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Microbial Exopolysaccharides: A Review of Their Function and Application in Food Sciences

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Abstract

Extracellular polymeric substances are defined as high molecular weight compounds secreted by the microorganisms in the surrounding area. Since these extracellular substances are mainly polysaccharide, they are named exopolysaccharide. Microbial exopolysaccharides composed of sugar residue have growing interest as a new class of microbial products which can be used in food, pharmaceutical, and biomedical industries. Microbial derived exopolysaccharides are considered as either good substitute of other synthetic or natural polymers or novel biopolymers which are used in food for thickening, suspending and gelling function. However, microbial derived compounds have a versatile reputation and the numbers of published articles in this area are increasing, only three exopolysaccharides xanthan, gellan and dextran have been survived the industrial competition. Considering the extensive function of microbial exopolysaccharides and the importance of physical properties and chemical structure in functionality determination, the function and application of microbial exopolysaccharides are discussed with the emphasis on physical properties and chemical structure in this review.

Introduction

Water-soluble polymers as ingredients which dissolve, disperse or swell in water are mainly used as thickening, gelling, and suspending agents (Kadajji and Betageri, 2011; Mohammadifar et al., 2006; Mollakhalili Meybodi et al., 2014; Williams, 2008). These substances are industrially applicable in food, pharmaceutical and biomedical industries to act as gelling and/or flocculating agent which modify the rheology properties and enhance the emulsion stability. These substances can be classified in three separate groups namely synthetic, semisynthetic and natural. The natural water-soluble polymers include microbial, plant and animal derived materials (Finch, 2013). Regarding the increasing costs of collection, unstable prices of plant and algal gums and the increased requirement for natural polymers in different applications has encouraged the manufacturers to look at industrially produced gums like modified starches and also the microbial derived polysaccharides (Mano et al., 2007).

Microbial polysaccharides are long-chain, natural and/or semisynthetic polymers with different molecular weight and structure. They are manufactured via sugar fermentation by some microorganisms like *Xanthomonas campestris*, *Spingomonas paucimobilis* and *Leuconostoc*

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mesentroides (Mende et al., 2016; Sutherland and Ellwood, 1979). They can be categorized in three different groups, including exocellular, cell wall, and intercellular ones. However, the cell wall (structural) and intercellular polysaccharides are fundamental parts of the cell wall and difficult to be apart from cell biomass. The exocellular ones named exopolysaccharides, are easily isolated and released into the cell culture medium. Exopolysaccharides can be used as substitute of other synthetic or natural water-soluble polymers or as original polymers in thickening, suspending and gelling applications in food, pharmaceutical and other industries (Ogaji, 2012). These abilities are mainly based on their chemical structure and their tendency to interact with other molecules via hydrogen bonding, ionic effect, etc. Considering these main facts, the main aim of this review article is to study the function and application of microbial exopolysaccharides in food sciences with the emphasis on their various physical as well as chemical characteristic.

Table 1: The origin and physical properties of main microbial exopolysaccharides

Microbial exopolysaccharides	**Properties**				
	Origin	**Backbone structure**	**Molecular weight (g/mol)**	**Nature of polymer**	**Solubility**
Dextran	Lactic acid bacteria	α 1-6 glucan	1×10^6	neutral	aqueous/ nonaqueous soluble
Xanthan	*Xanthomonas campestris*	β1-4 glucan	6×10^6	acidic	water-soluble
Pullulan	*Aureobasidium pullulans*	α1-6 glucan	$5\text{-}900\times10^3$	neutral	water-soluble
Gellan	*Pseudomonas elodea*	Heteropolysaccharide	5×10^6	acidic	water-soluble
Curdlan	*Alcaligenes faecais*	β1-3 D-glucose	500- 240000	neutral	water-soluble
Scleroglucan	*Sclerotinum rolfsii*	β1-3 glucan	500 000	neutral	water-soluble
Levan	*Zymomonas mobilis*	β 2-6 D-fructose	$<10^8$	neutral	water-soluble
Xylinan (Acetan)	*Acetobacter xylinum*	1, 2 D mannose	2.5×10^6	neutral	water-soluble

Table 2: The main food industrial application and function of microbial exopolysaccharide

