Food and Health Applications of Exopolysaccharides produced by Lactic acid Bacteria

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Abstract

Majority of the polysaccharides used in foods are of plant, animal and algae origin. The exopolysaccharides (EPS) produced by food grade lactic acid bacteria (LAB) have gained much importance as biothickeners and texturizers in recent time. Several animal studies and in vitro tests are also suggestive of beneficial health effects associated with the regular consumption of EPS producing LAB. Such biopolymers are not synthesized in abundant amounts, which are a major factor impacting upon production cost and recovery time, considered as major constraints to full commercialization of these technologically important biopolymers. In current article, we reviewed prospective food and health applications of bacterial EPS.

Keywords: Exopolysaccharides; Prebiotic; Weissella; Antitumour; Fermented foods; Biosorption

Introduction

Exopolysaccharides may function in foods as viscosifying agents, stabilizers, emulsifiers, gelling agents, or water-binding agents. The global market for hydrocolloids, which includes many polysaccharides, is still dominated by plant and algae derived polysaccharides such as starch, galactomannan, pectin, carrageenan and alginate [1]. This market valued at >4 million US$ in 2008, with xanthan gum being the only significant bacterial exopolysaccharide (EPS), which accounted for 6% of the total market value [2]. However, most of them are chemically or enzymatically modified in order to improve their rheological properties, e.g. cellulose, starch, pectin, algin and carrageenan and therefore, their use is strongly restricted for food applications. An alternative source of biopolymers is microbial EPS. The EPS of microbial origin have unique rheological properties because of their capability of forming very viscous solutions at low concentrations and their pseudoplastic nature [3]. Commercially available microbial EPS are xanthan and gellan which are produced by Xanthomonas campestris and Pseudomonas elodea, respectively. Products containing these EPS are required to be labelled since these bacteria are plant pathogens.

Inherently, Lactic acid bacteria (LAB) are associated with many fermented foods; particularly milk based products such as curd, yoghurt, sour cream, cheese and buttermilk where they contribute to develop taste, flavour and shelf life of fermented foods [4]. LAB possess generally regarded as safe (GRAS) status which allows them to be incorporated in food without labelling. Some strains of LAB have been reported to produce EPS and gained increasing attention over the last few years because of their contribution to the rheology and texture of fermented milk and food products [5]. Most of the LAB producing EPS belongs to the genera Streptococcus, Lactobacillus, Lactococcus, Leuconostoc, and Pediococcus. Production of EPS is also reported from some non starter LAB like Bifidobacteria. LAB are able to produce mainly two types of polysaccharides according to their location in the cell, intracellular polysaccharides and extracellular polysaccharides [6]. Some bacteria produce only capsular EPS, some produce only slime (ropy) form, whereas, in some cases, bacteria can produce both forms of EPS [7,8].

EPS impart highly desirable rheological changes in the food matrix such as increased viscosity, improved texture and reduced syneresis [9]. EPS-producing LAB have a greater ability to withstand technological stresses [10] and survive the passage through the gastrointestinal tract compared to their non-producing bacteria. Further, EPS may induce positive physiological responses including lower cholesterol levels [11,12], reduced formation of pathogenic biofilms [13], modulation of adhesion to epithelial cells [14] and increased levels of bifidobacteria showing a prebiotic potential [15,16]. Hence, the choice of EPS-producing starter cultures seems to give several advantages over non-producing ones.

EPS in Food Applications

Various microbial and plant derived biopolymers with their applications in different fields are summarized in Table 1. Dextran is the first industrial polysaccharide produced by LAB like Leu. mesenteroides. It was discovered in 1880 in sugar cane or beet syrups where dextran was found to be responsible for the thickening and gelation of the syrups [17]. Due to their structural differences, some dextrans are water soluble and others are insoluble. Dextran can be used in confectionary to improve moisture retention, viscosity and inhibit sugar crystallization. In gum and jelly candies, it acts as a gelling agent. In ice cream it acts as a crystallization inhibitor, and in puddings mix it provides the desirable body-texture and mouth feel [18]. In addition, dextran has also been used as blood plasma extenders [19] and as the basic component of many chromatographic stationary phases [20]. Dextran from Leu. mesenteroides protects the producer strain during starvation and helps in survival at alkaline and acidic conditions [21].

