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Microbial Polysaccharides - Chemistry and Applications

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Abstract: Polysaccharides resultant from microorganism are a class of the real polysaccharides occurred in nature during any metabolism. Due to the novel characteristics and physiochemical nature, these polysaccharides attain more attention in the field of food, feed, pharmaceutical, biomedical and cosmetic application. In the food industries these polysaccharides gave desirable rheological property, texture and sensory. Also, in biomedical industries microbial polysaccharides are potential in wound healing, surgical adhesives, and tissue regeneration. This review presents futuristic view on microbial polysaccharides, with unique consideration regarding potential applications in promising areas and to later advance on the finding of novel polysaccharides for future needs.

Key words: Food, feed, biomedical, microbial polysaccharides, rheology.

Introduction

In recent years, the biopolymers are gaining more importance over synthetic polymers since they are safe and environmental friendly. The natural biopolymers, especially polysaccharides are obtained from trees (cellulose), tree gum (gum arabic, gum karaya, gum ghatti and gum Traganth), plants (starch, pectin and cellulose), seeds (guar gum, locust bean gum, tara gum, tamarind gum) tubers (konjac mannan), seaweeds (carrageenan, agar and alginate) [1], animal (gelatin, whey protein, chitosan) and microbes (gellan gum, xanthan, curdlan, pullulan, dextran).

Microbial polysaccharides are high molecular weight polymers that share a substantial component of the cellular carbohydrates found in and surrounding the microbial cells. An array of polysaccharides is produced by a wide variety of microorganisms and majorities are water soluble gums with unique physical properties. Microbial polysaccharides are generally classified into three groups: 1. Exocellular, 2. Cell wall, and 3. Intercellular. The exocellular polysaccharides are those that diffuse out from cell into the cell culture medium. The cell wall i.e., structural and intercellular polysaccharides are integral parts of the cell envelope or capsular products and are generally difficult to separate from cell mass.

Polysaccharides, in many forms, play a central role in all living organisms for supply and storage of energy and/or structural integrity and protection of cells. The extracellular polysaccharides (EPS) have specific biological functions as the adhesion to surfaces, as protective barrier or as structural elements of the biofilms. EPS such as xanthan gum, scleroglucan, gellan gum, curdlan, bacterial alginate, dextran, pullulan, bacterial cellulose, etc. are already successfully used in the food industry, in medicine, pharmacy, cosmetics or oil industry [1].

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Progresses in the use of polysaccharides are closely linked to the ability of the scientific community to unravel the complexity of polysaccharides in Nature. Translation of this knowledge to practical applications is required to model and shape the various biological, physical and chemical inter-relations taking place and to invent new and improved characterization tools [2].

Types and chemistry of polysaccharides

Microbial polysaccharides may be ionic or non-ionic and are primarily linear molecules with side chains of varying length and complexity are attached at regular intervals. Most microbial polysaccharides are linear hetero-polysaccharides consisting of three to seven different monosaccharides arranged in groups of 10 or less to form repeating units. The monosaccharides may be pentoses, hexoses, amino sugars, or uronic acids etc. Different types of polysaccharides manufactured from microbial sources and their chemistry and functions have been reviewed [3] and same is shown in Table 1.

Applications of polysaccharides

Food and other industries

Several of today's foods require the unique texturization, viscosity, flavor release, appearance and water-control properties. The polysaccharides are incorporated into foods as thickeners, gelling agents, and agents to control ice crystal formation in frozen foods. They are used in instant foods, salad dressings, sauces, whips, toppings, processed cheeses, and dairy products to improve the texture and control the rheology of the final food product [2, 3]. Concentrations recommended and function of different microbial polysaccharides used in food products is given in Table 2.

Agricultural sector

Microbial exopolysaccaharide are considered as soil nourishment for organic matter. These polysaccharides have potential features in transferring toxic compounds and declining its mobility into the soil [4]. A few scientists brought up the significance of rhizobial surface polysaccharides in building up profoundly particular advantageous interaction. It has been accounted that the metals fre

Table 1. Principal microbial polysaccharides and their chemical structures and Properties

Type	Origin	Monomers	Charge	Characteristics of chemical structure	MW	Properties
Bacteria						
Alginate	*Pseudomonas aeruginosa, Azotobacter vinelandii*	Guluronic acid, Mannuronic acid	Anionic	Blocks of β-1,4-linked d-mannuronic residues, blocks of α-1,4-linked l-guluronic acid residues, and blocks with these uronic acids in random or alternating order	1000 - 1400 KDa	Hydrocolloid, Gelling capacity, Film forming
Curdlan	*Alcaligenes faecali, Cellulomonas flauigena*	Glucose	Neutral	β-1,3-D-glucan	$5x10^4$ - $2x10^6$	Gel forming ability Water insolubility Edible and non-toxic Biological activity

table 1. (continued).

