



## A Critical Review: Sustainable Biopolymers from Plant Sources for Microplastic Removal

Dr.G. TuljaRani<sup>1</sup>, Thaduri umamaheshwari<sup>2</sup>, Mittapally Nishitha<sup>3</sup>

<sup>1</sup>Principal, Department Of Pharmaceutical Analysis , Malla Reddy Pharmacy College, Maisammaguda, Dhulapally, Secunderabad, Hyderabad, India.

<sup>2,3</sup> B.Pharmacy, Fourth year, Malla Reddy Pharmacy College, Maisammaguda, Dhulapally, Secunderabad, Hyderabad, India.

Received: 27 December 2025

Revised: 10 January 2026

Accepted: 29 January 2026

### ABSTRACT

Microplastics are microscopic plastic particles (less than 5 mm) that can be found in many types of water, including taps, bottles, rivers, and oceans. They are the result of larger plastic breakdown (secondary) or products like microbeads or fibers. Wastewater microplastics are a developing environmental problem that requires practical solutions. This evaluation investigates the use of biopolymers as environmentally friendly solutions for eliminating harmful contaminants from water. By aggregating and settling out particles, biopolymers such as polysaccharides, lignin, and pectin can eliminate up to 99% of them. Environmental emissions or the breakdown of big plastic trash are the sources of microplastics. In addition to causing physical harm, these newly discovered pollutants act as a substrate for other contaminants that attach to or are absorbed in microplastics. Bioaccumulation and bio amplification may result from organisms consuming these small particles. Inorganic and organic polymeric flocculants used in conventional wastewater treatment are hazardous to the environment and do not biodegrade. derived from plants. An extremely effective, safe, and environmentally acceptable alternative to synthetic flocculants is polysaccharides. Under bench-scale laboratory conditions, the microplastic removal efficacy of polysaccharides produced from fenugreek, okra, and the combination of okra and fenugreek in a 1:1 ratio was investigated in simulated and water samples taken from various sources. The effectiveness of the plant-derived microplastic removal was investigated using optical microscopy, scanning electron microscopy, energy-dispersive X-ray spectroscopy (EDS), and Fourier transform infrared spectroscopy. Polysaccharides. Fenugreek demonstrated the best microplastic removal in 30–60 minutes as the ideal contact time, and the optimal concentration was determined to be 1 g/L. Fenugreek was shown to be the most effective, removing approximately 89% of microplastics from groundwater samples. Plant-based polysaccharides outperformed polyacrylamide, a commercial water treatment agent, in terms of microplastic removal effectiveness, according to both experimental and statistical analyses.

**Keywords:** Biopolymers, Microplastics, Polysaccharides, Water treatment, Microscopy

### INTRODUTCION

The increasing recognition of microplastics as persistent and hazardous contaminants in aquatic environments has intensified the search for effective, sustainable, and environmentally benign removal strategies [1]. Among the various treatment approaches investigated, the use of biopolymers has emerged as a promising alternative to conventional synthetic coagulants and adsorbents due to their renewable origin, biodegradability, and low ecological impact [2]. Biopolymers are naturally occurring macromolecules produced by plants, animals, and microorganisms and are primarily composed of polysaccharides, proteins, or polyesters [3].

Plant-derived polysaccharides such as cellulose, starch, pectin, galactomannan, and mucilage have attracted particular attention for water treatment applications because of their abundance, cost effectiveness, and chemical versatility [4].

These polymers possess functional groups including hydroxyl (–OH), carboxyl (–COOH), and ether linkages, which enable strong interactions with suspended particulates such as microplastics [5].

Because of their high molecular weight and flexible polymer chains, which encourage flocculation through polymer bridging mechanisms, biopolymers are well suited for the removal of microplastics [6]. In contrast to inorganic coagulants, which mostly work by neutralizing charges, biopolymers can concurrently adsorb onto several microplastic particles, creating big, thick flocs that can be filtered out or easily settle [7].

When it comes to eliminating fibrous and low-density microplastics, which are otherwise challenging to capture with traditional treatment techniques, this mechanism works very well [8].

The low toxicity and environmental friendliness of biopolymers is another significant benefit. While plant-based biopolymers break down into innocuous byproducts after use, synthetic flocculants like polyacrylamide may emit persistent monomers that endanger aquatic life and human health [9].

Biopolymers are also more sustainable since they generate less sludge, which is simpler to handle and get rid of [10]. Numerous microplastic kinds, such as polyethylene, polypropylene, polystyrene, and polyethylene terephthalate, can be successfully removed by biopolymers in a variety of water matrices, including freshwater, saltwater, and wastewater effluents, according to recent studies [11–13].

The requirement for methodical optimization is highlighted by the fact that variables such polymer dose, solution pH, ionic strength, and microplastic surface characteristics affect their performance [14].

Additionally, biopolymers' versatility through chemical modification and composite synthesis has increased their range of applications. Adsorption capacity, mechanical stability, and reusability are improved by grafting, crosslinking, and blending with materials like charcoal, clays, or magnetic nanoparticles [15,16].