Xanthan gum, produced by the plant-pathogen, Xanthomonas campestris is the second microbial EPS which was approved for use in...
foods in 1969. Xanthan has been described as “benchmark” product with respect to its importance in both food and non-food applications [22], which include dairy products, drinks, confectionary, dressing, bakery products, syrups and pet foods, as well as the oil, pharmaceutical, cosmetic, paper, paint and textile industries. The production of xanthan is relatively inexpensive because of the high conversion of substrate (glucose) to polymer (60-70%) [22]. According to Becker et al. [3], this biopolymer exhibits a high viscosity at low concentrations in solution and strong pseudoplasticity, and stable over a wide range of pH, temperature and ionic strength.

Microbial polysaccharides have rheological properties that match or exceed those of synthetic polymers, and they are non-toxic, biodegradable, cost-effective, and free of chemical residues when applied in food products. Fructan, inulin, and FOS have interesting properties for food applications as they have pharmaceutical and food applications. Fructose-oligosaccharides (FOS) have high purity. Since 1940, dextran and levan have found numerous industrial demands and can be produced in large amounts and at low cost. Glucuronan, Glucuronic acid polymer

<table>
<thead>
<tr>
<th>Biopolymer</th>
<th>Monomer units</th>
<th>Producer Organism</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xanthan</td>
<td>Glucose, mannose, glucuronic acid</td>
<td><em>Xanthomonas</em></td>
<td>As viscosifier, stabilizer, emulsifier and suspending agent in food industries, in food as thickening and stabilizing agents—often used in combination with guar gum, in secondary and tertiary crude-oil recovery, in paints, pesticide and detergent formulations, pharmaceuticals, cosmetics, printing inks (to control viscosity, settling and gelation).</td>
</tr>
<tr>
<td>Levan</td>
<td>Fructose</td>
<td><em>Bacillus, Streptococcus, Pseudomonas, Zymomonas</em></td>
<td>For production of sweet confectionary, ice cream as viscosifier and stabilizer</td>
</tr>
<tr>
<td>Alginate</td>
<td>Guluronic acid, mannuronic acid</td>
<td><em>Pseudomonas aeruginosa and Azotobacter vinelandii</em></td>
<td>As an immobilization matrix for viable cells and enzymes, coating of roots of seedlings and plants to prevent desiccation, micro-encapsulation matrix for fertilizers, pesticides and nutrients, hypo-allergic wound-healing tissue</td>
</tr>
<tr>
<td>Emulsan</td>
<td>Sugar and fatty acid</td>
<td><em>Acinetobacter calcoaceticus</em></td>
<td>Crude-oil recovery and other applications are similar as for alginate</td>
</tr>
<tr>
<td>Gellan</td>
<td>Glucose, rhamnose, glucuronic acid</td>
<td><em>Sphingomonas paucimobilis</em></td>
<td>As stabilizer and suspending agent for food. As gelling agent for solidifying culture media, especially for studying marine microorganisms</td>
</tr>
<tr>
<td>Cellulose</td>
<td>Glucose</td>
<td><em>Acetobacter spp.</em></td>
<td>In human medicine as temporary artificial skin to heal burns or surgical wounds, in nutrition as natural non-digestible fibers (which can be impregnated with amino acids, vitamins and minerals), in separation technology, as acoustic membranes in audio-visual equipment</td>
</tr>
<tr>
<td>Curdlan</td>
<td>Glucose</td>
<td><em>Rhizobium meliloti and Agrobacterium Radiobacter</em></td>
<td>As a gelling agent, immobilization matrix, curdlan along with zidovudine (AZT), displays promising high antiretroviral activity (anti AIDS-drug)</td>
</tr>
<tr>
<td>Hyaluronic acid</td>
<td>glucuronic acid, N-acetyl glucosamine</td>
<td><em>Streptococcus equi and Streptococcus zoepediucus</em></td>
<td>As replacer of eye fluid in ophthalmic surgery, in artificial tear-liquid, synovial fluid replica, in wound healing, cosmetic industry (lotions, moisturizing agent)</td>
</tr>
<tr>
<td>Succinoglycan</td>
<td>Glucose, galactose</td>
<td><em>Alcaligenes faecalis var. myxogenes</em></td>
<td>As a gelling agent and other functions are same as for curdlan</td>
</tr>
<tr>
<td>Acetan</td>
<td>Cellobiose, glucose</td>
<td><em>Acetobacter xylinum</em></td>
<td>As viscosifier and gelling agent for food. For production of sweet confectionary and vinegar.</td>
</tr>
<tr>
<td>Glucuronan</td>
<td>Glucuronic acid polymer</td>
<td><em>Sinorhizobium melloti M5N1CS, Glucuronacetobacter hansenii</em></td>
<td>Food and cosmetics products</td>
</tr>
<tr>
<td>Colanic acid</td>
<td>Fucose, glucose, glucoronate, and galactose</td>
<td><em>E. coli, Shigella spp., Salmonella spp., Enterobacter spp.</em></td>
<td>Cosmetics and personal care products</td>
</tr>
</tbody>
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Table 1: Microbial biopolymers and their applications (Kumar et al. [36] and van Kranenburg et al. [37]).