Type	Origin	Monomers	Charge	Characteristics of chemical structure	MW	Properties
Dextran	*Leuconostoc mesenteroides*	Glucose	Neutral	α-d-glucan linked by α-1,6-glycosidic bonds; some 1,2-,1,3-, or 1,4-bonds are also present in some dextrans	10^6 - 10^8	Non-ionic, Good stability, Newtonian fluid behaviour
Gellan	*Sphingomonas paucimobilis*	Glucose, Rhamnose, Glucuronic acid	Anionic	Partially O-acetylated polymer of d-glucose-1,4-β-d-glucuronic acid-1,4-β-d-glucose-1,4-β-l-rhamnose tetrasacharide units connected by α-1,3-glycosidic bonds	5 x 10^6	Hydrocolloid-stable over wide pH range Gelling capacity Thermoreversible gels
Hyaluronan	*Pseudomonas aeruginosa, Pasteurella multocida*	Glucuronic acid, Acetylglucosmine	Anionic	Repeating units of β-1,4-linked disaccharides of β-d-N-Acetylglucosmine-β-1,3-d-Glucuronic acid	5000Da to 20MDa	Biological activity Highly hydrophilic Biocompattible
Levan	*Bacillus subtilis, Zymomonas mobili, Halomonas sp.*	Fructose	Neutral	β-2,6-D-fructan	<10^8	Low viscosity, High water solubility, Biological activity, (anti-tumour & anti-inflammatory activities), Adhesive strength, Film-forming capacity
Xanthan	*Xanthomonas campestris*	Glucose, Mannose Glucuronic, Acid, Aceate, Pyruvate	Anionic	β-1,4-d-glucan with β-d-mannose-1,4-β-d-glucuronic acid-1,2-α-d-mannose side chain. Approximately 50 % of terminal mannose residues are pyruvated and the internal mannose residue is acetylated at C-6	2.0-50 x 10^6	Hydrocolloid, -High viscosity yield at low shear rates even at low concentrations, Stability ver wide temperature, pH and salt concentrations ranges
Fungi						
Pullulan	*Aureobasidium pullulans*	Glucose	Neutral	α-1,6-linked α-1,4-d-triglucoside maltotriose units	5-900 x 10^3	-

Table 2. Application of Microbial polysaccharides in food Industries and other industries

Type	Application in food products	Concentration used in food products (w/w %)	Other Applications	Price (US$/Kg)
Alginate	Confectionary, Dairy products, Beverages, Jams, Soups, Sauces, Meat, Fish	0.3	Medicine Surgical dressings Wound management Controlled drug	5 - 20
Cellulose	Ingestible fibre		Wound healing Tissue engineered blood vessels Diaphragms	5.8 - 12
Curdlan	Deep fat frying, Processed food, Sauses, Freeze-dried foods, noodles	0. 1 to 1.0	Pharmaceutical industry Heavy metal removal	55
Dextran	Frozen products	1.0	Pharmaceutical industry: Blood volume expander, Chromatographic media	-
Geallan	Emulsion based gels	0.1-0.5	Pet food,	55-66
			Pharmaceutical agar substitute and gel electrophoresis	
	Beverages	0.01-0.2		
Hyaluronan			Medicine, Solid culture media	100000
Levan	As a prebiotic	-	Feed, Medicines, Cosmetics Industry	
Xanthan	Frozen products, Salad dressings, Syrups, Toppings, Beverages, Baked foods	0.05-0.5	Petroleum industry Pharmaceutical Cosmetics and personal care products	3 -5

quently intrude with the root take-up of supplements, like Fe, P, Mg, Ca, and Zn with metabolic elements for prompting plant development impediment. Previous reports showed that bacterial EPS strains essentially adds to the fertility of soil and enhances plant development [5]. However, rhizobial EPS had potent function as in plant host specificity. These EPS demonstrated various reactions to metal particles that incorporate metal biosorption, metal precipitation, and enzymatic metal change that allow their utilization for plant growth hormone [7]. As studies by Alami *et al.* [6] the rhizobium spp (EPS) showed high percent of dry biomass, nitrogen fixation and water holding capacity of plants, its mainly due to the root-adhering soil (RAS) and macroporosity on root. Enhanced soil aggregation in rhizosphere of wheat seedlings was seen because of EPS generation by rhizobium which upgrades plant growth under stress [7, 8].

