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Bacterial exopolysaccharides could eiher be used to preserve food, modulate food sensory properties, and develop functional food.

Eudes L. ANIHOUVI[*1,2], Adanze N. CYNTHIA[3]

ABSTRACT: Through the utilization of diverse substrates, bacteria (LAB) produce various biopolymers including polysaccharides which have been used for several years in many fields due to their biocompatibility and apparent non-toxicity. Their applications have been extended in fields like food science and the pharmaceutical industry while the prospects could include their uses as an alternative to address public health issues (anti-gastritis, antiulcer, prebiotic, anticholestérémique, anti-mutagenic, and anti-tumor). This article provides a summary of EPS while exposing their recent applications in both food and pharmaceutical sciences to boost their future use to preserve food, modulate food sensory properties and to address public health issues (functional foods development).

Key Words: *Exopolysaccharides, food preservation, public health, disease prevention, sensory properties.*

INTRODUCTION

Latest trends in food science involve the use of polysaccharides for various foods formulation. Even though the polysaccharides widely tested up to date are from the animal, vegetable, and algae origin, those from lactic acid bacteria (LAB) have been investigated over the past years for their technical aspects as bio thickeners and texturizers. The LAB is mainly associated with the shelf life of fermented foods as well as the formation of taste and flavor [1]. However, recent work aimed at a better understanding of their functionalities has revealed promising avenues to explore concerning their abilities to release various biopolymers such as polysaccharides [2,3]. Commonly called exopolysaccharides (EPS), they are synthesized externally by enzymes anchored in the cell wall [4,5]. and they present an extensive diversity of structural combinations which define their unique properties [6]. They possess several advantages over products derived from plants or macroalgae [6]and are obtained from biocompatible and apparently non-toxic resources [6,7]. Bacterial EPS has determined an exceptionally expanded field of applications, in which their medical and food use carry out a critical role. With a view to a future perspective of their use, this review aims to provide an understanding of EPS and to expose their assets to be used by the food industry and to prevent diseases.

EXOPOLYSACCHARIDES (EPS)

The discovery in the middle of the 19th century of dextran in wine [8,9,4] stimulated the concept of bacterial EPS which was later exposed through their structural and functional roles [10,4]. In fact, through the use of substrates, bacteria produce diverse biopolymers known either as intracellular or extracellular based on their location [11,12] [4]. Intracellular biopolymers are few and their use are limited in comparison with those extracellular that are wide and can be subdivided into four categories including polysaccharides (Figure 1)[13,9,4]. Polysaccharides are the most available [14,4]. and possess specific roles depending on their position compared to the cell [4]. At the cell wall, they help for protective purposes while outside the cell, they are rather as a capsule [15,4]. or as a vase [13,4]. The biocompatibility aspect, as well as the non-toxicity of some of these bacterial EPS, have led to their use in many fields such as food science and for disease prevention [16,9,4]. They are therefore more valuable compared to those from other sources like plants, and microalgae [16,17,9,4]. EPS are classified based on different aspects regrouping their molecular weight, bonding links, chemical structure and their functionalities [4]. [18,4]. classified them into seven categories (constructive, sorptive, surfactant, active, informative, redoxactive and nutritive exopolysaccharides) while depending on their chemical composition, we have two groups identified as heteropolysaccharides (HePS) and homopolysaccharides (HoPS) as shown in Figure 1 [19]. HoPS are formed from a unique type of monosaccharide [19] and are generated in excess by certain strains of LAB summarized in Table 1. On the other hand, HePS are formed intracellularly from more than one type of monosaccharide [4,19]Their compositions incorporate units of D-glucose, D-galactose, L-rhamnose and, in some cases, N-acetylglucosamine, N-acetylgalactosamine or glucuronic acid. Non-carbohydrate substituents (phosphate, acetyl, and glycerol) are sometimes also present (Figure 1).

BACTERIAL EPS: APPLICATION IN FOOD SCIENCE.