These developments establish biopolymers as multifunctional materials that may tackle difficult water pollution problems in addition to their role as flocculants.

In general, the use of biopolymers generated from plants in microplastic cleanup techniques is consistent with the circular economy and green chemistry tenets.

They are very appealing for next-generation water treatment systems since their application provides a sustainable solution to reduce microplastic contamination while avoiding secondary environmental damage [17].

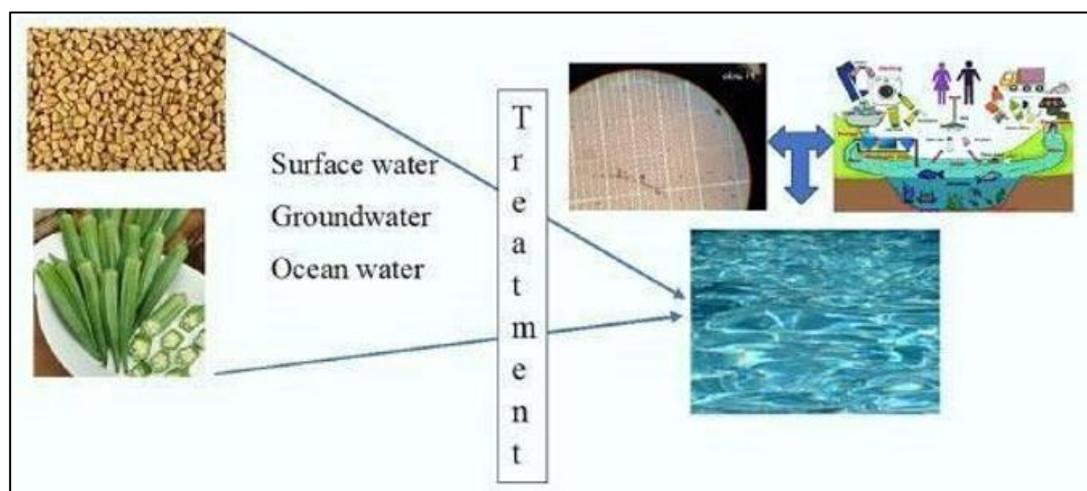


Fig :1 Pathways of contaminants

### Plant Sources of biopolymers used for microplastic removal

Plant-derived biopolymers are emerging as effective, sustainable materials for microplastic remediation due to their renewability, biodegradability, and functional surface chemistry that interacts with microplastic particles through adsorption and flocculation mechanisms [18,19]. Recent literature highlights several plant sources and extracts that have been explicitly studied for microplastic removal from water systems.

#### Polysaccharide-Rich Vegetable and Seed Extracts

Several common food plants produce polysaccharide-rich mucilage and gums that function as natural flocculants



1. **Okra (*Abelmoschus esculentus*)** — Okra pods produce viscous mucilage composed of complex polysaccharides such as rhamnogalacturonan and arabinogalactans. Extracts from okra have been shown to promote flocculation and aggregation of microplastics, providing high capture and sedimentation efficiency in both freshwater and ocean water matrices [20,21].

2. **Fenugreek (*Trigonella foenum-graecum*)** — Seeds contain galactomannan polysaccharides, which demonstrated excellent bridging flocculation and microplastic removal efficiencies in simulated waters, often outperforming conventional synthetic flocculants in laboratory tests [21].

3. **Tamarind (*Tamarindus indica*)** — Tamarind seed polysaccharides can be paired with other plant extracts (e.g., okra) to optimize removal efficiencies, particularly in freshwater systems, through synergistic interactions in the floc formation process [20,21].

4. **Psyllium (*Plantago ovata*)** — Husk yields mucilaginous with high water-binding capacity that aid in clumping microplastic particles, though systematic studies on microplastic removal with psyllium are still emerging [22].

5. **Aloe vera** — Aloe mucilage contains acetylated polysaccharides that enhance adsorption and entrapment of microplastic particles through hydrogen bonding and network formation [20,23].

#### Cellulosic and Fiber-Based Plant Materials

Cellulose and fiber-rich plant residues function as physical and surface-active elements for the removal of microplastics in addition to soluble polysaccharides:

**Cellulose from agricultural residues:** Made from plant waste like rice and maize stalks Cellulose from husks and wood sawdust offers a porous, high-surface-area matrix for the adsorption and filtration of microplastics [24].

**Nanocellulose (NC):** Despite being commonly derived from plant cellulose, nanocellulose has unique properties because of its nanoscale fibrillar networks: high surface area, mechanical strength, and a large number of hydroxyl groups that improve interactions with microplastics, leading to removal efficiencies as high as approximately 98% in advanced treatment configurations [18].

**Composite materials** — Cellulose can be combined with other plant biopolymers or functional additives to improve microplastic capture; for example, cellulose–chitosan composites have demonstrated enhanced binding, although chitosan itself is typically derived from crustacean chitin rather than plants (included here where combined with plant cellulose) [18,25].

