APPLICATIONS OF PLANT-DERIVED POLYSACCHARIDES WITH SPECIAL EMPHASIS ON MUCILAGE

Abstract

The recent advancements in scientific knowledge and its diverse applications made us recognize the importance and need of some old practices. The use of synthetic materials, especially polymers with many side effects, also prompted human kind to switch on to plant-derived products. Among the various unavoidable substances in our daily lives, polymers are of prime importance. They may be natural, semi-synthetic and artificial. Natural polymers are biocompatible, biodegradable and less toxic than artificial polymers. Among various natural polymers, plant derived polysaccharides such as mucilage, gums and starch. Mucilage is utilized in tablet formulations, drug delivery systems and waste water purification by removing dyes and heavy metals. It shows pharmacological properties such as antioxidant, antibacterial and anti-inflammatory. This chapter reviews the importance and applications of plant mucilage with special reference to its pharmaceutical, pharmacological and bioremediation perspectives.

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I. INTRODUCTION

Polymers are unavoidable substances in our daily life and were considered the physical aggregates of small molecules for a long time. Though the polymers were present from the very existence of life, there was no clear picture of their chemical nature available till the 1920s. The age of polymer started when Hermann Staudinger published his paper titled ‘Uber polymerisation’. He introduced the word ‘macromolecule’ and he explained polymer as a composition of very large molecules containing long sequences of monomers joined together by covalent bonds [1,2]. The word ‘polymer’ originated from Greek where *poly* means many and *meres* means parts. As their name depicts, polymers are long molecular chains consisting of thousands of atoms [3]. Mandelkern, (1972) described the rising of polymers in relation to different ages of history. The present age can be marked as the age of macromolecules or polymers. Including nucleic acids and proteins, all macromolecules provide raw materials for all our necessities and amenities of life [4].

II. DEMAND FOR BIOPOLYMERS

Polymers in the form of medicine, food, communicative devices, vehicles, containers, cloths, buildings, etc. are closely attached to human lives. On the basis of origin or source, polymers are of three types: synthetic, semi-synthetic, and natural. Nylon, polystyrene, polyvinyl chloride, and polyethylene are synthetic polymers obtained by the polymerization process from different raw materials. On the other hand, semi-synthetic polymers are obtained from natural polymers through chemical modifications. Nitrocellulose, rayon, and vulcanized rubber are examples of semi-synthetic polymers. Polynucleotides, polypeptides, polysaccharides, natural rubber, silk, wool, etc. are listed under natural polymers. Polyethylene, nylon, polyvinyl chloride, etc are synthetic polymers. They are artificially developed and are equipped to shape into different microstructures due to their less sensitivity to physical parameters such as temperature, pH, UV radiations, water, etc. Since natural polymers are obtained directly from natural sources, there is least or no modification in their chemical structure.

The polymers synthesized in living organisms have been considered biopolymers. They are biocompatible, biodegradable, less toxic, and even renewable when compared with synthetic ones. The need for biopolymers has increased nowadays due to their biodegradable nature. Semi-synthetic polymers are partially biodegradable because of their combination with natural and synthetic forms [5]. Nowadays the decomposition of polymer waste is becoming a threatening problem to the world. Improper decomposition of such wastes adds greenhouse gases to the atmosphere. So people are searching for environmentally friendly polymers. In order to save Earth and life, we need biodegradable polymers which should be free from petrochemicals. Natural polymers are the appropriate solution to the harmful effects of plastics. The residues of natural polymers can be eliminated biologically [6].

III. POLYSACCHARIDES: SELECTED BIOPOLYMER

Among the natural polymers, polysaccharides acquire prime attention due to their bio-friendly nature. Polysaccharides can be of animal, plant, microorganism, and algal origin. In the drug processing field, polymers have been employed as drug formulations and drug delivery systems. Polysaccharides from biological sources have been proven effective in medical and pharmaceutical applications [7]. Polysaccharides are the best-chosen biopolymers for biomedical and pharmaceutical applications. They consist of monosaccharide units with O-glycosidic bonds. Hydrolysis of polysaccharides yields simple sugar units such as glucose, galactose, mannose, uronic acids, arabinose, etc. Natural polysaccharides are obtained from plants, animals, microbes, and algae. Plant sources are abundant on earth with the availability of numerous varieties like gum, mucilage, and starch. Chitin, chitosan, hyaluronic acid, heparin, keratin sulfate, etc. are examples of animal polysaccharides. Microbial polysaccharides are more favoured at the commercial level because of the high yields under a controlled environment. Dextrans, xanthan gum, scleroglucan, bacterial alginate, etc., are microbial polysaccharides. Hot water extraction, alkali-water extraction, and enzymolysis are the main methods of extraction of polysaccharides [8]. Agars, alginates, galactans, and carrageenan are examples of algal polysaccharides [9]. Natural polysaccharides possess various functional groups and physiochemical properties and hence have been utilized in different biomedical fields. They exhibit pharmacological activities such as antioxidant, anti-inflammatory, immunomodulatory and antitumor. Different biomedical applications that employ polysaccharides include cell encapsulation, tissue engineering, drug delivery, gene delivery, protein binding, wound healing, tissue engineering, bioimaging, preparation of contact lenses, development of implants, and manufacturing of antibacterial textiles or papers, and anti-microbial food packaging materials [10].