Type	**Application**	**Concentration (w/w%)**	**Function**	**Reference**
Xanthan	frozen products	0.05-0.2	Improving freeze-thaw stability.	(Palaniraj and Jayaraman, 2011)
	beverages	not mentioned	Xanthan addition to fibers decelerated degradation reactions with a protecting effect.	(Paquet et al., 2014)
Gellan	emulsion based gels	0.1-0.5	Emulsions high concentration of gellan showed mainly an elastic behavior producing flexible gels.	(Lorenzo et al., 2013)
	beverages	0.01-0.2	Native gellan can be partially deacylated during fermentation, post-fermentation treatments, or recovery by alkali, enzymes or high temperature.	(Cho, 2001)
Dextran	frozen products	1	The viscosity and viscoelastic characteristic of the product was not affected by dextran addition.	(Lopez et al., 2005)
	as a potential prebiotic	not mentioned	The presence of dextran as a prebiotic was able to increase the counts of *Bifidobacteria*.	(Sarbini et al., 2014)
Scleroglucan	cooked starch pastes	2	Scleroglucan was able to prevent syneresis without affecting pH, gelling properties, hardness or colour.	(Vinarta et al., 2006)
Pullulan	enhancement of other polysaccharides function	not mentioned	Increasing the pullulan concentration, decreased flow behavior index (n) of gel solutions and increased the viscosity.	(Liu et al., 2014)
	edible film	various	The coatings delayed mold formation and decreased weight loss, softening and degradation of ascorbic acid and carotenoids in the fruits. The most effective films were 10% pullulan-based films.	(Eroglu et al., 2014)
Curdlan	as a barrier during deep fat frying	0, 1	The addition of curdlan showed a linear effect on reducing oil and moisture transfer. This effect of curdlan probably has been attributed to its thermal gelling property, and the heat-induced gel during frying probably functioned as an oil and moisture barrier.	(Funami et al., 1999)
	noodle	various	The chewiness, flexibility and toughness of the noodle were improved when curdlan was added.	(Ji et al., 2010)
Levan	as a prebiotic	-	Levan can be hydrolyzed by gastric acids. Its smaller sized levan or levan oligosaccharides can be subsequently utilized by lumen bacteria.	(Gupta et al., 2015)

Physical properties and chemical structure

The application of microbial exopolysaccharides in industries like food and pharmaceutical are mainly determined by their distinctive physical properties (Kumar et al., 2007). Generally, microbial polysaccharides are ionic or non-ionic linear molecules which have regularly attached side chains with different length and complexity in some structure. Usually, the Microbial exopolysaccharides can be categorized in two important groups considering their construction units, namely: homopolysaccharides and heteropolysaccharides (Donot et al., 2012). While the homopolysaccharides comprise of only one monosaccharide, the heteropolysaccharides are mainly composed of three to seven dissimilar monosaccharides. The monosaccharides creating the exopolysaccharides may be pentoses, hexoses, amino sugars, or uronic acids (Kumar and Mody, 2009). The possibility of different linkages in polysaccharides and also the variation of monomer arrangements have resulted in a wide range of shapes and structure. The observed unique physical properties of high molecular weight microbial gum can be attributed to their complex entanglement. Microbial polysaccharides are mainly composed of D-glucose, D-galactose and D-mannose; L-fucose and L-rhamnose; and N-acetyl hexosamines, N-acetyl-D-glucosamine and N-acetyl-D-galactosamine. Some oxidized derivatives of monosaccharides like D-glucuronic and D-galacturonic acids could also be carried by some microbial exopolysaccharides (Poli et al., 2010). The acyl groups either as ester-linked acetate or ketal-linked pyruvate may be present in some microbial exopolysaccharides which consequently influence the structures of these polymers and then their physical properties. It should be noted that ester-linked O-acetyl group as a typical organic substituent in microbial polysaccharides structure do not change their overall charge, but the ketal-pyruvate can contribute to charge of these polymers (Sutherland, 1990). Considering the microbial polysaccharides structure, it is now possible to attribute the physical properties of microbial exopolysaccharides to their chemical structures.

Physical properties of polysaccharides are mainly determined by their monosaccharide composition, glycosidic linkage, molecular weight, etc. (Kothari et al., 2015). The origin of microbial exopolysaccharides and their main physical properties which determine their application in food science are summarized in Table 1.

Function and application in foods

Carbohydrates and microbial exopolysaccharides are used in food industry to improve the rheological properties and create specific characteristics; including cryoprotection, sweetening, hygroscopicity, crystallization inhibition, flavor encapsulation, and coating ability (Rosalam and England, 2006). The functions of microbial exopolysaccharides in different application are summarized in Table 2. Although, microbial derived compounds have a versatile reputation and the numbers of published articles in this area are increasing, only three exopolysaccharides xanthan, gellan and dextran have been survived the industrial competition. Regarding the importance of these three ones, they will be discussed in detail in below.

Xanthan gum

Xanthan gum has been approved as a food grade component about thirty years ago by the USA food and drug administration (FDA). It is an anionic exopolysaccharide which secreted by *Xanthomonas campestris*. Xanthan gum is considered as a heteropolysaccharide which its main chain consists of β (1-4) linked D-glucose with a side chain in the C3 position of each glucose residue (Kumar and Mody, 2009). The side chains are mainly consist of two mannose units with a glucuronic acid residue (Kumar et al., 2007). Regarding the anionic nature of xanthan gum, its microstructure in a solution is extremely affected by the ionic strength. In other words, increasing the ionic strength of solution is able to create an ordered conformation with higher stability and transition temperature due to its charge screening effect (Chen and Sheppard, 1980; Wever et al., 2011).

Xanthan gums have specific characteristic such as high viscosity at low concentration, high solubility in water (cold and hot) along with the stability in acidic condition and defrosting which make them good substances to be used in food industry (Imeson, 2012; Kadajji and Betageri, 2011). In other words, the main applications of xanthan gums are being used as thickener, emulsifier and stabilizer.

