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A Review: Introduction to Biopolymers from Medicinal Plants

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Abstract: *In recent years, biopolymers derived from medicinal plants have attracted more attention due to their biocompatibility, biodegradability, and therapeutic potential. Natural polymers, such as gums, mucilages, starches, and polysaccharides, are produced by pharmacologically active plants and provide extra health benefits while ecologically replacing synthetic components. Biopolymeric biomaterials have been used in cardiovascular surgery, medication delivery, and tissue engineering. Due to their abundance of bioactive chemicals, medicinal plants have long served as the basis for custom in contemporary treatments. Alkaloid-linked polymers, proteins, polyphenols, and polysaccharides generated from medicinal plants are among the biopolymers that have attracted increasing attention due to their biocompatibility, biodegradability, and therapeutic flexibility. This chapter provides a thorough introduction to plant-derived biopolymers, emphasizing their extraction, categorization, and biomedical uses. A few particular instances are in fact highlighted to illustrate their various roles in antimicrobial formulations, tissue engineering, wound healing, and medication delivery. These examples are provided by the well-known medical plants Moringa oleifera and Aloe vera etc. In contrast to synthetic polymers, plant biopolymers are less hazardous, more cost-effective, and more ecologically sustainable.*

Keywords: Biopolymers, Medicinal Plants, Natural Polymers, polysaccharides, biomedical applications, eco-friendly polymers

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1. Introduction

Natural polymers, which are any polymers found naturally in the environment (such cellulose or starch), or bio-based polymers, which are synthetically made from natural materials, can both be referred to as "biopolymers." They are lengthy chains of biomolecules made up of monomeric units that repeat like a chain and are joined by covalent bonds. Chitin, starch, cellulose, peptides, proteins, DNA, and RNA are examples of biopolymers that contain amino acids, sugars, or nucleotides as their monomeric components. Biopolymers have been found to be both biocompatible and biodegradable, which makes them valuable for a range of uses. In the food business, for instance, they can be utilized as packing materials, emulsions, and edible coatings. They can be utilized as tissue scaffolds, dressing materials, medical prosthesis, and drug carrier materials in the pharmaceutical sector [1].

Table 1.1 Selected lists of the common natural polymers

S.No.	Natural polymer
1	Polysaccharides
2	Starch
3	Cellulose
4	Chitin
5	Proteins
6	Collagen/gelatin
7	Casein, albumin, fibrogen, silks
8	Polyesters
9	Poly(hydroxyalkanoates)
10	Other polymers
11	Lignin
12	Lipids
13	Shellac
14	Natural rubber

1.1 Properties of Polymers:

Based on its physical foundation as well as the scale at which they are specified, polymer properties are categorized into different groups. The similarity of a polymer's constituent monomers is its most crucial property. The arrangement of these monomers within the polymer at the level of a single chain is described by a second set of properties called microstructure [2].

1.1.1 Chemical Property

The forces of attraction between a polymer's chains largely dictate its properties. The interchain forces between polymer chains are significantly stronger than those between regular molecules due to their length. Intermolecular forces in polymers can be affected by dipoles in monomer units. A strong attraction exists between partially negatively charged oxygen atoms in C=O groups in one chain and partially positively charged hydrogen atoms in N-H

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groups in another chain when polymers with amide or carbonyl groups form hydrogen bonds between adjacent chains [3,4].

1.1.2 Mechanical properties

The macroscopic behavior of the polymer is determined by these characteristics. Because of their lengthy chains and large molecular weight, polymers exhibit unique properties [5]. The amount of stress that a material can sustain before experiencing irreversible distortion is determined by its tensile strength [2]. Prior to use, the following important properties of polymers should be taken into account.

- The capacity to maintain high mechanical strength until it degrades [6].
- The permeability and processibility of the material should be appropriate for the intended use [7, 8].
- The material's shelf life should be suitable.

1.1.3 Transport Property

The pace at which molecules travel through the polymer matrix is referred to as diffusion. In a variety of polymer film and membrane applications, these are highly important. The term "melting point" describes the change from a crystalline or semi-crystalline phase to a solid amorphous phase, not from a solid to a liquid, in the context of polymers [2].

1.1.4 Elasticity

When stress is alleviated, polymer chains stretch and regain their original shape. With the exception of glassy or partially crystalline states, all polymers exhibit notable elasticity [4].

2. Biopolymers derived from plants and their uses

Table 2 lists the different plant-derived biopolymers and their uses, which are covered in more detail below.

