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A Comparative Analysis of The Removal of Microplastics from Water Using Okra, Fenugreek, and Tamarind Extracts

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Abstract:
The constant introduction of plastic particles in the aquatic systems, the soil and the food chains has become a major environmental issue, causing the microplastic pollution (WHO, 2019; UNEP, 2021). Microplastics are generally smaller than 5 mm and are formed by the degradation of larger plastics, industrial waste, textiles, cosmetics, and household products (Sun et al., 2019). These organisms persisted in environment that can cause the negative impacts on human health, biodiversity and aquatic life (Ali et al., 2021; Yin et al., 2020). Common methods of microplastic removal include chemical coagulation, membrane filtration, and advanced oxidation processes. These methods, however, are energy-intensive, expensive and may generate secondary pollutants (Tchobanoglous et al., 2014; Sun et al., 2019). This means there is more interest in the development of sustainable and eco-friendly alternatives. In this study, green bioremediation approach for removal of microplastics using natural plant based bioflocculants obtained from okra (*Abelmoschus esculentus*), fenugreek (*Trigonella foenum-graecum*) and tamarind (*Tamarindus indica*) is reported. These plant materials contain high quantity of natural bio polymers such as mucilage, galactomannans and polysaccharides which have adsorption, flocculation and coagulation property (Patale & Pandya, 2012; Prajapati et al., 2013). The extracts function as biodegradable flocculants, binding and agglomerating the microplastic particles in order to facilitate their settling and removal from contaminated water (Salehizadeh & Shojaosadati, 2001). The experimental evaluation was carried out by varying pH, dosage, settling time and contact time. Among the screened extracts okra showed highest extraction efficiency (92%) followed by fenugreek (88%) and tamarind (85%). Synergism of natural polymers achieved the highest removal efficiency (96%) of combined plant extract. The recent study published in ACS Omega shows the effectiveness of okra and fenugreek polysaccharides for the removal of microplastics from freshwater, groundwater and ocean water, with up to 90% removal rate (Srinivasan et al., 2025).

Keywords — Okra, Fenugreek, Tamarind, Wastewater Treatment, Natural Coagulants, Bioflocculants, Green Remediation

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I.INTRODUCTION
Because of the huge production and inadequate disposal of plastic materials, plastic pollution has become one of the most serious environmental problems in the world (UNEP, 2021). Microplastics are small particles that are produced from the degradation of larger pieces of plastic waste through physical, chemical and biological processes (WHO, 2019). Microplastics sources: primary and secondary Primary micro-plastics are small particles specifically made and used in personal care products, industrial abrasives and cosmetics. Secondary microplastics are formed by the degradation of larger plastic wastes (Sun et al., 2019). Microplastics are light and small in size which allows them to remain in the environment for a longer period of time and easily enter the food chains (Ali et al., 2021). They are not biodegradable. Microplastics can adsorb toxic pollutants, such as pesticides, heavy metals and persistent organic contaminants (Yin et al., 2020). The ingestion of these particles often causes oxidative stress, reproductive disorders, tissue damage, digestive blockage and bioaccumulation in aquatic organisms (WHO, 2019). Human exposure through contaminated water and food is also becoming a major public health concern (WHO 2019; UNEP 2021). Microplastics can be removed by conventional wastewater treatment techniques such as electrocoagulation, chemical coagulation, membrane filtration and advanced oxidation processes (Tchobanoglous et al., 2014; Sun et al., 2019). However, these techniques suffer from high operational cost, energy consumption and generation of chemical waste (Ali et al., 2021). Green bioremediation is the natural biological process for the removal of the pollutants by the natural biological agents (Kumar et al., 2021). Plant based bioflocculants are renewable, biodegradable, non-toxic and inexpensive and have gained considerable attention (Salehizadeh & Shojaosadati, 2001). Natural polymers, such as polysaccharides, proteins and

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galactomannans from plant mucilage, may be capable of efficiently coagulating and flocculating the suspended particles (Bolto & Gregory, 2007). The study looked into the effectiveness of tamarind, fenugreek and okra extracts for microplastic remediation. Okra mucilage has high amount of polysaccharides which helps in the formation of flocs and adsorption of particles (Patale & Pandya, 2012). The fenugreek seeds are rich in galactomannan gum and soluble fibres that improves the efficiency of coagulation (Srinivasan et al., 2025). Tamarind seed polysaccharides exhibited good thickening and binding properties (Prajapati et al., 2013). A recent study in ACS Omega shows that plant derived polysaccharides from fenugreek and okra could remove up to 90% of microplastics from different water sources and performed better than synthetic polyacrylamide flocculants (Srinivasan et al., 2025).