Due to the ability of xanthan gum to produce very stable emulsion, it is usable to produce oil-based and non-oil-based sauces and ketchups (Koocheki et al., 2009). Since the xanthan gum is stable in the presence of acids, alkalis and salts and also able to tolerate the temperature fluctuation, it has been revealed that the products containing xanthan gum have a long shelf life. These factors along with the textural properties, the ability to release flavor during a long time and thawing stability of xanthan gum make its derived products very successful ones (Bylaite et al., 2005). Xanthan gums are also applicable in dairy based products due to their ability to act as a stabilizer. In fact, their specific functionality in some dairy products is their protecting effect against heat shock and controlling the formation and production of ice crystals (Hemar et al., 2001; Miller-Livney and Hartel, 1997).

Gellan

Gellan gum is an extracellular polysaccharides produced by *Pseudomonas elodea* (Prajapati et al., 2013). It is a high molecular weight and anionic heteropolysaccharide with repeating tetrasaccharides units which composed of β-D-glucose, L-rhamnose, D-glucuronic acid and L-glyceric ester (Bajaj et al., 2006). The biopolymer gellan gum, as a gelling and thickening agent, is considered to be applied in food industry when other polymers are not ideal (Imeson, 2012). The gels produced by gellan gums differ in characteristic depending on their acylation degree (Lorenzo et al., 2013). In other words, the gels are brittle, firm and thermally irreversible in the presence of low-acyl gellan gum while they are flexible, elastic and thermo reversible when high-acyl gellans are used. The texture of gels produced by gellan gums differ from a delicate pourable gel to a viscose and spreadable paste. It is concluded that the appearance of gels are mainly determined by the ionic strength of solution as well as the polymer concentration. It is worthy to be indicated that raising the ionic strength will lead higher gel turbidity mainly due to increased intermolecular aggregation and the strongest gels are produced in acidic condition (Jampen et al., 2000; Nickerson et al., 2003; Yamamoto and Cunha, 2007).

Gellan gums are also applicable to fortify beverages as a suspending agent for protein, minerals, vitamins, etc. They are used in formulation of some food products such as confectionary products, jams, jellies, fabricated foods and dairy products such as ice cream, milk shake and yogurt (Bajaj et al., 2007; Bayarri et al., 2002; Saha and Bhattacharya, 2010). Since gellan gums have been derived from non-animal origin, they are applicable in preparation of foods intended for vegetarians and those having religious dietary restrictions.

Dextran

Dextran is a long-chain, high molecular weight heteropolysaccharides which is listed as safe additive for food application (Kothari et al., 2015). However, dextran secreted by lactic acid bacteria is mainly applicable in food and pharmaceutical industry, and also in cosmetic, paper, petroleum, and textile industries (Kaplan, 1998). Regarding the fact that dextran produced by lactic acid bacteria are heterogeneous in construction, their chemical and physicochemical characteristics must be considered in several different application. Suitable dextran for food application can be produced by different microorganisms like *Saccharomyces cerevisiae*, *Lactobacillus plantarum*, and *L. sanfrancisco* without any limitation (Bhavani and Nisha, 2010).

Dextran can be used in bakery products to improve the rheological properties. In fact, dextran is formed *in situ* by sourdough which enhanced the airiness, loaf volume and softness of bread. It also improves the breads mouth feeling and texture (Katina et al., 2009). Dextran used in sourdough should be high in molecular weight and low in branched linkages. *In situ* production of dextran in sourdough is reported to be more effective than external addition (Tingirikari et al., 2014).

The only available treatment for celiac diseases, patients with inability to ingest prolamin containing cereals like wheat, rye, barley, is complete avoidance of gluten intake (Mollakhalili Meybodi et al., 2015). Since the gluten is an important protein-building structure for the appearance and crumb structure of bakery products, the interest for sourdough-enriched gluten free bakery product is highly increased. In fact, the *in situ* production of dextran by sourdough plays the main role in preserving the structure in gluten free bakery products (Lacaze et al., 2007; Moroni et al., 2009).

Dextran is also applicable in dairy industry, confectionary and also frozen foods regarding their cryoprotective, creaminess and viscosity enhancement effects (Bhavani and Nisha, 2010). They are also odorless, tasteless, and nontoxic. Recently, dextran and also dextran-derived oligosaccharides have being paid growing attention due to their reported prebiotic effects. On the other hand, it has been stated that dextran enrichment may enhance the portion of some *Bifidobacterium* species in an *in vitro* model of the fermentation in the human colon (Sarbini et al., 2013).

Conclusion

Polysaccharides are used in food industry for their unique properties as thickening agent, stabilizers and emulsifiers. Since the food products are becoming more complex and diverse, the necessity for new and useful additives is increasing. Recently, different polysaccharides have been developed to be used as modifier of food viscosity and texture.

Microbial exopolysaccharides as non-fat substitutes are usually applied at low concentration and also create beneficial health effects for the consumers. Although, different microbial exopolysaccharides have the potential to be used in food industry, only xanthan, and in lower amount dextran and gellan are industrially produced and dominate the markets.

Conflicts of interest

None declared.

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