Table 2.1: Plant-derived biopolymers and their uses

Name of polymer	Source of origin	Physical appearance	Uses/applications	References
Cellulose	Plant tissue (trees,cotton etc), bacteria (*Acetobacter xylinum*).	Water indissoluble, chemical-free solvents odourless, hydrophilic, environment-friendly	Controlled Drug Delivery Devices, Wound Dressings, Scaffolds for Regenerative Medicine, cellophane films, thickener, wrappers, adhesives, agricultural chemicals, coatings, ligature, preserver, dispersing agent, flow controller, tile sealant, board	[9,10,11]

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			fixative, indelible inks, beauty products.	
Pectin	Plant cell walls, citrus peels, apple pomace.	Coarse or fine-powder, yellowish-white, odourless, mucilaginous taste, altogether soluble in 20 parts of water	Reduce blood cholesterol, treat gastrointestinal disorders, remove metals such as lead, mercury from intestine and lungs, control haemorrhage, tablet formulations, antimicrobial action, improves coagulation, treatment of overeating, anti inflammatory.	[12, 13,14]
Carrageenan	Cell wall matrix of red seaweeds.	Large, pliant molecules and make helical structures, at room tempera	Anticoagulant and antithrombotic activity, Antiviral activity, textural functionality	[15]
		ture, gets solidify.	particularly in dairy products.	
Xylan	Hardwood (eg *Eucalyptus globules* etc), almond shell, rice husk, corn cobs.	Yellow gummy hig	Low-caloric sweetener, preventative agent, paper making, textile printing, drug delivery system.	[16, 17]
Guar Gum	*Cyamopsis tetragonolobus* or *Cyamopsis psoraloides*	White to an off-white colour, unscented, greyish white granulate 90% of which dissolves in water.	Disintegrating agent, binding agent, film-forming agent, viscosity-enhancing, thickening or gelling agent, stabilizer, emulsifier, bioadhesive agent, bulk-forming laxative, non-toxic nature.	[18]
Gum Arabic	Stems and branches of *Acacia Seyal* and	Dried, gummy . white to yellowish white,	Stabilizer, thickening agent, emulsifier, fabric,ceramics,print photolithog	[19]

	Acacia Senegal tree.	practically with tasteless, and odourless	raph, beauty products,medicine manufacturing industries, treatment of internal as well as external inflammation , antioxidant , nephroprotectant .	

2.1.1 Chitosan

A naturally occurring carbohydrate derived from chitin is chitosan. Chitin, the second most abundant biopolymer on Earth, is found in the cell mass of yeast and parasites, the exoskeleton of insects and shellfish, nematodes, and mushrooms. High bioactivity, biocompatibility, penetrability, biodegradability, antimicrobial movement, explicit polyelectrolyte action, chelation ability, gel, film, and absorptive limit are just a few of the many qualities of chitosan. As a result, it makes chitosan a valuable tool in many areas, such as drug delivery for controlled release, bone tissue formation, bacterial plaque inhibition, anti-bacterial and anti-acid properties, promoting osteogenesis, fat absorption, decalcification of dental enamel, and ulcer and injury healing [20]. Alginate, chitin/chitosan, and fucoidan powder were combined to create a hydrogel sheet that will heal wounds quickly [21]. In addition to these, it has been used for orthopedic applications, wound healing, and ligament tissue building degradable polymeric lowers the requirement for a second, cautious action. In a variety of microorganisms, including growths, green growths, and organisms, chitosan has been shown to possess antibacterial properties. For example, it demonstrated antibacterial activity against a variety of yeast species and gram-positive bacteria. Additionally, the chitosan gel was mentioned as a potential treatment and prevention option for dental cavities [22].

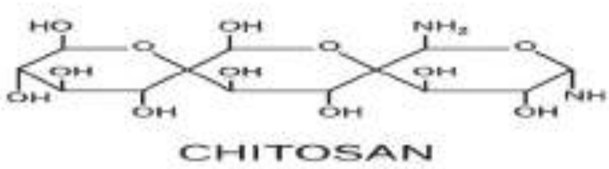

Fig 2.1 Structure of Chitosan

2.1.2 Cellulose

It is a glucose polymer and is found in large quantities in plants .A polymer, cellulose is made up of two or three hundred to more than ten thousand β (1→4) linked D-glucose units

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(C6H10O5). Cellulose is used as a biomaterial for tissue design frameworks because to its remarkable mechanical qualities and remarkable biocompatibility. Bacterial cellulose (BC) has been investigated for wound recuperating as a result of its virtue and high water maintenance limit [23]. Cellulose is broadly utilized for the generation of wrappers and coatings. Cellophane films, appropriate for nourishment bundling, are made up of cellulose.