Morris et al., (2010) described the use of animal polysaccharides such as pectin and chitosan in drug delivery systems and tablet formulations [11]. Park and Kim, (2010) described that chitin and its derivatives exhibit antimicrobial, anti-inflammatory, antioxidant, and anticancer activities and are attractive as drug carriers due to their excellent biocompatibility, biodegradability, and non-toxic nature [12]. According to Lima et al., (2017) heparin and other glycosaminoglycan polysaccharides obtained from cattle and pigs were used as anticoagulant and anticancer agents [13]. Salwowska et al., (2016) explained the therapeutic effect of hyaluronic acid in inflammatory conditions, skin healing, and tumour and even in ophthalmology due to its lubricating properties [14]. Giavasis, (2013) reported that biopolymers such as xanthan, gellan, alginate, pullulan, etc. have been obtained from different microbial sources. They can be used in pharmaceuticals in the form of thickening agents, viscosifiers, gelling agents, and emulsifiers. In addition, they exhibit antitumor, immunostimulatory, antimicrobial, and hypolipidaemic activities [15]. According to Misurcova et al., (2012) sulfated polysaccharides of green algae and red algae show many therapeutic properties and physiochemical functions such as antiviral properties against herpes simplex virus and anticoagulant activities [16].

Di Donato et al., (2014) reported that 90% of polysaccharides are obtained from green plants. In plants, polysaccharides are mainly formed through photosynthesis and then modified. The presence of physiochemical constituents and secondary metabolites in mucilage support their medicinal applications [17]. Li et al., (2018) described the utilization of plant polysaccharides in industrial applications and pharmacological applications. In industrial applications, they take the role of pharmaceuticals, biomaterials, biofuels, and nutrition [18]. Polysaccharides from Chinese medicinal plants regulate the immune system of the human body by modulating the function of macrophages. They can be widely used as biomaterials in tissue engineering. When compared with herbal polysaccharides, risk factors of animal polysaccharides are higher in tissue engineering. Cellulose is a polysaccharide and cell wall component of plants. It is effective in biomedical fields as adsorbent beads, filters, artificial tissue, and protective clothing and is able to regulate bowel movement. Pectin is part of the cell wall and is used as food additives and as raw materials in the pharmaceutical industry [19]. The polysaccharide obtained from *Juniperus scopolorum* shows an immunomodulatory effect [20]. *Konjac* glucomannan polysaccharide from *Amorphophallus konjac* reduces cholesterol levels and regulates the immune system and *Blettilla striata* polysaccharide modulates macrophages and controls immune responses [21]. The polysaccharide of *Chelidonium majus* is an antitumor immunomodulator [22]. Ginseng polysaccharide is extracted from the root of *Panax ginseng* and has an anti-rotavirus activity [23]. The polysaccharide from *Eucommia ulmoides* expresses an anti-inflammatory effect [24].

IV. MUCILAGE: A PLANT POLYSACCHARIDE

Mucilage and gums obtained from different herbs are considered non-starch polysaccharides in which mucilage is a heterogeneous branched polysaccharide and gum is a heterogeneous polyuronide [25]. Production of gums is always associated with plant injury or trauma and can be readily dissolved in water. Mucilages are products of plant metabolism and form slimy masses with water. Though mucilage is a physiological product of the plant, the exact role of mucilage inside the plant is not clear. It can be a shield against hydration because of its water-holding capacity [16]. These polymers obtained from plants are more acceptable because of their lesser toxicity, biodegradability, easy availability, and cheaper production cost. Natural polymers have been used as binders, diluents, disintegrating agents and sustaining agents in tablet formulation, viscous liquid formulations in ophthalmic drops, thickeners in oral liquids, protective colloids in suspension, and gelling agents, protective colloids in suspensions, bases in a suppository, etc. In this context, a detailed study on natural polymers became the need of the hour. Plant-derived materials were the only raw materials for all industries during the past [26]. In short, mucilage can be a valuable source of income for poor people as they are prevalent in all important live commodities [27]. Many plants that belong to families such as Bombaceae, Cactaceae, Crassulaceae, Lauraceae, Malvaceae, Cruciferae, Commelinaceae, Labiatae, Leguminosae, Liliaceae, Orchidaceae, Rosaceae, Plantaginaceae, Pedaliaceae, Teliaceae, Schisandraceae, Scrophulariaceae, Ulmaceae, and Vitaceae are sources of gums and mucilage that have medicinal and pharmaceutical properties and also used in the food industry as dietary supplements [28]. Proper optimization of such plant resources with gums and mucilage becomes necessary in the present era of synthetic drugs.

