currently offered. Biomaterials exhibiting antimicrobial and antioxidant properties have recently used for applications in food preservation. On other hand, the beneficial effects of bacteria to human health, with respect to the development of functional food, have largely been attributed to its polysaccharides. Some of these bacteria are referred to as probiotics; a concept describes live microbial food ingredients which are of benefit to human health [24]. Pharmacotherapy using natural substances can be currently regarded as a very promising future alternative to conventional therapy. With the rapid development of biotechnologies and analytical techniques, a great number of methods have been developed for the identification and quantification of the material, extracts, and products of natural ingredients. The advances are available today and will extensively be applied in near future. The need for safer drugs without side effects has led to the use of natural ingredients with proven safety [47]. In recent years, some bioactive polysaccharides, such as chitosan, pectin, and alginate, are isolated from natural sources have attracted much attention in the field of biochemistry and pharmacology due to their bioactive properties. As an example, polysaccharides or their glycoconjugates were shown to exhibit multiple biological activities including antimicrobial, antcarcinogenic, anticoagulant, immunostimulating, antioxidant, etc. These polysaccharides are suggested to enhance cell-mediated immune responses in vivo and in vitro and act as biological response modifiers and possess great antimicrobial effects.

The health promoting effects of probiotics has been attributed partly to their polysaccharides. Antitumor, antiulcer, immunomodulatory, antiviral and cholesterol lowering activities are some of the health benefits adduced to these polysaccharides. Although bacterial polysaccharide applications spans through areas such as the industry (textile, dairy, cosmetics, etc.), health (medicine and pharmaceuticals) and environment (remediation, flocculation etc.); its application as antimicrobial agents exceed regarding to health promotion and eco-friendly usage. Macroalgae are also an interesting source for a myriad of different bioactive polysaccharides ranging from industrial applications to novel food applications [48]. They possess many different interesting and often exotic polysaccharides that are currently explored for their functional properties in food and biomedicine. Considering the problems related to disposal of non-biodegradable materials, the use of biopolymers as food packaging materials is an important tendency. Among the known biopolymers, chitosan is especially promising because of its antimicrobial properties. The antimicrobial activity is related to the cationic character of chitosan, and has been successfully explored to extend shelf life of a variety of foods. Introducing alkyl chain and promoting the quaternization of chitosan it is possible to obtain water soluble films with different hydrophilic character, having potential application for minimally processed food industry. The beneficial use of water soluble quaternary salt of chitosan is devoted to its improvement on decreasing browning effect, increasing the fungicidal action and represents an advance in overcoming consumer acceptance [49]. Chitosan, a promising antimicrobial agent, is one of the most biomaterials to replace the synthetic ones, particularly for food and packaging applications.

7. Conclusion

The interest in polysaccharides has increased considerably in recent years, as they are candidates for many industrial sectors and pharmaceuticals. The need for new antimicrobial agents is greater than ever because of the emergence of multidrug resistance in common pathogens and the rapid emergence of new infections. Bacterial polysaccharides show great diversity and functions, and its production is not limited by species. Although numerous applications of the polysaccharides are available, it is vital to meet a generally regarded as safe status with respect to human usage, or at least have a cost effective means of neutralizing toxic constituents in cases of environmental applications such as in water (waste and municipal) treatment. Production cost, largely, has been a limiting factor in the non-industrial applicability of several prospective polysaccharides. However, the search for bacteria with high polysaccharides yields is an ongoing process, while the manipulation of fermentation conditions, genetic, and metabolic engineering as well as the exploration of cheap fermentation substrates for their production are suggested tools for improving the chances of commercial scale production and field application of these compounds.

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