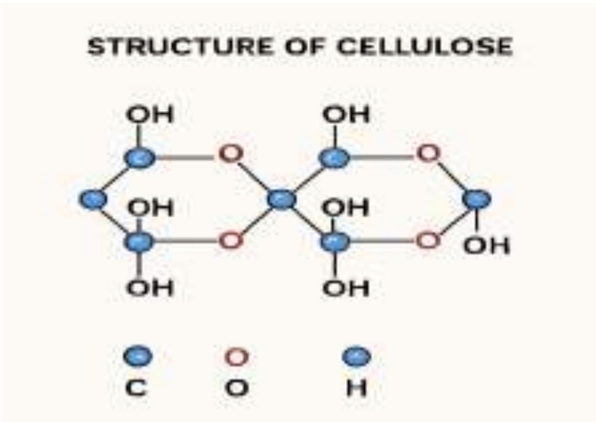

Fig 2.2 Structure of Cellulose

2.1.3 Xylan

After cellulose, xylan, a hemicellulose, is employed as a polysaccharide. Up to 30% of the lignocellulosic and cell divider elements in hardwood are xylans from plants and cereals. Colonic medication delivery systems have been constructed using xylan, a crude fitting material.

Fiber's viscosity and water-extractable character aid in lowering blood cholesterol, postprandial hyperglycemia, insulin response, and alcoholic liver disease, respectively [24]. It is believed that hemicelluloses with xylan collected from plant debris, such as maize stalks, bamboo leaves, and wheat straws, slow the growth of sarcoma 180 and other tumors. Carboxymethylated xylan and hemicelluloses are used to actuate T-lymphocytes and immunocytes. As a coagulant antagonist, pentosan polysulfate (PPS) is utilized in gel form to treat implantation thrombophlebitis [25].

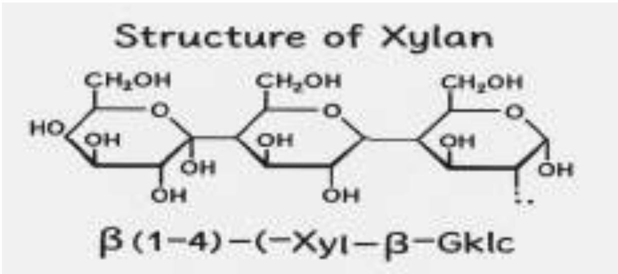

Fig 2.3 Structure of Xylan

2.1.4 Alginates

One of the water-soluble polymers found in hydrocolloids extracted from drab, darkened seaweeds is this one. Alginate is frequently employed in biomedical applications such as tissue building, calm transport, and gastric reflux because of its biodegradability, biocompatibility, non-antigenicity, and chelating limit. For tissue repair and recovery, alginate is utilized to support networks or transport structures. Ascophyllum nodosum and Macrocystis porifera are two important sources of alginates [26]. Alginate hydrogels can be formed primarily by ionic cross-connection with multivalent cations, but they can also be formed by material or even physical crosslinking of the polymer chains.

These gels can withstand heat treatment without dissolving and have a water content of over 95% [27]. Alginate is utilized in organic product texturization, the arrangement of gels, uses in protein expulsion, expansion of the capacity life of potatoes, immobilization of banana chemicals, minced fish patties, meat items, water-holding, frozen yoghurt stabilizers, dispersive capacity.

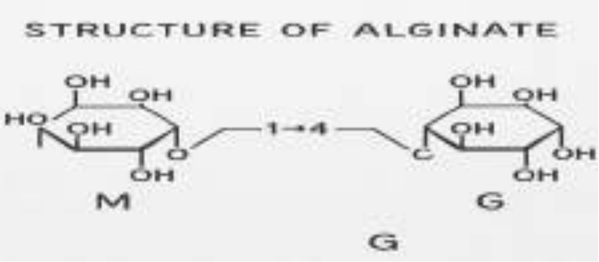

Fig 2.4 Structure of Alginates

2.1.5 Gelatin

The heteropolysaccharide gelatin is found in the cell dividers of herbs. Gelatin is a complex mixture of carbohydrates that are found in vital cell dividers and in particularly large quantities in non-woody plants. Commercial gelatins are made from apple pomace or citrus strips, which are leftover biomass from juice manufacturing facilities. Gelatin is thought to comprise basically of D-galacturonic acid (GalA) units, participating in chains by methods for á-(1-4) glycosidic linkage [28]. Additionally, there are numerous studies showing that green growth could be used to produce biofuels [29]. It is widely used as a gelling agent, to solidify the good ingredients and as a stabilizer in pharmaceutical products [30].