EPS produced by LAB, are widely used to improve the body and texture of yoghurt and other fermented milk products like dahi [8,28]. Dahi is a popular fermented milk product of India having 3.5-8% fat, similar to yoghurt, consumed in almost every household [29]. Health awareness among consumers generated more demands for low-caloric, especially low-fat or fat-free dairy products in market. However, since milk fat contributes to the flavour, body and texture development of dairy products, removal leads to textural and functional defects in low fat fermented milk products. In case of low fat yoghurt and dahi, a lack of flavour, weak body and poor texture are the major problems [30]. In this perspective, EPS producing LAB as ‘biothickeners’ offer natural, more acceptable and preferred approach to many additives. These cultures meet the consumer requirement for products with low levels of chemical additives [31,32], reduce the amount of total solids required without affecting the textural attributes [31,33] and improves sensory properties [34]. Low fat dahi made using different EPS producing cultures of *L. Lactis* subsp. *Lactis* PM23, *S. thermophilus* ST and *L. Lactis* NCDC 191 found to be more acceptable in terms of body, texture and flavour as compared to dahi made with EPS negative culture NCDC 167 [35].

The microstructural studies showed that dahi made with EPS-producing strains had more open structure and pores with discontinuous casein matrix than the controlled dahi, which had relatively compact linear structure [38]. To overcome the defects of
low fat cheeses, manufacturers have used texture promoting or ropy cultures for many years particularly where addition of stabilizer is prohibited. Such ropy strains may impart higher flavour intensity in the fermented milk due to the carbohydrate masking the flavour, mouth feel and other attributes may also be affected. The apparent viscosity of skim milk gel made by two ropy cultures, namely B-6 and KT-24 (later identified as Lc. Lactis subsp. Lactis strains) was increased as compared to that made by non-ropy cultures [35,39]. Recently, Florencia [40] studied rheology of spreadable goat cheese made with autochthonous lactic cultures differing in their ability to produce EPS and concluded that cheese made with EPS producing strain showed smaller elastic or storage module (G’), viscous or loss module (G”), and complex viscosity (η*) values over the range of frequencies studied and smaller critic stress values than the cheese without EPS producing strain.

