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Polysaccharides: Pharmaceutical Applications-An Updated Review.

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Abstract:

Background: In recent years, the pharmaceutical industry has increasingly relied on natural polysaccharides due to their bioactive properties. These biopolymers, derived from various sources including plants, animals, microorganisms, and algae, play a crucial role in drug delivery systems, offering biocompatibility, biodegradability, and versatility in pharmaceutical formulations.

Aim: This review aims to provide an updated overview of natural polysaccharides, exploring their physicochemical properties, sources, and applications in pharmaceutical and biomedical fields.

Methods: The review synthesizes recent research on natural polysaccharides, focusing on their chemical structure, classification, and modifications. The study categorizes polysaccharides into homopolysaccharides and heteropolysaccharides, based on the type of monosaccharide units they contain. It also discusses the chemical and physical modifications, such as sulfation and phosphorylation, which enhance their performance in drug delivery.

Results: Natural polysaccharides, including plant gums, chitosan, guar gum, and xanthan gum, have shown significant potential as excipients in pharmaceutical formulations. They are employed in diverse dosage forms, such as implants, nanoparticles, and injectable systems. The physicochemical properties, including solubility, viscosity, and gelling ability, vary depending on the source, and modifications are used to optimize these characteristics for specific pharmaceutical applications.

Conclusion: Natural polysaccharides have emerged as key materials in the pharmaceutical industry due to their unique properties and eco-friendly characteristics. Their versatility allows them to serve multiple functions in drug delivery systems, from suspending agents to emulsifiers. With further research into their modifications, polysaccharides will continue to provide sustainable alternatives to synthetic polymers in pharmaceutical applications.

Keywords: Polysaccharides, bioactive polymers, drug delivery, biopolymers, excipients, natural gums, pharmaceutical formulations, biodegradability, sustainability.

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Introduction:

In recent years, polymers and polymeric substances have been widely utilized across various sectors to address pharmaceutical demands. The concept of polymers, however, was first elucidated in the 20th century [1]. At present, bioactive polymers play a significant role in the health and food industries, demonstrating considerable potential for biological activity [2]. Bioactive polymers are generally categorized into two primary groups: natural biopolymers and synthetic biopolymers [3]. Although synthetic bioactive polymers have been recently developed and exhibit promising bioactivity, they may present challenges in terms of degradation and cost-effectiveness. Notably, biologically active polymers are vital to life processes. A substantial portion of both our food and body composition consists of polymers, the majority of which are bioactive. These polymers can either be biosynthesized by living organisms or chemically synthesized from biological materials [4]. Biopolymers are composed of monomeric units such as nucleic acids, saccharides, and amino acids, which are covalently linked to form larger polymeric structures with linear or branched molecular configurations. Furthermore, natural biopolymers are preferred in medical research and industrial applications due to their renewable source, biocompatibility, biodegradability, eco-friendliness, and non-toxicity.

Natural bioactive polymers, particularly polysaccharides, are derived from a variety of sources, including plants, animals, microorganisms, and algae. These polymers play an integral role in both food and pharmaceutical formulation development. Natural polymers have recently been explored as excipients in pharmaceutical formulations, where they perform diverse functions such as suspending agents, emulsifying agents, binding agents, and thickening agents [5], [6]. Additionally, natural polymers are employed in the formulation of implants, microparticles, films, nanoparticles, beads, solid monolithic matrix systems, and injectable and inhalable systems, as well as in the preparation of viscous liquid formulations [6], [7]. Commonly utilized plant-based polymers in the pharmaceutical industry include chitosan, ispaghula, acacia, agar, guar gum, carrageenan, gelatin, shellac, and gum karaya. Mammalian and microbial polysaccharides such as chitin, carrageenan, and xanthan gum further enrich the array of polymeric materials used in industry.