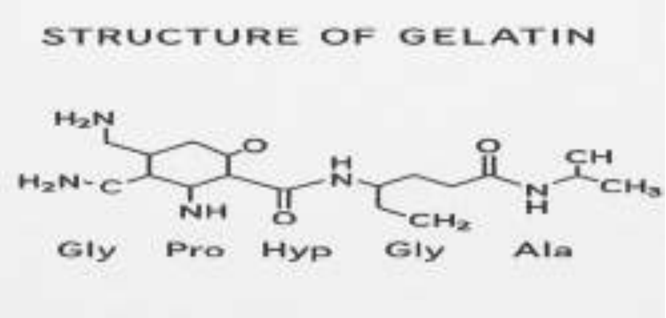

Fig 2.5 Structure of Gelatin

2.1.6 Pectin

The complex polysaccharide family known as pectin is found in the walls enclosing developing and dividing plant cells. In secondary cell walls, such as xylem and fiber cells in woody tissue, it is also found in the junctional zone between cells [31,32]. Pectin has been investigated as excipients in many different types of dosage forms such as film coating of colon- specific drug delivery systems when mixed with ethyl cellulose, microparticulate delivery systems for ophthalmic preparations and matrix type transdermal patches. Depending on the botanical source, pectin's composition might change. For instance, pectin from citrus has a smaller molecular size and fewer neutral sugars than pectin from apples [33,34].

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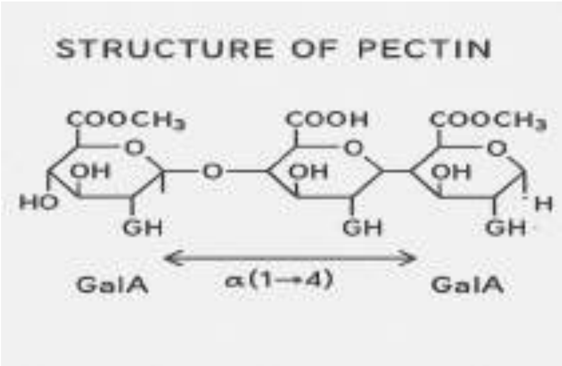

Fig 2.6 Structure of Pectin

2.1.7 Carrageenans

The general term for a family of high molecular weight sulphated polysaccharides derived from some red seaweed species in the Rhodophyceae class—particularly Chondrus crispus, Euchema spp., Gigartina stellata, and Iridaea spp.—is carrageenans. The human body cannot absorb seaweed-derived carrageenan, which gives the body weight but no nourishment. Carrageenan comes in three primary varieties: lambda (λ), iota (ι), and kappa (κ). Whereas the κ-type carrageenan forms a brittle gel, the λ-type carrageenan produces viscous solutions but is not gelling. Elastic gels are produced by ι-type carrageenan. 45 Hydrogel beads were prepared from a mixture of cross- linked κ- carrageenan with potassium and cross- linked alginate with calcium and they exhibited a smoother surface morphology than that of the one- polysaccharide network beads. The hydrogel's carrageenan components significantly improved the polymeric network's thermostability. These beads were unveiled as innovative medicine delivery systems' carriers [35].

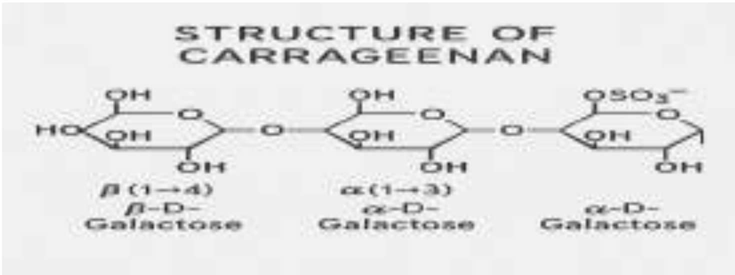

Fig 2.7 Structure of Carrageenans

3. Applications of Biopolymers from Medicinal Plants

Medicinal plant-based biopolymers have become multipurpose materials with a wide range of uses in the food, pharmaceutical, biomedical, and environmental sectors. They are appealing substitutes for synthetic polymers due to their non-toxic nature, biocompatibility, bioactivity, and renewability.