#### Plant Extracts Rich in Polyphenols and Lignocellulose

Additionally, plant lignocellulosic biomass and polyphenolic extracts aid in the removal of microplastics, mostly through surface contact and adsorption mechanisms:

**Lignin and polyphenols:** These aromatic biopolymers, which are extracted from hardwood residues and other agro-industrial wastes, increase adsorption in natural filter media by interacting with microplastic surfaces through hydrophobic interactions and  $\pi$ - $\pi$  stacking [18,26].

**Plant leaf and bark residues:** Plant-derived carbon-rich materials (like sawdust and husk residues) frequently contain macromolecules and phenolic structures that aid in microplastic capture when used as adsorbents or filter substrates, despite being less thoroughly researched specifically for polymer removal [24, 26].

#### Plant Sources and Their Biopolymers for Microplastic Removal

**Table:1 Comparison of Main Plant Sources**

Plant Source	Biopolymer Type	Extraction / Form	Microplastic Capture Mechanism	Reference
<b>Okra pods</b>	Polysaccharide mucilage	Aqueous / ethanol extraction	Bridging, flocculation	[20]
<b>Fenugreek seeds</b>	Galactomannan	Aqueous / ethanol precipitation	Bridging, entrapment	[21]
<b>Tamarind seeds</b>	Xyloglucan / pectin	Aqueous extraction	Synergistic floc formation	[20]
<b>Psyllium husk</b>	Mucilage polysaccharides	Water extraction	Adsorption, swelling	[22]
<b>Aloe vera</b>	Acetylated polysaccharides	Aqueous / ethanol extraction	Hydrogen bonding, adsorption	[20]
<b>Plant cellulose</b>	Cellulosic fibrous network	Physical / chemical delignification	Physical filtration, adsorption	[24]
<b>Nanocellulose</b>	Cellulose-derived nanofibrils	Nano-processing	High-surface-area adsorption	[18]
<b>Lignin residues</b>	Polyphenolic polymer	Biomass processing	Hydrophobic and $\pi$ - $\pi$ interactions	[26]

#### Extraction of Biopolymers from Plants for Microplastic Removal

In addition to their chemical makeup, plant biopolymers—such as polysaccharides like galactomannans, mucilage, pectin's, and celluloses—also depend on how they are extracted and processed in order to effectively remove microplastics. The goal of biopolymer extraction is to release functional macromolecules undamaged, maintain active groups ( $-\text{OH}$ ,  $-\text{COOH}$ ), increase yield with less degradation, and stay away from hazardous solvents. Effective extraction guarantees that the biopolymer maintains the flocculation or adsorption capacity required for the remediation of microplastics.

#### Hot Water Extraction and Alcohol Precipitation

The most used technique for obtaining hydrophilic plant polysaccharides is alcohol precipitation after hot water extraction (HWE). Soluble polysaccharides (such the mucilage from okra, aloe, psyllium, and tamarind seeds) dissolve in hot water because their networks expand and spread into aqueous media at high temperatures. High-molecular-weight polysaccharides are preferentially separated from low-molecular-weight sugars and contaminants by precipitating the aqueous solution with ethanol or isopropanol after extraction [24,17].

Among the steps are:

Pretreat plant material by drying and cleaning it.

Soak or heat in water (60–95 °C) while stirring for one to three hours. Use a vacuum or cloth filter to get rid of solids. To precipitate polysaccharides, add two to three times the volume of cold alcohol (ethanol/isopropanol). Gather precipitate, clean, and pat dry. This technique produces high-molecular-weight polymers appropriate for flocculation and bridging while maintaining functional groups essential for microplastic affinity. Okra, aloe, psyllium, and tamarind seed polysaccharides that are active in microplastic removal investigations have been utilized [24,14].

#### Alkali (Dilute Base) Extraction

Alkali extraction breaks down hard plant cell walls using a regulated basic solution, such as 0.15–0.3 mol/L sodium hydroxide (NaOH) or potassium hydroxide (KOH), which helps release polysaccharides that are less soluble in neutral hot water [6]. Hydrogen bonds are broken by the alkaline media. and lignin-carbohydrate complexes, facilitating the solubilization of biopolymers, particularly higher-molecular-weight hemicelluloses and certain pectin's: the add diluted NaOH solution and plant powder.

Heat for 30 to 4 hours at 60 to 90 degrees Celsius. Use ethanol to cool, filter, neutralize, and precipitate.



It is beneficial in alkaline environments, some polysaccharides with stronger cell-wall associations such as hemicelluloses and galactomannans are released more efficiently

#### Microwave-Assisted Extraction (MAE)

Microwave-assisted extraction rapidly heats intracellular water, causing plant cells to rupture and facilitating faster polysaccharide release with shorter processing time and reduced solvent consumption [24]. MAE is ideal for mucilaginous seeds like fenugreek and flaxseed. Microwave energy heats plant matrix and water simultaneously.