II.LITERATURE REVIEW

Microplastic pollution is an emerging environmental problem. Microplastics are increasingly found in ecosystems and water bodies. Many disposal methods commonly used are synthesized by chemical synthetic, which may cause the secondary pollution. Therefore, the researchers are trying to find sustainable alternatives of coagulants and bioflocculants from natural plant resources [19]. 2.1 Bioflocculants from Okra The okra gum was mainly composed of polysaccharides of galactose, rhamnose and uronic acid. These compounds get adsorbed and agglomerate with common atoms (Patale and Pandya, 2012). Okra extract is effective in removing turbidity, dyes, suspended solids and heavy metals from waste water (Patale & Pandya, 2012). Okra polysaccharide was shown to be about 80% effective in removing microplastic from ocean water (Srinivasan et al., 2025). 2.2 Bioflocculants 2.2.1 Definition Galactomannan gum and soluble fibers are abundant in Fenugreek seeds and are known to enhance viscosity and coagulation (Srinivasan et al., 2025). These properties can increase flocculation and sedimentation efficiency in wastewater treatment systems (Salehizadeh & Shojaosadati, 2001). Recent studies have found that under optimal conditions, fenugreek extract has been able to remove 89-93% of microplastic from samples of ground water (Srinivasan et al., 2025). 2.3 Bioflocculants from tamarind the polysaccharides from tamarind seeds exhibited good thickening, adsorbing and binding properties (Prajapati et al. 2013). The effectiveness of these methods for the removal of organic pollutants, suspended solids and dyes from polluted water has been reported earlier (Prajapati et al., 2013). 2.4. Gap in the Literature Most of the studies were conducted on turbidity and dye removal. The combined use of Okra, Fenugreek and Tamarind extracts for the remediation of microplastics have been studied very few (Kumar et al., 2021). The current study attempts to address this gap by evaluating the combined efficacy of these sustainable plant based bioflocculants.

III. MATERIALS AND METHODS

➢ Material

Chemistry

- Water, reverse osmosis
- Polyethylene/polypropylene microplastics powder
- 70% Ethanol

Material Biological

- Young okra pods
- Fenugreek seed
- Tamarind kernels

Gear

- Magnetic stirrer 1,5
- Centrifuges
- Hot plates
- Paper filter
- Analytical balance
- Microsco

➢ Extraction of Plant Extracts

Okra Extract Okra Extract

The fresh okra was washed nicely and chopped into small pieces. Ten grams of okra was added to 100 mL distilled water and heated at 60°C for 20 min with constant stirring. The extract of viscous mucilage was filtered and kept at 4 °C.

Extract of Fenugreek

The seeds of fenugreek were soaked in distilled water for 12 h and then grinded in a mortar and pestle. The extract was filtered and centrifuged at 5000 rpm for 10 min to get a clear supernatant.

Tamarind Extract

The dried tamarind seeds were powdered and then heated with distilled water at 60 °C for 20 min. The solution was cooled, filtered to give polysaccharide-rich extract.

➢ Microplastic suspension preparation

To prepare a uniform microplastic suspension, 0.5 g microplastic powder was dispersed in 500 mL distilled water and then continuously stirred for 30 min.

➢ Experimental Procedure

The jar test experiments were performed by adding plant extracts at different concentrations in the microplastic contaminated water samples.

Conditions of Mixing

- Fast mixing: 2–5 minutes
- Slow mixing: 15-20 minutes

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Settle
Samples were allowed to stand for sedimentation and formation of flocs.

Discussion
The remaining microplastics were analyzed through filtration and microscopic observation.

IV. RESULTS

Table 1. Functional Components of Plant Extracts

Plant Material	Major Component	Functional Role	Observation
Okra	Mucilage	Flocculation	Strong aggregation
Fenugreek	Galactomannan	Coagulation	Improved settling
Tamarind	Polysaccharides	Binding	Enhanced sedimentation

Table 2. Individual Microplastic Removal Efficiency

Extract	Removal Efficiency (%)	Optimum pH	Dosage (mL/L)	Settling Time
Okra	92%	6.5–7.5	10–25	45 min
Fenugreek	88%	6–7	15–30	60 min
Tamarind	85%	6–7.5	10–20	70 min

Table 3. Combined Extract Efficiency

Treatment	Removal Efficiency (%)	pH	Dosage (mL/L)	Settling Time
Combined Extract	96%	6.5–7.5	20–40	65 min