Fig 2.8 Applications of Biopolymers

3.1. Drug Delivery Systems

3.1.1 Drug delivery methods based on collagen: Collagen films are mostly used as barrier membranes Tissue infections, such as infected corneal tissue or liver cancer, have been treated with collagen film, sheet, or disc. In order to treat infected corneal tissue with a high dosage of antibiotic medicines like gentamycin and tetracycline, soluble ophthalmic inserts in the form of wafers or films were developed as a drug delivery method. In order to promote bone formation, collagen film and matrix have been employed as gene delivery vehicles [36].

3.1.2 Drug delivery and chitosan: It may enhance drug absorption and stabilize drug constituents to improve drug targeting. Chitosan can also extend the time that genes express themselves and safeguard DNA. Derivatives of chitin or chitosan that have been conjugated with some anticancer drugs can produce improved anticancer effects by releasing free medicine gradually into the cancer tissues [37].

3.1.3 Devices for Controlled Drug Delivery Based on Cellulose: The inclusion of cellulose ether in solid tablets enables the medicine to be released by swelling when bodily fluids come into contact with the tablet. On the tablet surface, the cellulose ether begins to swell, forming physical hydrogel and chain entanglements. The medication gradually dissolves in water and diffuses out from the polymer network as swelling moves from the tablet's surface to its glassy center [38,39].

3.1.4 Alginate-based drug delivery: Because alginate is biocompatible and biodegradable, it is frequently utilized as a carrier to immobilize or encapsulate medications [40,41].

3.2. Tissue Engineering and Wound Healing

By encouraging cell division, angiogenesis, and collagen formation, biopolymers such gum acacia and aloe vera gel have demonstrated exceptional wound healing qualities [42]. Because of their ability to form gels and retain moisture, hydrogels made from Aloe vera polysaccharides are utilized as scaffolds for tissue regeneration [43].

3.3. Packaging for Antimicrobials and Antioxidants

Biodegradable food packaging materials are biopolymer films enhanced with antioxidants obtained from plants (such as Azadirachta indica and Moringa oleifera). These films prolong shelf life and prevent microbiological development [44].

3.4. Treatments for Cancer

Certain plant biopolymers, like pectin from Citrus sinensis and arabinogalactans from Echinacea purpurea, have been investigated for their potential to inhibit cancer by altering the apoptotic and cell signaling pathways [45].

3.5. Synthesis of Nanoparticles

In the environmentally friendly manufacturing of nanoparticles utilized in targeted drug delivery and imaging, medicinal plant biopolymers serve as stabilizing and reducing agents. For instance, silver nanoparticles with antibacterial properties have been synthesized using Terminalia arjuna gum [46].

3.6. Applications in Dermatology and Cosmetics

For skin hydration, anti-aging, and anti-inflammatory properties, polysaccharides such as beta-glucans from Ganoderma lucidum and mucilage from Aloe vera are frequently found in creams, lotions, and serums [47].

3.7. Biodegradable Materials and Bioplastics

Biodegradable plastics can be created by modifying cellulose and starches obtained from plants, providing a sustainable option for packaging and single-use products. Bioplastics made from cassava starch and reinforced with plant extracts have demonstrated improved antibacterial and durability qualities [48].

3.8. Uses in Agriculture

Medicinal plant biopolymers can be used as slow-release fertilizer matrices, soil conditioners, and natural seed coverings. For instance, fenugreek gum promotes plant growth and improves soil water retention [49].

Conclusion

Biopolymers are naturally occurring substances that are created throughout the life cycles of bacteria, fungus, green plants, and mammals. Biopolymers include polysaccharides like cellulose, starch, and carbohydrate polymers made by bacteria and fungus, as well as biopolymers based on animal proteins like collagen, gelatin, wool, and silk. Biopolymers, particularly those derived from carbohydrates, have shown great promise for use in a variety of biomedical applications. Because to its renewable nature, stability, biodegradability, and low toxicity. Biopolymers are choice of research as excipient. Some of the most widely utilized biopolymers as excipients in biomedical science are included in this chapter.

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