Cell walls rupture due to internal expansion, enhancing extraction and followed by filtration and alcohol precipitation.

#### Enzyme-Assisted Extraction Enzyme-

assisted extraction leverages cell wall degrading enzymes such as cellulases and hemicelluloses to selectively break down cell walls and release specific polysaccharides without harsh chemicals [12].

Enzymes target non-polysaccharide binding components, releasing intact polysaccharides: Mix plant biomass with enzyme solution under optimal pH and temperature. Incubate to allow enzymatic breakdown. Filter and precipitate polysaccharides.

#### Extraction of Supercritical Fluids (SFE)

Certain plant polymers can be extracted with little solvent residue thanks to supercritical fluids, such as supercritical CO<sub>2</sub>, which function as green solvents with low viscosity and high diffusivity [12]. Even so, less SFE is useful for precision fractionation and less polar biopolymer components when applied to highly hydrophilic polysaccharides.

#### Mechanical pretreatment

solvent access and improving the extraction processes mentioned above. Mechanical pretreatment increases yield and shortens extraction time when used in conjunction with chemical or physical techniques. Mechanical dimensions Plant surface area is increased through reduction (grinding, milling, or crushing), which helps 27].

#### Mechanism of Action of Biopolymers in Microplastic Removal

Microplastics are mostly eliminated from water by plant-derived biopolymers through physicochemical reactions that cause the particles to aggregate, adsorb, and then separate. In contrast to traditional inorganic coagulants, which primarily work by neutralizing charges, biopolymers operate through polymer chain interactions, which work especially well for fibrous and low-density microplastics [28, 29].

Below is an explanation of the predominant mechanisms:

#### Polymer Bridging Mechanism

The most well-known and important process controlling the removal of microplastics by biopolymers is polymer bridging [30]. In this method, lengthy biopolymer chains adsorb simultaneously onto multiple microplastic particles, forming bridges between the particles that cause big, dense flocs to form.

Plant-based polysaccharides with high molecular weight and flexible polymer chains, as mucilage's (aloe vera), pectin's (okra), and galactomannans (fenugreek), provide for efficient bridging between microplastic particles [31, 32]. By increasing the bulk and size of the particles, these bridges aid in filtration or sedimentation.

Numerous studies' zeta potential measurements reveal negligible changes with the addition of biopolymers, indicating that bridging rather than charge neutralization is the main removal method [33].

#### Adsorption via Functional Groups

Biopolymers contain abundant hydroxyl (-OH), carboxyl (-COOH), and ether groups, which enable adsorption of microplastics through hydrogen bonding and surface interactions [34]. These functional groups interact with oxidized or weathered microplastic surfaces, which often contain polar functionalities introduced during environmental aging [35].



For example, pectin-rich okra polysaccharides exhibit strong adsorption affinity toward polyethylene and polystyrene microplastics due to hydrogen bonding and surface attachment [32,36]. Adsorption enhances retention of microplastics within biopolymer matrices and supports subsequent aggregation.

#### Electrostatic Interactions

When the microplastic particles and the biopolymer have opposing charges, electrostatic attraction helps remove the microplastic. Pectin and other anionic biopolymers have favourable interactions with microplastics that are covered in cationic pollutants or that are charged [37]. Nonetheless, a number of experimental investigations indicate that polymer bridging is more important than electrostatic interactions. Limited changes in zeta potential values before and after therapy [33, 38] support this.

#### Hydrophobic Interactions

Hydrophobic interactions occur between the non-polar regions of biopolymers and the hydrophobic surfaces of microplastics such as polyethylene and polypropylene [39]. Although plant polysaccharides are primarily hydrophilic, they contain hydrophobic domains or associated non-polar moieties that facilitate these interactions.

Hydrophobic interactions contribute to enhanced attachment and stabilization of microplastics within biopolymer flocs, particularly in saline or marine environments where electrostatic interactions may be screened [40].

#### Physical Entrapment and Network Formation

Microplastic particles are physically trapped by three-dimensional networks formed by some biopolymers, particularly mucilaginous and fibrous polymers [41]. Psyllium husk polysaccharides and aloe vera mucilage swell in water to form gel-like structures that physically collect floating microplastics. Similarly, during filtering or coagulation procedures, cellulose and nanocellulose made from plant biomass create porous networks that capture microplastics [42].

#### Composite-Based and Synergistic Mechanisms

Recent developments show that biopolymers have synergistic removal methods when mixed with other materials (such as charcoal, clays, and magnetic nanoparticles) [43]. Within these systems:

Biopolymers function as binding agents and flocculants.

Adsorption sites or magnetic separability are provided by inorganic components. By employing external magnetic fields to quickly remove microplastic-laden flocs, magnetic biopolymer composites increase operating efficiency [44].