EPS-producing L. rhamnosus JAAS8 in combination with non- EPS-producing yogurt strains increased both the water-holding capacity (WHC) and viscosity of the fermented products when compared with the control made with non-EPS-producing yogurt starters [41]. Partial or total replacement of non-EPS-producing L. delbrueckii subsp. bulgaricus with EPS-producing L. rhamnosus JAAS8 resulted in significant increases of about 16% and 21%, respectively, in apparent viscosity and an increase of about 2% in the WHC of the fermented products. To reduce the amount of added milk solids, to improve yoghurt viscosity, to enhance texture and mouth feel and to avoid syneresis during fermentation or upon storage of the fermented milk products, EPS producing functional starters are interesting. Yogurt made with EPS producing cultures has better water binding capacity, which decreases the product’s susceptibility to syneresis [42-44]. However, no simple correlation has been established between viscosity and quantity of EPS produced. It is opined that it may be more beneficial to use a combination of ropy and non-ropy starter cultures than using only ropy strains [45].

Besides dahi, yoghurt and cheeses, the other fermented milk products in which EPS cultures have been shown to affect product rheology are sour cream, kefir, and European cultured dairy products. Use of slime producing S. thermoophilus strains greatly improved rheological properties of cream turo and number of other Hungarian cultured milk and cultured cream products [46]. Kefir is traditional self-carbonated, slightly alcoholic fermented milk from Eastern Europe [4,47]. Kefir is prepared using kefir grains which consist of homofermentative and heterofermentative LAB, yeasts and acetic acid bacteria. These cells are embedded in kefiran, a slimy polysaccharide, which also found to affect texture of kefir [48]. Furthermore, some associated LAB strains also produces EPS within the matrix acting as natural viscosifying agent.

Dextran from Leu. mesenteroides finds commercial application in baking improvers. A study performed by Brandt et al. [49] provided evidence that EPS effectively improve dough rheological parameters and bread quality. Remarkably, EPS produced in situ was more effective when compared to externally added levain and addition of 1% (flour base) sucrose to wheat doughs suffice to induce polymer formation by Lactobacilli to effective concentrations. The in situ formation of EPS from sucrose resulted in further metabolites such as manninitol, glucose, and acetate that may contribute to the improved bread quality [50]. The EPS producing strains of Weissella in sourdoughs improved the textural properties and quality of bread [51,52]. Polymers produced from Lactobacilli thus may be expected to beneficially affect one or more of the following technological properties of dough and bread: (i) water absorption of the dough, (ii) dough rheology and machinability, (iii) dough stability during frozen storage, (iv) loaf volume and (v) bread staling.

During prolonged fermentation and storage, idli batters start collapsing and whey is separating that leaves idli with a hard, unwanted texture. Addition of different hydrocolloids in the batter may help to improve the texture of the final product [53]. Xanthan at a concentration of 0.1% improved the textural properties resulting in sensory analysis scores that are higher compared to idli without additives [54]. Nisha et al. [53] added different hydrocolloids to idli batter where all gave an increased viscosity. The decrease in batter volume during storage was less compared to the control and less whey separation was reported. However, only agar and guar gum gave idli that were acceptable from a sensory point of view with the right mouth feel and texture. Starter cultures producing EPS may be used to provide natural stabilizing agents in situ. EPS may work as natural thickening agents, giving the product a higher viscosity and reducing syneresis [55] thus giving an improved product without the use of additives.

Physiological Functions of EPS

Apart from their industrial applications, EPS have been found to be associated with many additional functions in microbial cell. However, the physiological role of EPS in bacteria has not been clearly established, and is probably diverse and complex. The precise role of the EPS, apparent in different ecological niches, is dependent on the natural environment of the microorganism. In general, microbial EPS are thought to play a role in the protection of the microbial cell in their natural environment against adverse condition such as desiccation, osmotic stress, antibiotics or toxic compounds (e.g. toxic metal ions, sulphur dioxide, and ethanol), predation by protozoans, phagocytosis and phage attack. The ability of a microorganism to surround itself with a highly hydrated exopolysaccharide layer may provide it with protection against desiccation and predation by protozoans [36]. Also, the presence of a gelled polysaccharide layer around the cell may have paramount effects on the diffusion properties, both into and out of the cell [56]. Some researchers have claimed that cell-associated EPS reduces sensitivity of the bacteria against bacteriophages and lysozyme, most likely by masking the targets for the phages and the enzyme [57,58]. Bacterial strains with relatively high EPS producing capacity were insensitive against phages and nisin suggesting their beneficial physiological function in natural environment [57].