1. **Mucilage in pharmaceuticals**: According to Prajapati et al, (2013), among the plant polysaccharides, gums and mucilage become prominent due to their complex and branched polymeric structure, high cohesive and adhesive properties, and multifaceted applications in pharmacy. They are polysaccharide hydrocolloids. Gums are exudates of cells whereas mucilage is a part of the cell. Hence, mucilage can be obtained from different parts of plants such as leaves, seed coats, roots, barks, and middle lamella [29]. According to Kumar et al., (2009a), mucilage obtained from *Abelmoschus esculentus* (Okra) of the Malvaceae family is used in cosmetic and pharmaceutical industries as a stabilizer and thickener and has binding properties in tablet formulation. It also exhibits the roles of pharmaceutical adjuvant and suspending agent [30]. Ahad et al., (2010a) studied the efficiency of okra mucilage as a release retardant in controlled release matrix tablet formation and stated that its good flow and stability made it suitable for matrix [31]. Ahad et al., (2010b) found that transdermal films for drug delivery can be prepared with the

mucilage from the fruits of *Ficus reticulate* due to the good physical and mechanical properties of the matrix [32]. Patel et al., (1987) reported that bavchi mucilage from *Ocimum canum* and Rosario mucilage from *Lepidium sativum* can be used as suspending agents and emulsifying agents in tablet formulation [33]. Laux et al (2019) stated that mucilage from the leaves of different species of *Aloe* is used as a tablet binder, sustained release matrix of tablets, and a dissolution enhancer in tablet formulation [34]. They have an effective role in oral drug delivery, buccal drug delivery, and transdermal drug delivery. Kulkarni et al (2002a) explained the fenugreek mucilage from *Trigonella foenum-graecum* as a tablet binder, sustaining agent, disintegrant, gelling agent, emollient, and demulcent [35].

Datta and Bandyopadhyay (2005) stated that fenugreek mucilage is a fine mucoadhesive agent in nasal drug delivery. It is edible, non-allergic, and biodegradable [36]. Shoaib et al (2014) used 8 and 10 % of *Sesbania grandiflora* seed mucilage in uncoated tablets and reported it as a good tablet binder [37]. Jani and Shah (2008) evaluated the mucilage isolated from leaves of *Hibiscus rosasinensis* Linn and proved its efficacy as a sustained release agent in tablets [38]. Linseed mucilage obtained from seeds of *Linum usitatissimum* of Linaceae was proved as a disintegrant agent in the formulation of dispersible tablets by Shrotriya et al, (2010) and tablet binding agent by Abuelrakha and Hamedelniel (2019) [39,40]. Alalor and Augustine (2017) concluded in their study that mucilage of *Colocasia esculenta* can be used as a suspending agent, stabilizer, and thickener in pharmaceutical suspensions [41]. *Ocimum* seed mucilage from *Ocimum gratissimum* has been evaluated and proved as a suspending agent by Anroop et al., (2005) and as a binding agent in pharmaceutical formulations by Anroop et al., (2006) [42,43]. According to Kulkarni et al., (2002b) mucilage isolated from *Asparagus recemosus* and *Cassia sophera* possessed proper binding properties in uncoated tablets and also good disintegrant properties [44]. Shukla et al., (2018) reviewed tamarind seed polysaccharide or mucilage as a pharmaceutical excipient and described it as a binder in tablets, mucoadhesive polymer, sustained drug delivery agent, bioadhesive tablets, and suspending agent in pharmaceutical drug formulations [45]. *Mimosa pudica* seed mucilage was reported as a sustained release matrix by Singh et al., (2009), a promising mucoadhesive polymer for buccal delivery of drugs by Ahuja et al., (2010), and binder and disintegrant in tablets by Ahuja et al., (2013) [46,47,48]. Salehi et al., (2019) reported that different species of cactus are easily extractable sources of mucilage [49]. These mucilages are applicable as a biopolymer in pharmaceutical, food, and cosmetic industries. Kumar et al., (2009b) studied the properties of mucilage powder of *Salicornia fruticosa* (L.) and reported its disintegrating property in pharmaceutical formulations [50].