Even though various studies during the past years highlighted the potential use of some types of EPS in science [20] Tieking and Gänzle, 2005; [4,5]. [19] only a handful of them, summarized in Table 2 has been found to be appropriate with significant commercial values [20,4]. EPS could be used in food science due to their aptitude on modulating food sensory features (viscosity, rheology, gels stability, and compounds suspension) [4,19]. Indeed, through their interaction with water molecules, they positively impact some rheological properties as well as the physical stability of food [21,4,19]. For example, in the baking process, [22]as well as [19]. reported the beneficial effect of the use of an EPS-producing LAB strain on the technological features of dough and bread. Thus, the use of sourdough where EPS-producing LAB is present has some advantages related to flavor, texture and shelf life [23,24,19]. Likewise, [19] reported that the production of EPS seems to be a key characteristic of the microbial sourdough consortium since most of the sourdough analyzed in the context of their work, contained at least one strain of EPS-producer from sucrose. Regarding the dairy industry, EPS offers various possibilities for enhancing the product sensory characteristics [25,19]. Since consumer acceptance of dairy products is firmly correlated to firmness and creaminess, the use of an EPS-producing strain may be a valuable alternative to increase the viscosity of the by-product, to bind water and interact with other milk constituents (proteins and micelles) [26,19]. This would undoubtedly lead to a reduction in the synthesis of harmful by-products and an improvement of stability. In addition, in the manufacture of yogurts, the utilization of LAB starter cultures synthesized by EPS would be a viable alternative compared to the use of artificial food additives [5], hydrocolloids of plant origin and of microbial polysaccharides recently used to stabilize the gel structure of the product and stop syneresis [27,19]. On the same line, based on the latest food trends encouraging the production of low-fat milk yogurts, Korkmaz,

[1]*Department of Dairy Technology, Ege University, 35100, Bornova-Izmir, Turkey.*
[2]*Department of Nutrition and Food Science, University of Abomey-Calavi, 01 BP 526 Cotonou, Benin.*
[3]*Department of Public health, Dokuz Eylül University, Izmir, Turkey. ORCID ID: 0000-0003-3802-9653*

Correspondence: Eudes L. ANIHOUVI, aeudeslandry@gmail.com. ORCID ID: 0000-0002-0786-1837.

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2005, [27]and [19]. highlighted that the functional and textural defects of low-fat dairy products can be adjusted by the use of EPS-producing strain. Besides its beneficial effects on textural and rheological properties of milk/ milk products and the health of the consumers, EPS protects against natural environment dangers like water activity, phage hazards, toxic compounds, antibiotics, and osmotic pressure, etc... [28] Due to their new functionality and interesting physicals, chemical, and rheological properties, EPS acts like many other newly implemented biomaterials and offers a wide potential for their applications in fermentation, and food additives.

TABLE 1: Description of EPS including structure, EPS-producer LAB and difference between HoPS/HePS.

EPS	Structure	EPS-producer LAB		Features	References
HoPS	One variety of monosaccharides (glucose or fructose)	*Lactobacillus, Leuconostoc, Streptococcus, Weissella, Oenococcus.*		Requires a specific substrate (sucrose) for its synthesis	Uchechukwu et al., 2012; Valery Ripari, 2019.
HePS	Different variety of monosaccharides varying from disaccharides to heptasaccharides (e.g., galactose, rhamnose)	Mesophilic	Thermophilic	The precursor repeating units of HePS are formed intracellularly and isoprenoid glycosyl carrier lipids are involved in translocation of the precursors across the membrane for subsequent polymerisation extracellularly	Uchechukwu et al., 2012; Valery Ripari, 2019.
		Lactococcus lactis subsp. lactis, Lactobacillus rhamnosus, Lactobacillus sakei, Lactobacillus casei	*Lactobacillus delbrueckii subsp. bulgaricus, Lactobacillus acidophilus, Lactobacillus helveticus, Streptococcus thermophiles*		

HEALTH APPLICATIONS OF EPS

Numerous scientific works and publications have been devoted to the applications of EPS in both food and medical science. The table 2 aims to highlight the results of these works, to provide a relevant image of EPS and to envisage future perspectives regarding their use for preventing disease (functional food development). Indeed, only a few EPS-producing bacteria have been investigated to date. Among them, we can cite the dextran discovered in wine. Considered as the first valid example of a microbial EPS used in various applications, including pharmaceuticals [29,6],dextran has been utilized as a plasma volume expander to control wound shock since 1953 [30,6]. Other microbial EPS have been applied in medical applications as pharmaceutical excipients after being approved as food additives. Xanthan, a bacterial HePS used in the food industry, was discovered in 1950 [31,6]and was approved as a food additive in 1969 (FAO /WHO, 1974). Based on its thickening and stabilizing suspension properties, it is additionally utilized likewise in pharmaceutical creams and suspensions. Gellan was discovered in 1978. It is categorized as anionic linear bacterial HePS and has a repeated unit of [illegible]-rhamnose [6]. Its native form contains acyl substituents (acetyl and glyceryl) allowing its practical use as a disintegrating agent in tablets with a rapid delivery or at more significant concentrations, as matrix excipient with prolonged release, depending on its swelling behavior [32,6].