Polysaccharides, which are significant bio-macromolecules found in living organisms, consist of uronic acids and monosaccharides linked by glycosidic bonds [8]. These polysaccharides are derived from natural sources in abundant quantities and have numerous applications. Among the widely used natural excipients in both conventional and novel dosage forms, plant gums have garnered increasing interest in pharmaceutical formulations due to their natural origin. Plant gums, which are exudates produced by plants as part of a defense mechanism known as gummosis, are typically insoluble in oils and organic solvents such as hydrocarbons, ether, or alcohol. These gums are water-soluble or absorb water, swelling to form viscous solutions or gels. The exudation of gums is often induced by environmental stressors such as heat, nutrient deficiency, or microbial infections, leading to the production of exudates that harden and solidify into glossy, amber-colored droplets after a few weeks. This natural gum production process is an efficient means of sourcing polysaccharides for various applications [9]. Water-soluble gums, known as hydrocolloids, are widely used as thickeners, stabilizers, emulsifying agents, dietary fibers, packaging films, texture modifiers, coating agents, and gelling agents in diverse formulations [10]. This review presents a discussion on the different sources of naturally occurring polysaccharides with bioactive properties. It also provides an overview of the physicochemical characteristics of these biopolymers, specifically polysaccharides, and highlights their significance in pharmaceutical formulations and biomedical applications based on recent research findings.

Classification of Natural Polysaccharides and Their Physicochemical Properties

Polysaccharides are among the most abundant carbohydrates in nature. Their chemical structure consists of monosaccharides linked by glycosidic bonds or covalently bonded to other molecules such as peptides, amino acids, and lipids. Natural polysaccharides are primarily classified into homopolysaccharides, which consist of identical monosaccharides, and heteropolysaccharides, which contain heteroglycans composed of various types of monosaccharides [11]. Further classification can be based on the types of monosaccharide components, chain lengths, and branching patterns. In nature, polysaccharides serve both storage functions, such as starch, and structural functions, such as cellulose, providing physical structure and stability [12]. They can also be categorized according to their polyelectrolyte charges, with negatively charged polysaccharides (e.g., alginate, heparin, hyaluronic acid, and pectin) and positively charged polysaccharides (e.g., chitin, chitosan).

These polysaccharides, derived from diverse sources, are extensively utilized in pharmaceutical formulations and biomedical applications. However, developing suitable formulations can be challenging due to the complex macromolecular structures of polysaccharides. To address this, chemical modifications such as sulfation, phosphorylation, and carboxymethylation can be employed to modify the biological characteristics of these polysaccharides [13]. These modifications enhance the stability, non-toxicity, and biodegradability of the drug delivery systems, making polysaccharides an attractive alternative to synthetic and non-biodegradable polymers. The applications of natural polysaccharides in biological and pharmaceutical industries stem from their responsiveness to physical and chemical modifications, which improve their characteristics. Techniques such as sulfation, phosphorylation, and carboxymethylation are effective in altering the biological properties of polysaccharides, rendering them more suitable for drug delivery systems and biomedical preparations, while maintaining their stability, non-toxicity, and biodegradability [11]. However, the physicochemical properties of natural polysaccharides are influenced by their source and chemical composition.

The physicochemical properties of naturally occurring polysaccharides exhibit diverse characteristics that influence their applications in various industries, such as pharmaceuticals, food, and biotechnological processes. These properties encompass both chemical and physical attributes, which determine their solubility, viscosity, color, and odor, among others.

1. **Guar Gum**: Composed of galactose and mannose units, guar gum appears white and is highly soluble in water, exhibiting low viscosity.
2. **Gum Arabic/Gum Acacia**: Contains arabinose and galactose, it is odorless and water-soluble but does not have a distinct taste, with no information available regarding its viscosity.
3. **Karaya Gum**: A mixture of galactose, rhamnose, galacturonic acid, and glucuronic acid, karaya gum has a pink-gray color and a slightly acetic odor. It is less soluble in water and is known for its acetic taste, though its viscosity is unspecified.
4. **Tara Gum**: Composed of galactose and mannose monosaccharide units, tara gum is highly soluble in cold water, has a neutral taste and odor, and exhibits high viscosity.
5. **Fenugreek Gum**: This polysaccharide is composed of galactose and mannose, presenting as a colorless or slightly cream-colored powder. It is highly soluble in water and has a faint odor and bland taste, with its viscosity not indicated.
6. **Locust Bean Gum**: Made of galactose and mannose, locust bean gum is white to creamy white and is hot water-soluble, particularly at approximately 80 °C. It has a low viscosity.
7. **Tragacanth Gum**: This polysaccharide, consisting of galactose, arabinose, fucose, and galacturonic acid, is water-soluble, odorless, tasteless, and viscous.