Stack et al. [10] analyzed the ability of β-glucan-producing L. paracasei NFBC 338 to survive both technological and gastrointestinal stresses. Heat stress assays revealed that production of the polysaccharide was associated with significantly increased protection during heat stress (60-fold), acid stress (20-fold), and simulated gastric juice stress (15-fold). While bile stress assays revealed a more modest but significant 5.5 fold increase in survival for the β-glucan producing strain compared to that of the control strain. These results propose that production of a β-glucan EPS by strains destined for use as probiotics may afford them greater performance /protection during cultivation, processing, and ingestion. Similar to this, in one of the in vitro experiments, Lebeer et al. [59] suggested that EPS of L. rhamnosus GG form a protective shield against innate immune factors in the intestine. The mutant strain (with no EPS production trait) was more sensitive towards host innate defence molecules, such as the LL-37 antimicrobial peptide and complement factors. This suggests that EPS forms a protective shield for LGG against these molecules in the GI tract.

The production of EPS in the form of capsules is eminent in pathogenic bacteria, wherein the pathogenicity of an organism...
depends on the rate of synthesis and the amount of EPS synthesized. Capsules attached with pathogen enable evasion of phagocytosis. A noteworthy fact is that all capsular polysaccharides do not activate the immune system, which is due to the fact that their chemical structures may mimic the host cell surface components [36]. The lectins, polysaccharide binding proteins secreted by the plant, (e.g. Trifolin A) play a crucial role in the establishment of the symbiotic association between Rhizobium spp. and leguminous plants [60]. EPS may help bacterial cells for adhesion to solid surfaces and biofilm formation, and also in cellular recognition. It is not likely that EPS serves as a food reserve for the bacteria producing them, because most slime-forming bacteria are not capable of metabolizing the EPS they produce [61]. Apart from protection, few studies on EPS suggested that EPS produced by specific LAB could exert health beneficial effects through immunomodulation or by other means [36,62,63], some of these observations are discussed below.

**Prebiotic effect**

The possibility of acting as prebiotic substrates has been demonstrated successfully by Korakli et al. [26] for a fructan-type EPS produced by one strain of *L. sanfranciscensis*. There was evidence of a bifidogenic effect for the levans-type EPS produced by another strain of the same species [15]. Another experimental approach carried out by Salazar et al. [64] showed that EPS synthesized by intestinal *Bifidobacteria* act as fermentable substrates for microorganisms in the human gut environment, modifying interactions among intestinal populations.

**Antigastritis, antiulcer and cholesterol lowering effects**

Purified EPS from *S. thermophilus* CRL 1190 was found to be effective for preventing chronic gastritis [63]. The authors justified that the EPS-protein interaction might be responsible for the observed gastroprotective effect; such interactions may be affected by industrial manufacturing conditions. Similarly, Nagaoka et al. [65] reported certain antiulcer effects of EPS produced by *bifidobacteria*, lactobacilli, and streptococci strains. However, the protection of the gastric epithelium by EPS-producing LAB has not yet been described in detail.

The milk fermented with an EPS-producing strain *L. Lactis* spp. cremoris SBTO495 had cholesterol lowering activity, however, the mechanism is unknown [66]. In another research, the adsorption of total cholesterol by polysaccharides was measured *in vitro* by enzymatic reactions, including the polysaccharide precipitation procedure [67]. They mentioned that with 0.1% (wt/vol) polysaccharide dissolved in distilled water, the adsorption capacities of alginate, pectin, gelan gum, xanthan gum, and zooglan were 2.9, 2.88, 2.5, 2.9, and 2.4 mg/dL, respectively. However, 0.2% of zooglan was able to completely adsorb the cholesterol (3 mg/dL), whereas dextran could not. Tok and Aslim [68] also stated that out of total 5 strains of *L. delbrueckii* subsp. *bulgaricus*, isolated from home-made yoghurt, three strains that were producing high amounts of EPS were able to remove more cholesterol from the medium compared to low EPS producer strains. They reported that immobilized cells were much effective in cholesterol adsorption than free cells.