FLOW CHART FIGURE 1

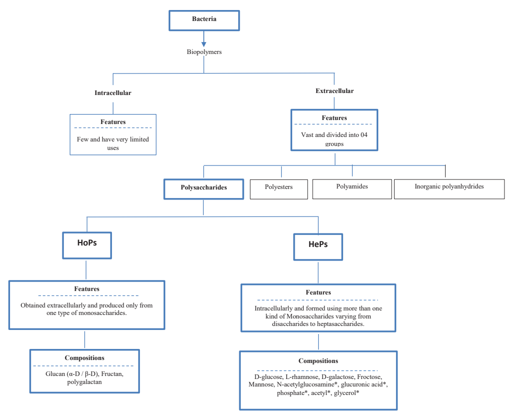

Figure 1) *Schematic description of EPS.* **Present in some instance*

TABLE2

Additionally, EPS may affect positively gut health due to their non-digestibility allowing them to be classified as prebiotics. Their prebiotic features have been conclusively demonstrated by Korakli et al. 2002 for a fructan-type EPS produced by a strain of L. sanfranciscensis. It has been reported in similar studies, that EPS synthesized by intestinal bifidobacteria can be fermented by microorganisms in the human intestine and may consequently modify the interactions between intestinal populations [33,1,23]. EPS is also suggested to have anti-tumor properties [34,35,23] anti-ulcer properties[36][23] immunomodulator [37,23]and are proposed to decrease blood cholesterol values [38,39,23].

TABLE 2: EPS used in food industry and for preventing disease: Properties and Functional features

Type	Polysaccharide Component	Application	Properties / Functions	Bacteria Strains	References
Xanthan	Glucose, mannose and glucuronic acid	Foods and pharmaceuticals sciences	Due to its aptitude of being stable over wide temperature, pH and salt concentrations ranges, it's used in food science to improve freeze-thaw stability. Likewise, add to fibers decelerate degradation reactions with a protecting effect in beverages.	*Xanthomonas spp.*	Palaniraj and Jayaraman, 2011; Uchechukwu et al., 2012; Paquet et al., 2014; Mollakhalili and Mohammadifar, 2015; Misu Moscovici, 2015.
Gellan	Glucose, glucuronate, rhamnose	Food (emulsion based gels and beverages)	Used by the food industry to stabilize by-product and as a gelling agent	*Pseudomonas elodea*	Edwin et al., 2012; Lorenzo et al., 2013; Mollakhalili and Mohammadifar, 2015.
Dextran	Glucose	Food and pharmaceuticals sciences; as potential prebiotic	Addition of dextran to food production increases the counts of some microorganisms like Bifidobacteria (Prebiotic effect). It's uses also as plasma expanders	*L. mesenteriodes*	Lopez et al., 2005; Uchechukwu et al., 2012; Sarbini et al., 2014 ; Mollakhalili and Mohammadifar, 2015, Misu Moscovici, 2015.
Levan	Fructose	Food science (Functional food)	Can be hydrolyzed by gastric acids and used by lumen bacteria due to its small size. May acts too as anti-tumor agent, cholesterol-lowering agent. Additionally, levan could be investigated as bio thickener by the food industry.	*Steptococcus salivarius, Steptococcus mutans, Leuconostoc mesenteroides NRRL B-512F, Lactobacillus sanfranciscensis LTH 2590 and Lactobacillus reuteri LB 121*	De Vuyst et al., 2001 ; Yoo et al., 2004 ; Gupta et al., 2015 ; Mollakhalili and Mohammadifar, 2015.
Kefiran	Glucose and galactose	Food; disease prevention	Improves the antimicrobial and visco-elastic properties of acid milk gels. It could be used as a valuable bio-compound for functional food manufacturing due to its both anti-cholesterolemia and anti-tumourigenic abilities.	*Lactobacillus kefiranofaciens, L. kefirgranum, L. parakefir, L.kefirandL.delbrueckiisubsp.bulgaricus*	Micheli et al., 1999; Medrano et al. 2008; Vinderola et al., 2006; Seema et al., 2012
Inulin	Fructose	Food industry and disease prevention	Nourishes gut mucosal cells and inhibits pathogens, for targeted drug delivery against colon cancer. Could also be used as a substitute for fat in	*Lactobacillus johnsonii NCC 533. Streptococcus mutans JC2, Leuconostoc citreum CW28 Lactobacillus reuteri 121*	Seema et al., 2012

CONCLUSION

This review shows the diversity and several viable functions of bacteria exopolysaccharides in both food science and for preventing disease. Although there is a wide application of EPS produced by bacteria, it would still be prudent with regard to its utilization for humans (food science and for disease prevention) to label them as GRAS to encourage its future use as a biological preservative in food manufacturing and as a valuable bio-compound to address public health issues (functional foods development). This could increase their commercial impact and may lead to their use as a strategy to address some public health issues using food science as a carrier. Further perspectives could also investigate EPS for their use in food packaging as bio-based food contact materials.

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