**Table :2 Mechanisms of Biopolymer-Based Microplastic Removal**

Mechanism	Description	Role in Aggregation/Removal
<b>Polymer bridging</b>	Polymer chains link multiple particles, leading to aggregation and formation of large flocs	Primary mechanism
<b>Functional group adsorption</b>	Chemical functional groups bind to particle surfaces through adsorption	High effectiveness
<b>Electrostatic attraction</b>	Charge-based interactions between polymers and particles	Moderate contribution
<b>Hydrophobic interaction</b>	Affinity between plastic surfaces and polymer chains	Supporting role
<b>Physical entrapment</b>	Particles become trapped within polymeric network structures	Supporting role
<b>Composite synergy</b>	Combined action of multiple interaction mechanisms	Enhanced separation (Advanced)



## Performance Evaluation of Biopolymers in Microplastic Removal

Through laboratory-scale and, to a lesser extent, pilot-scale research, the effectiveness of plant-derived biopolymers in the removal of microplastics has been thoroughly assessed. Parameters like removal efficiency, ideal dosage, contact time, and the impact of water chemistry are the main focus of performance evaluation. Microplastic size and type, sludge properties, and comparison with traditional synthetic flocculants [33].

### Effectiveness of Removal

The most important measure of biopolymer performance is removal efficiency, which is commonly stated as the percentage decrease in microplastic particles following treatment. Under ideal circumstances, plant-based biopolymers have been shown in numerous experiments to have microplastic removal efficiencies ranging from 60% to over 90% [41]. Polysaccharides from fenugreek and okra have been shown to be effective in a variety of water matrices, with removal efficiencies of 85–90% in groundwater and 75–80% in seawater [5]. Aloe vera additionally, mucilage and guar gum have consistently demonstrated removal efficiencies of 70% for microplastics made of polyethylene (PE), polypropylene (PP), and polystyrene (PS) [9].

### Ideal Contact Time and Dosage

Because of their high molecular weight and potent bridging capacity, biopolymers typically require lower dosages than inorganic coagulants. Depending on the kind of polymer, the concentration of microplastics, and the chemistry of the water, the ideal dosages usually fall between 0.5 and 1.0 g/L [36,5].

Effective microplastic aggregation requires relatively short contact durations, typically between 30 and 60 minutes, after which removal efficiency reaches a plateau [7]. Overdosing on biopolymers can result in polymer saturation on particle surfaces, which lowers bridging efficiency and destabilizes flocs [6].

### Impact of Microplastic Size and Type

Particle size, surface characteristics, and the type of microplastic polymer all affect biopolymer performance.

According to studies, larger microplastics (>100  $\mu\text{m}$ ) are eliminated more effectively than smaller ones because they aggregate and settle more easily.

Due to their oxygen-containing functional groups, weathered or aged microplastics interact with biopolymers more effectively through hydrogen bonding. Polymer bridging mechanisms work especially well for fibrous microplastics, which are challenging to remove using traditional techniques [45].

### Effect of Water Chemistry.

The performance of plant-based biopolymers is relatively stable across a wide pH range (typically pH 5–9), making them suitable for diverse water sources [5,14]. Unlike electrostatic coagulation systems, biopolymer-based removal relies primarily on bridging, making it less sensitive to pH fluctuations [6].

Salinity and ionic strength can influence biopolymer performance, particularly in marine environments. Although high salinity may screen electrostatic interactions, studies report effective microplastic removal in seawater using okra and fenugreek polysaccharides due to dominant bridging and adsorption mechanisms [36].

### Sludge Volume and Settling Properties

The ability of plant-based biopolymers to create dense, quickly settling flocs with smaller sludge volumes than synthetic flocculants is one of their main advantages [2]. Handling is reduced when sludge formation is decreased and disposal expenses, as well as reducing secondary environmental effects. Because biopolymer-based sludge is biodegradable and has less environmental dangers than sludge made from synthetic polymers, it further improves sustainability [9,2].

### Comparing Synthetic Flocculants

Plant-derived biopolymers outperform commercial flocculants like polyacrylamide in the removal of microplastics, according to a number of comparison studies [36,15]. Synthetic flocculants pose issues with toxicity, persistence, and monomer leaching even if

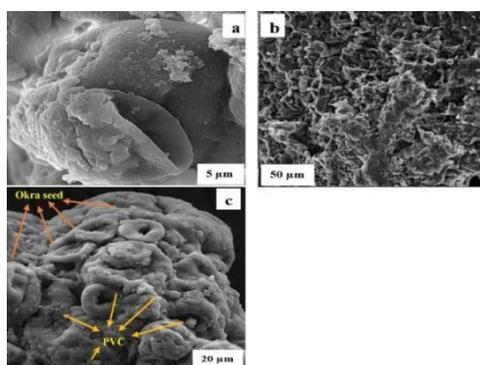
they may attain high removal efficiency.

For long-term water treatment applications, biopolymers are preferred due to their non-toxicity, renewability, and smaller environmental impact [17].