8. **Cassia Tora Gum**: Featuring galactose and mannose, this gum is off-white to light tan in color, odorless, and tasteless. It becomes viscous when dissolved in hot water.
9. **Gum Odina**: Containing galactose, arabinose, and uronic acid, gum odina is white, odorless, and practically insoluble in cold water and ethanol. Its viscosity remains unquantified.
10. **Pullulan**: Made up of maltotriose, pullulan is white, odorless, tasteless, water-soluble, and exhibits low viscosity.
11. **Xanthan Gum**: Composed of glucose, mannose, glucuronic acid, pyruvate, and acetate, xanthan gum is a cream-colored powder that is highly soluble in water and has high viscosity at low concentrations, despite its tasteless, slightly acetic odor.
12. **Gellan Gum**: Gellan gum, composed of glucose, rhamnose, and glucuronic acid, is beige and tasteless, soluble in water. Its viscosity increases with higher pH and cation concentration.
13. **β-Glucan**: This polysaccharide, composed of β-d-glucose, is bitter and water-soluble, forming a viscous solution when mixed with liquids.
14. **Inulin**: Derived from fructose, inulin is white, slightly sweet, and soluble in hot water while being slightly soluble in cold water. Its viscosity decreases with increasing temperature.
15. **Xyloglucan**: Consisting of glucopyranose residues, xyloglucan is highly water-soluble and exhibits high viscosity.
16. **Glucomannan**: Comprised of mannose and glucose, glucomannan is fishy in odor and tasteless. It is water-soluble and viscous.
17. **Xylan**: A polysaccharide made of xylose and glucuronic acid, xylan has an acceptable taste, lower solubility, and reduced viscosity.
18. **Arabinogalactan**: Composed of arabinose and galactose, arabinogalactan is white to pale beige, has a grassy fragrance, and slightly sweet taste. It is readily soluble in water and less viscous.
19. **Pectin**: Containing glucuronic acid, pectin is white to light brown, odorless, and fruity in taste. It is soluble in water and has a viscous nature.
20. **Starch**: Made of amylose and amylopectin, starch is white and odorless, insoluble in cold water, and exhibits low viscosity.
21. **Cellulose**: Composed of glucose units, cellulose is tasteless, odorless, and insoluble in both cold and hot water.
22. **Glycogen**: A polysaccharide composed of glucose units, glycogen is red-brown in color and poorly soluble in water, with low viscosity.
23. **Hyaluronan**: Composed of N-acetylglucosamine and glucuronic acid, hyaluronan is clear, odorless, water-soluble, and exhibits high viscosity.
24. **Chitin**: This polysaccharide, consisting of N-acetylglucosamine, is white, fishy, salty, and insoluble in water, with viscous properties.
25. **Chitosan**: Composed of glucosamine, chitosan is yellowish-white, fishy, astringent, and water-soluble with viscous properties.
26. **Heparin**: Made of uronic acid and glucosamine, heparin is white or nearly white, odorless, and soluble in water.
27. **Chondroitin Sulphate**: This polysaccharide, consisting of N-acetylglucosamine and glucuronic acid, is white or light yellowish, odorless, slightly salty, water-soluble, and viscous.