Current market profile of microbial PS

The hydrocolloids market in general estimated to be valued at USD 5.70 Billion in 2015 and at USD 7.56 Billion by 2020, is projected to grow at a CAGR of 5.80 % from 2015 to 2020. The use of hydrocolloids in the food and beverages industry has been in demand owing to increasing health consciousness among the consumers and multi-functionality of hydrocolloids. The consumption of convenience foods that contain xanthan gums has also increased significantly in the recent past. Enhancing government venture in healthcare is also boosting pharmaceutical sales across the globe, which is driving the xanthan gums market. Asia Pacific ruled the global xanthan gum market in 2014 owing to increasing demand for bakery and confectionary products from countries such as China, India, Malaysia, and Vietnam. Key players in the global xanthan gum market include Danisco, Cargill, Pfizer Inc, Jungbunzlauer, Archer Daniels Midland, CP Kelco, and Fufeng Group Company Ltd. [9].

The global market for hydrocolloids, which includes many polysaccharides, is still dominated by plant and algal polysaccharides. This market valued at >4 million US$ about a decade ago, with xanthan gum being the only significant (6 % market share) bacterial EPS. Xanthan Gum Market by Application (Oil & Gas, Food & Beverages, Pharmaceutical, Cosmetics) is expected to reach USD 987.7 Million By 2020 [9].

Research challenges

The hydrocolloids market is driven by R&D and innovations. Food manufacturers focus on high R&D expenditures to provide high quality, innovative hydrocolloids to cater to their increasing demand in processed and convenience foods. With growing importance current research is focused on producing newer biodegradable polymers. Present researches are slanted towards finding new sources of EPS from less explored sources such as the marine extremophilic microorganisms [10].

Several groups are developing polymeric matrices with altered properties for diverse applications, viz edible coatings for food products, pharmaceutical formulations and packaging purposes. Moreover, the ability of EPSs to establish polymeric matrices enables their *in-vitro* manipulation to shape them as structured materials like nanoparticles, scaffolds or hydrogels which are adapted to specific biomedical applications including drug delivery, imaging, tissue engineering and wound dressings. For example, xanthan, sulfated dextran and sulfated curdlan, are used as antiviral and anticancer agents. As a result of its high fucose content, FucoPol is seen as a product with potential to be used in antitumor, anti-inflammatory and immune-enhancer drugs [11].

Current challenges and future prospects of microbial PS

Despite the great diversity of molecular structures already described for bacterial EPSs, only a few have been commercially developed. The main limitations to full commercialization are their production costs, mostly related to substrate cost, availability in limited geographical areas, cultivation challenges and downstream processing. Different metabolic pathways might be followed because of the different nutrient composition. Extraction and purification have still been challenging, therefore, research is still required, either for the improvement of the existing extraction and purification processes, or for the development of new approaches that are focused on the specifications required for the final product [12]. The most interesting prospects for increasing pure and high quality EPS production are through metabolic engineering either by manipulation of the genes that encode the enzymes which catalyze the reactions in the pathways, or by altering the regulatory pathways that affect gene expression and enzyme activity. Metabolic engineering of EPS-producing strains has been attempted for the production of xanthan, gellan, bacterial cellulose and levan and this approach has been successful in the case of cellulose and has led to production [13]. However, for others, the results have not shown significant improvements, mostly because the steps and the regulation of the pathways are still poorly understood. Two newly reported bacterial EPSs with great potential include GalactoPol, synthesized by *Pseudomonas oleovorans*, which is composed mainly of galactose, and FucoPol, a fucose-containing EPS that is synthesized by Enterobacter A47. Several microorganisms isolated from extreme environments, such as deep-sea hydrothermal vents, Antarctic ecosystems, saline lakes and geothermal springs have recently started to be studied as potential sources of valuable biopolymers, including EPSs [14].

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