**Anti-mutagenic properties**

EPS-bound cells of strain *L. plantarum* showed binding ability to mutagens such as heterocyclic amines, and the mutagens were inactivated by binding to EPS [69]. There are very scarce studies on experimental animals to study either physiological or immunological effects by feeding or dosing EPS. In one of the animal studies, changes in blood pressure and serum components were examined in SHRSP/Hos rats using doses of 100 and 300 mg of kefran/kg of rat [12]. After 30 days, suppression in the increase in blood pressure was reported.

**Adhesion and colonization**

Studies on bacterial adhesion showed that capsular polysaccharide might promote the adherence of bacteria to biological surfaces, thereby facilitating the colonization of various ecological niches. The EPS were found to be present in adherent biofilms [36,70]; the EPS might function as initial adhesion, and permanent adhesion compounds [71]. Furthermore, EPS may function as adhesive agents and facilitate interactions between plants and bacteria, i.e., levans production by the root of the sugar cane invading *G. diazotrophicus* [72]. Homopolysaccharides (glucans and fructans) formed by oral streptococci have a major influence on the formation of dental plaque. They are involved in adherence of bacteria to each other and to the tooth surface, modulating diffusion of substances through plaque and serving as extracellular energy reserves [73]. Furthermore, fructans aid in the adhesion of bacterial cells to plant cell surfaces [72]. Although the involvement of these biopolymers in bacterial adhesion to the intestinal epithelium has not yet been validated through *in vivo* studies, some *in vitro* studies suggests that EPS could lead to increase the efficiency of adhesion to the epithelial layer of the GI tract by the LAB [74]. It has been known that the EPS of *Streptococcus mutans* play significant role for the adhesion of this bacterium to the tooth surface and hence in the formation of dental plaque [75], facilitating bacterial colonization and protection against hostile habitats. Several studies indicate that EPS produced by LAB appear to be associated in cellular recognition, adhesion and the formation of biofilms [55,75]. Adhesion of probiotic *Lactobacillus* cultures to HT29 cells was reported by Vishwanth et al. [76] by flow cytometry. These cultures are known to produce EPS.

**Antiump properties**

Oda et al. [77] reported an antitumor EPS produced by *L. helveticus* ssp. *jugurti*. The antitumor activity of the EPS was tested against ascites Sarcoma-180 by injecting the EPS preparation intraperitoneally. Mice given a 20 mg kg⁻¹ dose for nine successive days had an increased life span value of 144%, and a value of greater than 233% corresponding to a 40 or 80 mg kg⁻¹ dose. The authors concluded that the antitumor activity of the EPS might be based on its host-mediated actions. In order to understand the antitumor activity, the effect of the EPS or the EPS-producing cells on the immune system has been investigated. Forsen et al. [78] showed that cell surface materials, possibly lipoteichoic acids, of *Lc. Lactis* spp. *cremoris* T5 produced T-cell mitogenic activity in human lymphocytes. Few studies also reveal immunomodulating, and antitumor activities of EPS [62,79,80]. The slime produced by *B. adolescens* had immunomodifying effects on mouse splenocytes [81]. Kitazawa et al. [82] showed that the slime-forming *Lc. Lactis* spp. *cremoris* KVS20 had antitumor activity, and the slime contained strong B-cell dependent mitogenic substances.