28. **Keratan Sulphate**: Composed of galactose and glucosamine, keratan sulphate has a bitter or saline taste and is characterized by high viscosity.
29. **Dermatan Sulphate**: Containing N-acetyl-D-galactosamine units, dermatan sulphate is white, soluble in water, but has no defined viscosity.
30. **Curdlan**: Composed of β-d-glucose, curdlan is colorless, odorless, tasteless, and insoluble in water, exhibiting high viscosity.
31. **Scleroglucan**: A glucose-based polysaccharide, scleroglucan is soluble in both cold and hot water and exhibits viscous properties.
32. **Dextran**: Composed of glucose, dextran is bland, odorless, tasteless, and water-soluble, with its viscosity remaining undefined.
33. **Levan**: Made from fructose, levan is water-soluble, colorless, and has low viscosity.
34. **Succinoglycan**: This polysaccharide contains pyruvyl, succinyl, and acetyl groups, but its solubility and viscosity properties remain unspecified.
35. **Agar**: Comprising agarose and agaropectin, agar is beige, odorless, tasteless, and soluble in boiling water, exhibiting viscous properties.
36. **Agarose**: A component of agar, agarose is white to beige, odorless, tasteless, and soluble in boiling water with viscous properties.
37. **Ulvan**: Composed of carbohydrates, uronic acid, sulfate, ash, and nitrogen residues, ulvan is a yellowish to reddish substance, water-soluble, but exhibits low viscosity.
38. **Alginate**: Derived from mannuronic and guluronic acids, alginate is yellowish and dissolves slowly in water, with its viscosity influenced by pH and concentration.
39. **Carrageenan**: Composed of D-galactose and 3,6-anhydrogalactose, carrageenan is white to beige, has a slight marine odor, and is soluble in hot water, exhibiting high viscosity.
40. **Fucoidan**: This polysaccharide consists of fucose, sulfate, acetate, galactose, xylose, mannose, glucose, and uronic acid. It is white-yellowish to light brown, with a distinct seaweed taste and not highly viscous.
41. **Laminarin**: Made of β-d-glucose, laminarin is white to off-white, with low odor and water-soluble properties, exhibiting low viscosity.
42. **Spirulan**: Composed of rhamnose, deoxyhexose, and methylpentose, spirulan is blue-green to green, has a mild seaweed-like odor and taste, and is soluble in water.

Cellulose

Cellulose is a crucial fibrous biopolymer predominantly found in various plant species such as cotton, flax, jute, and hemp. It remains insoluble in both hot and cold water due to the strong intramolecular hydrogen bonds present within its structure, rendering it indigestible in the human gastrointestinal (GI) tract [14], [15]. Cellulose can undergo chemical modification to form cellulose esters or ether derivatives, making it water-soluble. The water-soluble variants of cellulose are extensively utilized in pharmaceutical and medical formulations. Microcrystalline cellulose, a derivative of cellulose, is widely employed as a diluent or binder in tablet manufacturing. Common water-soluble cellulose derivatives, including hydroxypropyl methyl cellulose (HPMC), hydroxypropyl cellulose (HPC), hydroxyethyl cellulose (HEC), and sodium carboxymethyl cellulose (Na-CMC), are used for various pharmaceutical applications. Notably, HPMC plays a significant role in controlled-release drug formulations [16].

Starch

Starch is an essential polysaccharide found in nearly all green plants, primarily serving as an energy storage medium. It consists of two major components: amylose and amylopectin. The basic structure of starch is represented by the molecular formula (C6H10O5)n, where glucose units are connected via glycosidic bonds [16]. Both amylose and amylopectin comprise chains of d-glucose residues linked through α-(1,4)-glycosidic bonds, with branching occurring via α-(1,6)-glucosidic linkages. While amylose is largely linear with minimal branching, amylopectin exhibits extensive branching and relatively shorter chains. The structural complexity of amylopectin, with branches constituting approximately 5% of its structure, leads to its crystalline formation, which contributes to the semi-crystalline structure of starch granules [17], [18]. Starch is commonly sourced from maize, rice, potatoes, and wheat and has significant applications in food and pharmaceuticals, particularly as a thickening, gelling, and binding agent [19]. Furthermore, non-starch polysaccharides, such as those found in whole-wheat flour, have notable therapeutic potential, including the management of type 2 diabetes, cardiovascular diseases, and gastrointestinal disorders, as they provide essential micronutrients [20].

Pectin

Pectin is a complex polysaccharide predominantly found in the cell walls of plants, particularly abundant in non-woody tissues. It constitutes a major component of the middle lamella, where it facilitates the adhesion of plant cells, and is also present in the primary cell walls. Pectin is synthesized through exocytosis and deposited into the cell wall via vesicles formed in the Golgi apparatus [22]. Commercially, pectin is obtained as a white to light brown powder, primarily extracted from citrus fruits. Its structure consists of a polygalacturonic acid backbone linked through α-(1 → 4) bonds, modified with neutral sugar side chains, including rhamnose residues. The degree of esterification, particularly methylation, categorizes pectin into low-methoxyl and high-methoxyl forms, depending on the extent of methyl esterification [23].

