International Journal of Biological Macromolecules 94 (2017) 10–27

Contents lists available at ScienceDirect

International Journal of Biological Macromolecules

journal homepage: www.elsevier.com/locate/ijbiomac

Blends and composites of exopolysaccharides; properties and applications: A review

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ARTICLE INFO

Article history:
Received 14 August 2016
Received in revised form
23 September 2016
Accepted 29 September 2016
Available online 3 October 2016

Keywords:
Curdlan
Xanthan
Dextran
Hyaluronic acid
Biomedical applications
Food industry

ABSTRACT

Exopolysaccharides are synthesized by bacteria and secreted into the external environment and they may be homopolymeric or heteropolymeric in configuration. They are believed to protect bacterial cells from heavy metals, desiccation or other environmental effect. EPS exhibit antitumor, anti-HIV, emulsion stabilization capacity, shear-thinning activity, suspension ability, high viscosities, excellent biocompatibility, high biodegradability and immunomodulatory properties. They are widely used in herbicides, functional food, nutraceuticals, cosmeceuticals, pharmaceuticals, insecticides, immunomodulation and anticoagulants. This review shed light on the properties and versatile applications of xanthan, curdlan, hyaluronic acid and dextran blends and composites with natural and synthetic polymers.

Contents

Abbreviations: HPAM, anionic polyacrylamide; BSA, bovine serum albumin; CDI, carbonyldiimidazole; CMC, carboxymethyl curdlan; CPAM, cationic polyacrylamide; CS, chondroitin sulfate; Cur, curcumin; Dx, dextran; DMSO, dimethyl sulfoxide; DOX, doxorubicin; DR, drag reduction; DDS, drug delivery system; EGCG, epigallocatechin-3-gallate; EPS, exopolysaccharides; GA, gallic acid; GLG, gellan gum; AuNPs, gold nanoparticles; LAB, lactic acid bacteria; HMW, high molecular weight; HLC, human-like collagen; HA, hyaluronic acid; KGM, konjac glucomannan; Lyz, lysozyme; MGs, microgel; MIPs, molecular imprinting; PEG, poly(ethylene glycol); PLGA, poly(lactide-*Co*-Glycolide); PAMs, polyacrylamides; PAA, polyacrylic acid; PPy, polypyrrole; QCS, quaternized chitosan; Ag NPs, silver nanoparticle; NaA, sodium alginate; XG, xanthan gum; XRD, x-ray powder diffraction.

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http://dx.doi.org/10.1016/j.ijbiomac.2016.09.104

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1. Introduction

1.1. Polysaccharides

Polysaccharides are the high molecular weight molecules linked through a glycosidic linkage. They usually contain 100 to 90,000 monomer units and on hydrolysis give monosaccharides. They differ from each other by their monomers, molecular weight, mole and other structural features. They may be linear or highly branched. Microbial polysaccharides are produced in two forms, capsular polysaccharide (CPS) and exopolysaccharides (EPS) [1,2].

1.2. Exopolysaccharides

Exopolysaccharides (EPS) are high-molecular-weight polymers that are secreted by a microorganism into the surrounding environment by cell wall-anchored enzymes and are composed of sugar residues. Microorganisms synthesize a wide-ranged spectrum of multifunctional polysaccharides including structural polysaccharides, intracellular polysaccharides and extracellular polysaccharides (i.e. EPS). EPS usually consist of monosaccharides and non-carbohydrate substituents such as pyruvate, acetate, phosphate and succinate [8–10]. They are divided into two groups (Table 1) homopolysaccharides and heteropolysaccharides [11,12].

1.2.1. Homopolysaccharides

These polysaccharides on hydrolysis give only one type of monosaccharide units e.g. cellulose, alginate, dextran etc.

1.2.2. Heteropolysaccharides

These polysaccharides on hydrolysis produce more than one type of monosaccharide units. Heteropolysaccharides are composed of repeating units, varying in size from disaccharides to heptasaccharides e.g. xanthan, hyaluronic acid, heparin etc. [3–7]

1.3. Structure of exopolysaccharides

Bonds between monomeric units at the backbone of the polymers are 1,4-β- or 1,3-β-linkages and 1,2-α- or 1,6-α-linkages (Fig. 1) [44].

1.4. Reason for choosing exopolysaccharides

Due to the unique functionality and reproducible physicochemical properties along with stable cost and supply, exopolysaccharides are widely used in many industries [36,37]. The increased demand of natural polymers for many industrial applications in recent years has increased the importance of EPS production by new sources [38]. Intelligent screening of microorganisms for EPS is necessary for its further exploration toward commercialization. An advanced approach is needed for applications of EPS in the medical or pharmaceutical field and food sectors [39–41]. In future, there will be further development of prebiotic and probiotic-based dairy goods where bacterial EPS will play an important role [42,43]. Applicability and acceptability of EPS in pharmaceutical industries has currently opened a new opportunity for the researchers to utilize new bacteria that inhabit unfamiliar marine ecosystems. EPS can be modified by combination or blending with natural and synthetic polymer, as a result of blending they change their properties and have wide applications in several fields [45].

1.5. Limitations

The main challenges for the commercialization of new EPS is the identification of strains and nature of EPS, improvement of novel structures, cost of production and development of downstream process. For production and commercialization of EPS a suitable downstream method is required. EPS have unique properties such as high gel strength, foaming and viscosity that can create several problems during fermentation processes for their production. Genetic engineering of microbes requires further developments to convert inexpensive raw materials to EPS. In the light of current knowledge, an emphasis should be given to produce new EPS with potential multifarious applicability [45].

2. Modifications of exopolysaccharides

Exopolysaccharides have a wide range of applications depending on their nature, composition and structure. Generally some specific monosaccharides form EPS and its structural diversity determines its possible applications [46]. EPS are used in the food, pharmaceutical, biomedical, bioremediation and bioleaching fields because of their physical, rheological, some unique properties and wide structural diversity [47–49]. EPS plays a key role in biofilm formation, facilitating initial adhesion leading to development of complex architecture [50]. In this review, we discussed only four EPS viz., xanthan, curdlan, hyaluronic acid and dextran that can be blended with natural and synthetic polymers. The techniques employed for characterization of EPS and their potential applications in various fields are summarized in Table 2.

2.1. Exopolysaccharides blend and composites with natural polymer

2.1.1. Blends and composites of xanthan with natural polymers

Xanthan is an exopolysaccharide produced by the bacterium *Xanthomonas campestris*. It is a heteropolysaccharide with repeated pentasaccharide units consisting of glucose, mannose and glucuronic acid [94,95]. It consists of β 1,4-linked D-glucose backbone and also substituted with a trisaccharide side chain linkage alternately with every second glucose residue [96,97]. Xanthan has remarkable emulsion stabilization, suspension ability, shear-thinning activity and high viscosities [98]. It is biocompatible, water soluble, has limited electrical conductivity and thermal stability [99].

2.1.1.1. Xanthan gum blend with alginate. Alginate (Alg), the most common encapsulating agent and linear polysaccharide consisting of 1 → 4 linked β-(D)-guluronic(G) and α-(L)-mannuronic (M) acids derived from brown algae. Alginate has been widely used