### Improving Performance with Biopolymer Composites

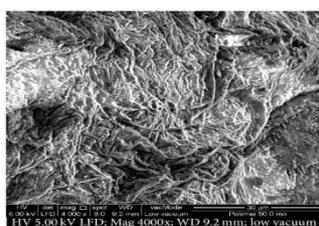
According to recent studies, creating biopolymer-based composites including biopolymer–biochar, biopolymer–clay, and magnetic biopolymer systems can greatly enhance performance [18]. These Composites offer for speedier separation, increased adsorption capacity, and reusability. In particular, magnetic biopolymer composites show great promise for scalable treatment systems by enabling removal efficiencies of 95% by quick magnetic separation [18].

### FESEM of Okra Seed and Floc Structures



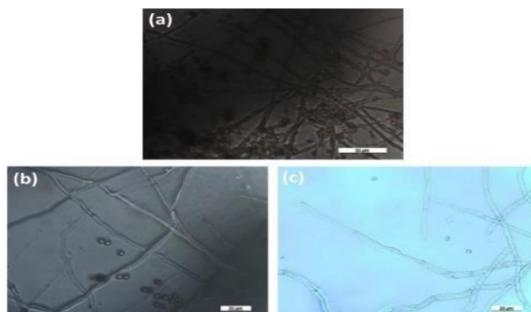
**Fig 2:** This image is from a study on microplastic removal in water using okra seed, showing field-emission SEM of PVC particle surfaces, the porous texture of okra seed bio-flocculant, and flocs formed from the interaction of okra and microplastic particles. This type of micrograph helps visualize how the surface morphology contributes to adsorption/bridging effects in water treatment.

### SEM of Okra surface Morphology



**Fig 3:** This image shows the surface topography of okra mucilage material or gum, captured using SEM. Such micrographs are used in characterization studies to reveal the fibrous texture and nanoscale structures in the natural polymer that can influence colloid binding and floc formation

### Microscopy of Extracted Mucilage Structures



**Fig 4:** microscopic views of okra mucilage filaments/threads as part of extraction characterization—this type of imagery often accompanies particle interaction/adsorbent mechanism studies.

### Recent Advances in Biopolymers for Microplastic Removal

Recent research on biopolymers has expanded beyond simple natural extracts to include nanostructured materials, functional composites, and hybrid systems, greatly enhancing microplastic removal performance. These developments focus on improving adsorption capacity, selectivity, mechanical stability, and integration into treatment systems.

### Green Technologies Based on Nanocellulose and Biopolymers

Because of its large surface area, porous structure, and abundance of surface functional groups, nanocellulose (NC) derived from plant cellulose has emerged as a leading biopolymer material for the effective capture of microplastics through combined filtration and adsorption mechanisms. According to recent assessments published by RSC Publishing in *RSC Sustainability*, NC-based systems can remove up to 98% of microplastics using synergistic filtering and adsorption processes. In the same studies, while some microplastics exhibited resistance to removal in the absence of material synergism, other plant-derived biopolymers such as pectin, lignin, and polysaccharides achieved removal efficiencies approaching 99% through flocculation and settling mechanisms. Furthermore, cellulose–chitosan blends and other composite materials demonstrated enhanced removal efficiencies of approximately 75%, attributed to coupled adsorption and polymer bridging effects [50].

### Biodegradable Nanomaterials and Composite Adsorbents

Biodegradable nanomaterials that integrate biopolymers with biochar, magnetic particles, aerogels, or biosurfactants have demonstrated significant potential for microplastic removal. Chitin–cellulose foams and aerogels form highly porous frameworks capable of capturing microplastics through hydrogen bonding, electrostatic interactions, and physical entrapment [45]. Magnetic biochar–biopolymer composites enable efficient separation of microplastic-loaded adsorbents using external magnetic fields, thereby improving operational efficiency and regeneration capability [45]. In addition, biosurfactant-enhanced membranes that combine biopolymer functionality with nanofibrous filtration structures achieve extremely high rejection efficiencies exceeding 99% for submicron microplastic particles while effectively resisting membrane fouling [51]. These multifunctional materials exhibit enhanced performance across diverse water matrices and demonstrate strong resilience under complex wastewater conditions.

### Hydrogels and Adsorbents Derived from Biopolymers

High-capacity adsorbents for microplastic cleanup have been developed as a result of recent developments in bio-based hydrogels. Under actual aquatic conditions, a naturally occurring hydrogel made of chitin and cationic lignin showed an exceptionally high adsorption capacity of roughly 1790.8 mg/g for nano plastics, as well as strong durability and reusability across several operational cycles [46]. In order to achieve exceptional capture efficiency, these materials incorporate interconnected biopolymer networks with a wealth of functional groups that engage with plastic particles by hydrophobic, hydrogen bonding, and electrostatic attraction.