Gum Arabic (Gum Arabica)

Gum Arabic, also known as Gum Arabica (GA), is a natural gum exuded from the branches and trunks of acacia trees, particularly Acacia senegal (Hashab) and Acacia seyal (Talha), both members of the Fabaceae family [24]. GA is a complex polysaccharide characterized by branching chains, which can either be neutral or slightly acidic. It is typically found as a calcium, magnesium, and potassium salt of polysaccharide acid. GA's structure includes a backbone of 1,3-linked β-D-galactopyranosyl units with side chains composed of two to five 1,3-linked β-D-galactopyranosyl units, attached to the main chain via 1,6 linkages [25]. GA is not only significant in the pharmaceutical and biomedical sectors but is also utilized in folk medicine for its antihypertensive, antihyperlipidemic, anticoagulant, antibacterial, antidiabetic, anti-inflammatory, and nephroprotective effects [24]. In pharmaceutical formulations, it serves as a suspending agent, emulsifier, binder, and in targeted drug delivery systems [26].

Guar Gum

Guar gum, derived from the seeds of Cyamopsis tetragonolobus or Cyamopsis psoraloides, members of the Leguminosae family, is a galactomannan polymer consisting of a linear backbone of (1 → 4) β-D-mannopyranosyl units, with side branches of α-D-galactopyranosyl units linked by (1 → 6) bonds [27], [28]. It is notable for its high water solubility, although it remains insoluble in hydrocarbons, fats, alcohols, and other organic solvents. Guar gum is utilized in pharmaceutical formulations, particularly in controlled-release drug delivery systems. It functions as a natural thickener, emulsifier, stabilizer, binder, gelling agent, and hydrocolloid. Furthermore, it is applied in various industrial processes such as soil stabilization and fracturing agent in oil recovery [29].

Karaya Gum

Karaya gum, also known by various regional names including Sterculia, Kadaya, and Katilo, is obtained from the Sterculia urens tree, a member of the Sterculiaceae family [30]. Its structure is characterized by a backbone consisting of α-D-galacturonic acid and α-L-rhamnose units, with side chains attached through β-D-galactose (1 → 2 linkage) or glucuronic acid (1 → 3 linkage) to the galacturonic acid backbone [31]. Karaya gum has extensive applications in the food, cosmetic, medicine, and pharmaceutical industries, where it is used as a laxative, stabilizer, and binder. In drug delivery, it has been explored for use in floating systems, sustained-release dosage forms, and hydrogels [32].

Tara Gum

Tara gum, derived from the endosperm of Caesalpinia spinosa, is a galactomannan polysaccharide with a backbone of (1 → 4)-β-D-mannopyranose units, linked to branched (1 → 6)-α-D-galactopyranose units [33]. Tara gum has been utilized in the preparation of hydrogels, microparticles, and coacervates as drug delivery carriers, offering potential in various pharmaceutical applications such as controlled drug release systems [34], [35].

Fenugreek Gum

Fenugreek gum is extracted from the seed endosperm of Trigonella foenum-graecum, a member of the Leguminosae family [36]. This galactomannan polysaccharide consists of a backbone of (1 → 4)-D-mannose, connected to α-D-galactose units at the O-6 position, with a galactose to mannose ratio of 1:1 or, in some cases, 1:2 [37]. Fenugreek gum has emerged as a promising excipient and therapeutic agent in the biopharmaceutical field, demonstrating potential antidiabetic, anticancer, anti-inflammatory, and hepatoprotective activities [38].