2. **Mucilage as adsorbent to remove contaminants from water:** Mucilage is a good natural adsorbent against dyes and heavy metals in water. It can be considered a green approach to the remediation of water. Mucilage from roots of *Alcea rosea* was found as efficient in the removal of dyes from sewage by Mahmoudabadi et al., (2019) [51]. Mijinyawa et al., (2019) reported that food-grade mucilage from *Colocasia esculenta* (L.) Schott is an efficient adsorbent of methylene blue dye from aqueous solutions [52]. Monrroy et al., (2017) studied the efficiency of mucilage from *Opuntia cochenillifera* (L.) Miller to remove blue and green fabric dyes [53]. Amari et al., (2019) in their review described the capacity of *Cactus-based* materials, especially the mucilage, to act as biosorbents against heavy metals and dyes in aqueous solutions [54]. Anastasakis et al.,

(2009) assessed the flocculation behaviour of mallow mucilage from *Malva sylvestris* and okra mucilage from *Hibiscus esculentus* and stated them as significant flocculants [55]. Tangri (2014) analyzed the eco-friendly food-grade mucilage obtained from seeds of *Trigonella foenum-graecum* as an adsorbent and remarked it as a proper adsorbent for the removal of sulphate ions from an aqueous medium [56]. The potential of mucilaginous leaves of *Diceriocaryum eriocarpum* to adsorb lead ions from an aqueous medium was reported by Edokpayi et al., (2015) [57]. According to Mishra et al., (2002) *Plantago psyllium* mucilage contained an anionic polysaccharide which was effective in the removal of suspended solids from sewage and tannery wastewater [58]. Nanomagnetic quince seed mucilage expressed the potential to remove cationic dyes from an aqueous medium and it was reported by Hosseinzadeh and Mohammadi, (2015) [59]. Biochar coated by okra mucilage act as an effective biosorbent and adsorbs methylene blue dye from water and it was experimentally proved by Nath et al., (2021) [60]. Recently, the mucilage from leaves of *Litsea quinqueflora* was reported as an effective adsorbent against cationic dyes such as methylene blue and malachite green [61].

3. **Pharmacological potential of mucilage:** Plant-derived mucilage is an easily available and cost-effective source of plant-derived natural materials for pharmacological activities. Kumar et al., (2019) described the antioxidant potential of mucilaginous polysaccharides obtained from vegetative parts of *Bixa orellana* which is used in the nourishment industry [62]. Sindhu et al., (2012) made a detailed study on the anti-inflammatory and antioxidant activities of fenugreek mucilage [63]. Maria Galati et al., (2005) identified lemon mucilage as an effective inhibitor against inflammation through different studies [64]. Wahyuningsih et al., (2018) reported that polysaccharides from okra increase immune response through cytokine production [65]. Anibarro-ortega et al., (2019) studied the activity of mucilage from *Aloe vera* leaves against microorganisms of skin flora that cause infections [66]. Antioxidant activity and antibacterial activity against *Klebsiella pneumoniae* and *Streptococcus pyogens* were studied in the mucilage from *Hibiscus rosa-sinensis* [67]. Sangeethapriya and Siddhuraju (2014) explained the antioxidant potential of mucilage isolated from *Zizyphus mauritiana* fruits against free radicals such as DPPH, ABTS, hydroxyl, and superoxide [68]. Adetuyi and Dada (2014) studied okra mucilage, water leaf mucilage, and Jews mallow mucilage in detail and concluded that they can be used as protein supplements under conditions of deficiency in animal protein and as an antioxidant agent to fight against degenerative diseases associated with aging [69]. Nguimbou et al (2014) reviewed that mucilage isolated from giant swamp taro tuber is having enough food supplements in the form of different sugar units and it is a potent antioxidant agent [70]. According to Lin et al (2005), crude and partially purified mucilage obtained from different Taiwanese yam cultivars exhibits antiradical activity against DPPH, hydroxyl and superoxide radicals [71]. Nampuak and Tongkhao, (2019) testified that okra mucilage possesses more antibacterial activity against gram-positive bacteria than gram-negative bacteria [72]. Traditional healers have been using the leaf paste of *L. quinqueflora* as a remedy against local inflammation [73]. Isolated mucilage of *L. quinqueflora* expressed significant antioxidant activity against DPPH and ABTS radicals and inhibition against protein denaturation [61].

V. CONCLUSION

Biopolymers, especially plant-derived polysaccharides, play a vital role in the healthy lifestyle of humans. Among them, mucilage is an easily available and economically feasible vegetarian source which is now replacing the position of synthetic materials with minimum demerits. While going through the specific and effective applications of mucilage, it was felt that they are routinely used in many pharmaceuticals and medicines. Even though the extraction of mucilage depends on different factors and there are limitations in its extraction, its effectiveness in different diseased conditions especially, present lifestyle-related diseases, demands its necessity. Moreover, the role of mucilage in the removal of waste, chemicals or metals from water features its demanding position in bioremediation. The systematic production and selection of exact sources aid to enhance its production level and applications in different industrial fields. The future of plant mucilage as a natural source of tablet formulations, antioxidant, anti-inflammatory agent and waste water purification system is yet to be explored.

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