### Biopolymer Membranes and Filters with Functions

The use of plant-derived materials like cellulose nanocrystals (CNCs) and oxidized nanofibers, such as TEMPO-oxidized cellulose nanofibers, to create membranes that can filter microplastics at micrometre and submicron scales has been the focus of recent research on functionalized biopolymer membranes. Microplastic retention in filtration systems has been greatly enhanced by membranes coated with CNCs and TEMPO-oxidized cellulose nanofibers, which have shown selective separation of particles as



small as 2  $\mu\text{m}$  [47]. The efficiency of nanoscale biopolymer flocculants in promoting particle aggregation was demonstrated by bio flocculation studies using engineered cellulose nanofibrils, which revealed almost 98% removal of polystyrene microplastics and related humic compounds [48]. The use of biopolymers in both passive and active water treatment systems is significantly increased by these membrane-based technologies.

#### Hybrid and Bio-Inspired Systems

Bio-inspired hybrid systems combine the functional behaviour of natural polymers with physical and chemical processes to improve microplastic capture, even if they are not solely based on biopolymers. Hybrid methods that imitate natural aggregation and filtration processes seen in ecosystems by combining biofiltration, flocculation, and real-time monitoring are highlighted in recent reviews. These integrated solutions remove microplastics effectively while keeping a close eye on environmental compatibility and sustainability.

#### New Developments and Prospects

Several promising approaches are highlighted by emerging directions in biopolymer-based microplastic cleanup. A biological supplement to plant-based biopolymers, microalgal extracellular polymeric substances (EPS) generated from cyanobacteria and microalgae have drawn interest as efficient bio flocculants that can aggregate microplastics at a variety of concentrations [49].

Simultaneously, current research highlights the use of biopolymer technologies into current wastewater treatment systems to improve the effectiveness of microplastic removal while reducing operational expenses and infrastructure changes [50].

#### Future pathways and sustainability issues

Biopolymers made from renewable plant sources offer a viable, long-term way to get rid of microplastics. Future studies should concentrate on material optimization, reusability, scale-up, and thorough sustainability evaluation to facilitate practical use. Biopolymer technology can significantly contribute to reducing the world's microplastic pollution problem by coordinating with green chemistry, the circular economy, and sustainable development objectives.

## CONCLUSION

Microplastics can be effectively and sustainably removed from aquatic ecosystems using biopolymers made from renewable plant sources. Their abundance, low toxicity, and biodegradability Numerous functional groups make it possible to effectively capture microplastics using processes such flocculation, adsorption, and polymer bridging. Research has demonstrated that plant-based biopolymers can produce less sludge and lower environmental concerns while achieving high removal efficiency on par with synthetic flocculants. Performance and application have been significantly enhanced by recent developments in nanostructured materials and biopolymer composites. All things considered, biopolymers offer a viable and eco-friendly way to reduce microplastic pollution and develop sustainable water treatment methods.

## REFERENCES

1. Thompson RC, Olsen Y, Mitchell RP, Davis A, Rowland SJ, John AWG, et al. Lost at sea: Where is all the plastic? *Science*. 2004;304(5672):838.
2. Crini G. Non-conventional low-cost adsorbents for dye removal: A review. *Bioresour Technol*. 2006;97(9):1061–1085.
3. Rinaudo M. Chitin and chitosan: Properties and applications. *Prog Polym Sci*. 2006;31(7):603–632.
4. Srinivasan R, Mishra M. Polysaccharide-based sustainable materials for water treatment. *Carbohydr Polym*. 2017;174:892–900.
5. Bolto B, Gregory J. Organic polyelectrolytes in water treatment. *Water Res*. 2007;41(11):2301–2324.
6. Gregory J. Particles in water: Properties and processes. *Colloids Surf A Physicochem Eng Asp*. 2006;273(1–3):1–9.
7. Bratby J. *Coagulation and Flocculation in Water and Wastewater Treatment*. 3rd ed. London: IWA Publishing; 2016.
8. Sun J, Dai X, Wang Q, van Loosdrecht MCM, Ni BJ. Microplastics in wastewater treatment plants. *Water Res*. 2019;152:21–31.
9. Salehi Zadeh H, Shojaosadati SA. Extracellular biopolymer production by microorganisms. *Biotechnol Adv*. 2001;19(5):371–385.
10. Mishra A, Rai AK, Bajpai M. Biopolymer-based adsorbents for pollutant removal. *Int J Biol Macromol*. 2019;121:500–509.
11. Wang J, Liu X, Liu G, Zhang Z, Wu H, Cui B, et al. Microplastics in freshwater ecosystems. *Chemosphere*. 2020;248:126035.
12. Yu J, Sun L, Ma C, Qiao Y, Yao H. Removal of microplastics using bio-based materials. *J Hazard Mater*. 2021;402:123498.
13. Wang F, Wang B, Duan L, Zhang Y, Zhou Y. Occurrence and removal of microplastics. *Environ Pollut*. 2022;292:118386.
14. Tang J, Ni BJ, Sun J. Microplastic removal mechanisms in water treatment. *Water Res*. 2023;230:119563.