Locust Bean Gum:

Locust bean gum is a galactomannan polysaccharide derived from the seed endosperm of *Ceratonia siliqua*, commonly referred to as the Carob tree, which belongs to the Caesalpinioideae subfamily of the Leguminosae family [39]. This polysaccharide, characterized by its galactose and mannose content, features a linear backbone composed of (1 → 4)-linked β-D-mannopyranosyl units, with α-D-galactopyranosyl side chains attached through (1 → 6)-linkages [40]. Biopharmaceutical applications of this gum primarily involve its use in developing a variety of drug delivery systems, including oral, buccal, topical, colonic, and ocular formulations. Additionally, locust bean gum serves as a versatile excipient, functioning as a binder, thickener, stabilizer, disintegrator, solubilizer, emulsifier, suspending agent, gelling agent, viscosity enhancer, matrix former, drug release modifier, and bio-adhesive [41].

Tragacanth Gum:

Tragacanth gum is sourced from small, woody evergreen shrubs of the *Astragalus* genus, particularly *A. gummifer*, *A. parrowianus*, *A. flaccosus*, *A. rahensis*, *A. gossypinus*, *A. microcephalus*, and *A. compactus*, which belong to the Leguminosae family and the Papilionidiae subfamily [42]. This heterogeneous polysaccharide is composed of two main components: tragacanthin, which is water-soluble, and bassorin, which is water-swellable. The gum consists of L-arabinose, L-fucose, D-galactose, L-galacturonic acid, and D-xylose [43]. The backbone of tragacanth gum is primarily formed by α-1, 4-D-galacturonic acid, with some residues featuring side chains attached to sugar units. Other sugar moieties, such as D-xylose and D-galactose or L-fucose, may replace D-galacturonic acid residues at various 3-O-positions. The primary structure is an arabinogalactan, a biopolymer composed of galactose units linked by 1, 3, and 6 bonds, with arabinose units (in furanose form) substituted at the 2-, 3-, and 5-O positions. Tragacanth gum has gained attention for its biomedical and pharmaceutical potential, particularly as a carrier in formulations aimed at wound healing, tissue regeneration, and antimicrobial applications [44].

Cassia Tora Gum:

Cassia tora gum, also known as Panwar gum, is obtained from the seed endosperm of *Cassia tora Linn.*, an annual undershrub in the Leguminosae family, commonly found in tropical regions. The primary constituent of the gum is a polysaccharide composed of 1–4-linked D-mannopyranose and D-glucopyranose units [45]. This heteropolysaccharide includes galactose and mannose [46]. *Cassia tora* is known for its diverse pharmacological properties, including antioxidant, hypolipidemic, antimicrobial, hepatoprotective, anti-inflammatory, antitumor, purgative, and antimutagenic effects [47]. The gum demonstrates excellent binding and disintegration properties, making it suitable for incorporation into pharmaceutical formulations such as orodispersible tablets [48] and creams [49].

Gum Odina:

Gum odina is an arabinogalactan polysaccharide sourced from the bark of *Odina wodier Roxb.*, a species in the Anacardiaceae family [50]. This negatively charged polysaccharide comprises D-galactose, L-arabinose, and uronic acids (D-galacturonic acid and aldoburonic acid) [51]. The gum has traditionally been used in Indian folk medicine to treat various ailments such as colds, coughs, dysentery, hepatitis, diabetes, ulcers, and heart disease [50]. In addition, its potential as a pharmaceutical excipient has been recognized, with applications as a binder, emulsion stabilizer, and matrix-forming material [52]. Furthermore, gum odina exhibits prebiotic properties that enhance the gut microbiome and support immune system function [53].

Arabinogalactan:

Arabinogalactans are major components of several gums, including gum arabic and gum ghatti. These large, structurally complex polysaccharides are primarily composed of arabinose and galactose monosaccharides [54]. Arabinogalactans are classified into two types: Type-I (arabino-4-galactans) and Type-II (arabino-3,6-galactans). They have been identified as promising additives to enhance the bioavailability of orally administered drugs such as ibuprofen, naproxen, atorvastatin, simvastatin, nifedipine, albendazole, and others. Additionally, arabinogalactans help address solubility issues in drugs like diazepam, clozapine, medazepam, and others [55].

Xylan:

Xylans, one of the most abundant biopolymers, are polysaccharides found in the secondary cell walls of dicotyledonous plants, certain grasses, cereals, and herbs [56]. Xylans belong to the hemicellulose family and consist of β–1, 4–linked xylose (a pentose sugar) units attached to α–glucuronic acids. Based on the presence of side branches, xylans are categorized into subtypes such as homoxylan, arabinoxylan, glucuronoxylan, and arabinoglucuronoxylan [57]. Xylan's adhesive, thickening, and biocompatible properties make it useful in pharmaceutical and biomedical applications, including microparticles, nanoparticles, hydrogels, and films [58][59].