**Miscellaneous applications**

Entertoxigenic *E. coli* (ETEC) is a big threat to swine industry. A recent study performed by Wang et al. [83] showed that EPS produced by strains of *L. reuteri* inhibited ETEC-induced heamagglutination of porcine erythrocytes suggesting potential application of EPS associated with probiotic strain to inhibit pathogenicity of ETEC. However, no effect was observed for dextran produced from *Weissella cibaria* and commercially available oligo- and polysaccharides in the same study. A low molecular weight heparin-like EPS exhibiting anticoagulant
property has been reported from *Alteromonas infernus*, obtained from deep-sea hydrothermal vents [84]. Clavan, an L-fructose containing polysaccharide has a potential application in preventing tumor cell colonization of the lung, in controlling the formation of white blood cells, in the treatment of the rheumatoid arthritis, in the synthesis of antibodies for antigen production and in cosmeceuticals as skin moisturizing agent [85]. The EPS of *L. paracasei* subsp. *paracasei* NTU 101 and *L. plantarum* NTU 102 demonstrated porphyrin open channel properties including in vitro 1,1-diphenyl-2-picrylhydrazyl radical scavenging activity, chelation of ferrous ions, inhibition of linoleic acid peroxidation, and reducing power [86]. EPS also found to stimulate cell proliferation and mild immune modulator of macrophages by inducing cytokine production (including IL-6, TNF-α, and IL-1β) in a dose-dependent manner (5-500 µg mL−1). Furthermore, studies by Martin et al. [87] show that some bacterial EPS alone or as conjugates could act as a very potent somogen, thus sleep induction with a natural product with no side effects will eliminate dependence on xenobiotics for sleep induction.

**Future Prospects for Bacterial EPS**

The industrial application of bacterial EPS is limited due to higher production cost and recovery processes. Though streptococci and related genera produces EPS in very less amount, most of the *Lactobacilli* are reported to produce 1-10 g of EPS per litre growth media [88,89], while *Weissella* species produce EPS in amount from a few grams up to 18 g/l under optimized conditions [90]. Such higher EPS producing strains can be explored to resolve the cost related problem. On the other hand, Pediococci and related genera have been found to produce EPS in few milligrams per litre in their favourable media as reported by Patel et al. [88].

Although bacterial EPS applications spans through areas such as the industry (textile, dairy, cosmetics, etc.), health (medicine and pharmaceuticals) and environment (remediation, flocculation, etc.); its application in the flocculation process will be a significant milestone to health promotion and eco-friendly usage especially in municipal and wastewater treatment processes. The flocculations of suspended particles in water treatment plants have applied the use of inorganic salts of aluminium such as aluminium sulphate and poly-aluminium chloride and organic synthetic polymers of polyacrylamide derivatives and polyethyleneimine. These flocculants have been shown to possess adverse health effects such as neurotoxicity, carcinogenicity and Alzheimer’s disease [91]. Microbial EPS could serve as safe alternative flocculating agents. Several researchers have reported high flocculation efficiency mediated by the biopolymers produced by non lactic bacteria like *Virgibacillus* spp., *Bacillus* spp. and *Artrobacter* spp. [92,93]. These findings imply that bacterial EPS effectively mediate flocculation and thus may be applied in large scale industrial processes, with particular reference to water and wastewater treatment. Studies should be designed to check the feasibility of EPS produced by LAB for such eco-friendly approaches.

EPS may also contribute to the provision of reduced oxygen tension and participate in the uptake of metal ions [60,94]. It was found that EPS obtained from *Pseudoalteromonas* spp. SM9913 (psychrotolerant bacterium) was found to enhance the stability of the cold-adapted protease MCP-01 secreted by the same strain through preventing its autolysis. The EPS could bind many metal ions, including Fe2+, Zn2+, Cu2+ and Go2+ [95]. It also worked as a very good flocculating agent and could conglomerate colloidal and suspended particles.  

**Conclusion**

Bacterial exopolysaccharides shows enormous diversity. In addition to their natural protective role, EPS produced by LAB is found to shield the cell against technological stresses during manufacturing fermented milk products. Recent development is suggestive of potential application of these polymers for human usage; medical, cosmetics, pharmaceutical, dairy products and other forms of industrial and agricultural aspects. However, production cost is the limiting factor for application of several prospective exopolysaccharides at industrial level. The search for high EPS producing strains is an ongoing process, while optimizing the fermentation conditions, biotechnological tools involving genetic and metabolic engineering as well as the exploration of cheap fermentation substrates for their production are optional methods for improving the commercial scale production and field application of microbial biopolymers.

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