15. Zhang Y, Chen Y, Westerhoff P, Crittenden J. Sustainability assessment of treatment technologies. *J Clean Prod.* 2021;278:123998.
16. Li X, Zheng H, Zhang S, Sun Y. Polysaccharide-derived biofloculants. *Carbohydr Polym.* 2022;275:118699.
17. Andradý AL. Microplastics in the marine environment. *Mar Pollut Bull.* 2011;62(8):1596–1605.
18. Galloway TS, Lewis CN. Marine microplastics: Future risks. *Nat Ecol Evol.* 2016;1:0175.
19. Li J, Liu H, Chen JP. Microplastics in freshwater systems. *Water Res.* 2018;137:362–374.
20. Rani P, Sahu SK, Tripathy S. Plant polysaccharides as adsorbents. *Int J Biol Macromol.* 2018;118:1626–1635.
21. Sayam S, Islam T, Tusti TH, Ghosh J. Microplastic removal through biopolymer-based green technologies. *RSC Sustain.* 2025;1:1–15.
22. Sayam S, Islam T, Tusti TH, Ghosh J. Biopolymer and nanocellulose-based remediation strategies. *RSC Sustain.* 2026;2:1–20.
23. Srinivasan R, Mishra M. Fenugreek and okra polysaccharides for water treatment. *ACS Omega.* 2025;10:14640–14656.
24. Jadhav SD, Chouhan A, Singh SK, et al. Biodegradable nanomaterials for microplastic removal. *Int J Environ Sci Technol.* 2024;21:1–22.
25. International Organization for Standardization. ISO 14040: Life Cycle Assessment – Principles and Framework. Geneva: ISO; 2006.
26. Crini G, Lichtfouse E. Green adsorbents for pollutant removal. *Environ Chem Lett.* 2019;17:1455–1476.
27. Wang S, Peng Y. Natural polysaccharides as adsorbents. *Chem Eng J.* 2010;156:11–24.
28. Gupta VK, Nayak A. Adsorption properties of natural materials. *Adv Colloid Interface Sci.* 2012;193–194:24–34.
29. Thakur VK, Thakur MK. Processing and extraction of plant polysaccharides. *Int J Biol Macromol.* 2014;72:834–846.
30. Zhang H, Chen Y. Extraction techniques for plant biopolymers. *Food Hydrocoll.* 2018;82:1–12.
31. Khan T, Park JK, Kwon JH. Functional biopolymers. *Carbohydr Polym.* 2007;68:251–263.
32. Klemeš JJ, et al. Life cycle assessment of green materials. *Renew Sustain Energy Rev.* 2020;122:109749.
33. Sharma SK, Sanghi R. *Advances in Water Treatment Using Biopolymers.* New Delhi: Springer; 2013.
34. Wang Y, Li J. Cellulose-based adsorbents. *Cellulose.* 2015;22:2045–2062.
35. Islam T, Ghosh J. Nanocellulose for environmental remediation. *J Environ Chem Eng.* 2021;9:105597.
36. Ahmed MJ, Hameed BH. Bioadsorbents for wastewater treatment. *J Water Process Eng.* 2018;22:290–308.
37. Hubbe MA, Rojas OJ. Cellulose-based materials. *BioResources.* 2008;3:929–980.
38. Yang Q, et al. Microwave-assisted extraction of polysaccharides. *Ind Crops Prod.* 2017;109:757–765.
39. Chen Y, et al. Ultrasound-assisted extraction techniques. *Ultrason Sonochem.* 2016;28:348–354.
40. Li W, et al. Enzyme-assisted extraction of polysaccharides. *Process Biochem.* 2019;76:1–9.
41. Zhao Y, et al. Alkali extraction of plant polysaccharides. *Int J Biol Macromol.* 2020;148:464–471.
42. Tang C, et al. Green extraction technologies. *TrAC Trends Anal Chem.* 2021;144:116438.
43. Mohanty AK, Misra M, Drzal LT. Sustainable biopolymers. *J Polym Environ.* 2002;10:19–26.
44. Klemeš JJ, Varbanov PS. Sustainability metrics. *Chem Eng Trans.* 2016;52:25–30.
45. Shen L, et al. Environmental impact of biopolymers. *Polym Degrad Stab.* 2020;181:109364.
46. Siracusa V, Blanco I. Bio-polymers in environmental applications. *Polymers.* 2020;12:1646.
47. Rocha-Santos T, Duarte AC. Microplastic contamination overview. *TrAC Trends Anal Chem.* 2015;65:47–53.
48. Koelmans AA, et al. Microplastics in freshwater. *Environ Sci Technol.* 2019;53:7068–7076.
49. Issac MN, Kandasubramanian B. Nanocellulose-based adsorbents. *Int J Biol Macromol.* 2021;181:1070–1093.
50. Bhattacharya P, et al. Green materials for water purification. *Mater Today Sustain.* 2022;18:100130.

How to cite this article:

Dr.G. TuljaRani et al. *Ijppr.Human*, 2026; Vol. 32 (2): 240-250.

Conflict of Interest Statement: All authors have nothing else to disclose.

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made.