Glucomannan:

Glucomannan, a hemicellulose polysaccharide present in the cell walls of plants like the konjac plant, certain orchids, and algae, contains D-mannose and D-glucose linked by β-1,4 bonds in a molar ratio of 1.4:1 to 1.6:1, depending on the genotype [60][61]. The presence of an acetyl group in glucomannan enhances its water solubility by preventing intermolecular and intramolecular hydrogen bonding [62]. Traditionally used as a food additive, glucomannan also has notable biopharmaceutical applications. It is known for its beneficial effects in weight loss, cholesterol reduction, diabetes management, and anti-tumor activity against sarcoma-180 solid tumors [63][64]. Furthermore, glucomannan has been utilized in drug delivery systems, such as films, beads, hydrogels, and nanoparticles, due to its sustained release profile [65].

Inulin:

Inulin is a fructan polysaccharide found in various plants like Liliaceae, Amaryllidaceae, Gramineae, and Compositae. It consists of fructose units linked by β-(2 → 1)-D-fructosyl-fructose bonds. Inulin has a wide range of applications in the food, pharmaceutical, and biomedical industries. It is a soluble dietary fiber used in the food industry as a fat and sugar alternative [66][67]. Inulin also functions as a stabilizer, drug carrier, and exhibits various biological activities, including antidiabetic, anticancer, antioxidant, and immunomodulatory effects [67]. Furthermore, inulin acts as a prebiotic, improving the intestinal microbiome and offering promise for colon-targeted drug delivery systems due to its resistance to hydrolysis in the gastrointestinal tract [67][68].

Xyloglucan:

Xyloglucan is a neutral matrix polysaccharide found in the cell walls of plants, consisting of xylose and galactose-xylose units. It is categorized as hemicellulose and possesses non-ionic properties. The backbone of xyloglucan consists of β-(1 → 4)-linked D-glucopyranose residues, with side chains of D-xylose substituted at the O-6 position and D-galactose residues attached at the O-2 position [69][70]. Xyloglucan is noted for its mucoadhesive properties, which help protect mucosal cells from damage by allergens and microorganisms. It is used in pharmaceutical formulations, including nanoparticles, hydrogels, matrix tablets, and films [70][71].

Beta-Glucan:

Beta-glucans) are polysaccharides found in the cell walls of cereals (barley and oats), bacteria (*Xanthomonas campestris*, *Bacillus subtilis*), and fungi (*Levilactobacillus brevis*, *Pediococcus claussenii*). These water-soluble polymers of glucose units are linked by β-glycosidic bonds with β-(1 → 3) and β-(1 → 6) linkages [74]. Beta-glucans possess various functional properties, including thickening, stabilizing, emulsifying, and gelling, making them useful in food products such as soups, sauces, and beverages [75]. In addition to their culinary uses, beta-glucans exhibit health benefits, such as anti-inflammatory, anticancer, hypocholesterolemic, and hypoglycemic effects. They also stimulate the immune system, enhancing resistance to infections, which makes them promising agents for various therapeutic applications [76].

Conclusion:

Natural polysaccharides have long been utilized in the pharmaceutical industry, owing to their unique chemical properties and bioactive functions. These biopolymers, sourced from diverse organisms including plants, animals, and microorganisms, have a significant role in the development of pharmaceutical formulations. The natural origin of polysaccharides offers several advantages, such as biodegradability, non-toxicity, biocompatibility, and renewability, making them ideal candidates for applications in drug delivery and biomedical systems. The use of polysaccharides like chitosan, guar gum, xanthan gum, and various plant gums as excipients has gained considerable interest, particularly for their ability to function as thickening agents, suspending agents, emulsifiers, and binders in pharmaceutical preparations. A major advantage of natural polysaccharides is their versatility in creating various dosage forms, including nanoparticles, microparticles, gels, films, and injectable systems. These versatile excipients are also crucial for the development of controlled-release formulations, enabling sustained and targeted drug delivery. Furthermore, the chemical modification of polysaccharides, such as sulfation, phosphorylation, and carboxymethylation, has expanded their applicability by enhancing their stability and solubility, as well as optimizing their performance in specific drug delivery systems. The modifications not only improve the properties of polysaccharides but also make them more adaptable for various therapeutic applications. Despite the promising potential of natural polysaccharides, challenges remain in optimizing their use in pharmaceutical formulations. For instance, variations in the source material can lead to inconsistencies in their chemical and physical properties, which may affect the reproducibility and efficacy of pharmaceutical products. Moreover, further research is needed to better understand the full range of biological activities and therapeutic potentials of these biopolymers. As the demand for more sustainable and environmentally friendly pharmaceutical ingredients grows, natural polysaccharides will continue to play a critical role in advancing drug delivery systems. In conclusion, natural polysaccharides represent a valuable resource in pharmaceutical and biomedical applications. Their unique properties and versatility, coupled with ongoing research into their chemical modifications, promise to drive innovation in the development of more effective, sustainable, and eco-friendly drug delivery systems.

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البوليمرات السكرية: التطبيقات الصيدلانية - مراجعة محدثة

الملخص:

الخلفية: في السنوات الأخيرة، اعتمدت صناعة الأدوية بشكل متزايد على البوليمرات السكرية الطبيعية بسبب خصائصها البيولوجية النشطة. هذه البوليمرات البيولوجية، المشتقة من مصادر متنوعة تشمل النباتات والحيوانات والكائنات الدقيقة والطحالب، تلعب دورًا حاسمًا في أنظمة توصيل الأدوية، حيث توفر التوافق الحيوي، والتحلل البيولوجي، والمرونة في التركيبات الصيدلانية.

الهدف: تهدف هذه المراجعة إلى تقديم نظرة محدثة حول البوليمرات السكرية الطبيعية، مستعرضة خصائصها الفيزيائية والكيميائية، مصادرها، وتطبيقاتها في المجالات الصيدلانية والطبية الحيوية .المنهج: تقوم المراجعة بتجميع الأبحاث الحديثة حول البوليمرات السكرية الطبيعية، مع التركيز على هيكلها الكيميائي وتصنيفها وتعديلاتها. تصنف الدراسة البوليمرات السكرية إلى بوليمرات سكرية متجانسة وغير متجانسة، بناءً على نوع وحدات السكريات الأحادية التي تحتوي عليها. كما تناقش التعديلات الكيميائية والفيزيائية، مثل السلفات والفوسفات، التي تعزز أدائها في توصيل الأدوية.

النتائج: أظهرت البوليمرات السكرية الطبيعية، بما في ذلك صمغ النباتات، والشيتوزان، وصمغ الجوار، وصمغ الزانثان، إمكانات كبيرة كمواد مساعدة في التركيبات الصيدلانية. يتم استخدامها في أشكال جرعات متنوعة مثل الغرسات، والجسيمات النانوية، والأنظمة القابلة للحقن. تختلف الخصائص الفيزيائية والكيميائية، مثل القابلية للذوبان، واللزوجة، والقدرة على التجلط، حسب المصدر، وتُستخدم التعديلات لتحسين هذه الخصائص لتطبيقات صيدلانية محددة.

الخلاصة: ظهرت البوليمرات السكرية الطبيعية كمواد رئيسية في صناعة الأدوية بسبب خصائصها الفريدة وميزاتها البيئية الصديقة. توفر مرونتها إمكانيات متعددة في أنظمة توصيل الأدوية، من عوامل تعليق إلى مستحلبات. مع مزيد من البحث في تعديلات هذه البوليمرات، ستستمر البوليمرات السكرية في تقديم بدائل مستدامة للبوليمرات الاصطناعية في التطبيقات الصيدلانية.

الكلمات المفتاحية: البوليمرات السكرية، البوليمرات النشطة بيولوجيًا، توصيل الأدوية، البوليمرات البيولوجية، المواد المساعدة، الصمغ الطبيعي، التركيبات الصيدلانية، التحلل البيولوجي، الاستدامة.