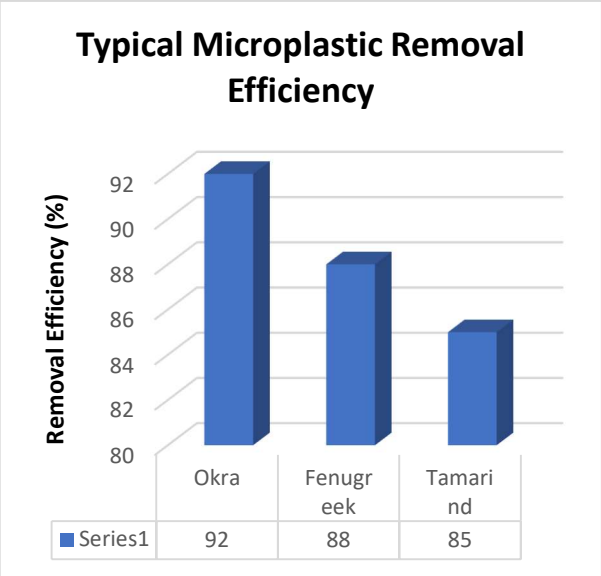


Fig. 1 Typical Microplastic Removal Efficiency that compares how effectively three plant-based materials remove microplastics from water

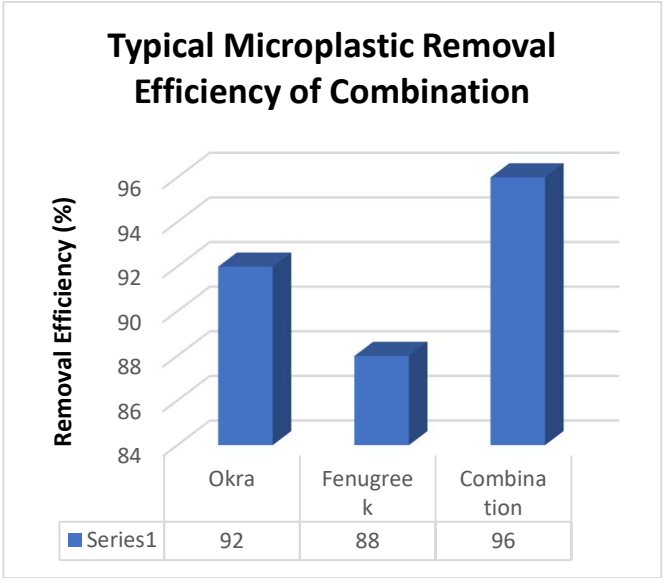


Fig. 2 Typical Microplastic Removal Efficiency of Combination that compares the individual microplastic removal performance of okra and fenugreek against their combined mixture



Fig. 3 The three images show laboratory filter papers used to collect and quantify microplastic particles after coagulation-flocculation water treatment with natural plant extracts

V. DISCUSSION

The work shows a great potential for the use of plant derived bioflocculants for sustainable remediation of microplastics. Natural biopolymers such as mucilage, galactomannan and polysaccharides are used in the coagulation and flocculation process through adsorption, charge neutralisation and bridging mechanisms, which results in high removal efficiency (Salehizadeh and Shojaosadati, 2001; Bolto and Gregory, 2007). Natural polymers help in forming larger flocs that settle and remove microplastic particles from contaminated water (Bolto & Gregory, 2007). (Srinivasan et al., 2026). Okra polysaccharides have been demonstrated to be able to remove microplastics from fresh water and ocean water samples. Okra extract exhibited the highest removal of 92 %. This could be due to the high amount of mucilage (galactose, rhamnose and uronic acid residues) in okra which aids in adsorption and particle bridging (Patale & Pandya, 2012). The high removal efficiency (88%) was explained by the galactomannan gum and soluble fibres

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of the fenugreek extract which improved the viscosity and better floc formation (Srinivasan et al., 2025). Galactomannans are natural polymer flocculants that can aggregate normal cells and therefore increase the sedimentation efficiency in wastewater treatment systems (Salehizadeh & Shojaosadati, 2001). Tamarind extracted polysaccharides have been investigated as versatile natural polymers with good thickening, stabilising and coagulating properties for water treatment applications (Prajapati et al., 2013). However, tamarind extract showed 85% of removal efficiency which shows that tamarind seed polysaccharides are very good in adsorption and binding. The combined extract exhibited the highest removal efficiency (96%) due to the synergistic effect of tamarind mucilage, galactomannan and polysaccharides. Higher polymer bridging and more active sites for adsorption improve the floc stability and performance, therefore enhancing the microplastic capturing. A similar observation is observed in mixed natural coagulant where the addition of biopolymers resulted in synergistic effect and better removal of pollutants than the individual components (Bolto & Gregory, 2007; Kumar et al., 2021).

The results of the present study are congruent with the recent findings of Srinivasan et al. (2025) who found that okra and fenugreek polymers are more efficient in removing microplastics from groundwater, fresh water and sea water than the traditional synthetic polyacrylamide flocculants with a removal rate up to 90%. The obtained results also pointed to the potential use of plant-derived bio-flocculants for microplastics' remediation. Maximum removal efficiency was obtained in the range of neutral to slightly acidic pH (6.0-7.5) and stable flocs also obtained. The coagulation behaviour in wastewater treatment using natural coagulants and bioflocculants is dependent on pH (Bolto & Gregory, 2007; Tchobanoglous et al., 2014). Moreover, the optimal dosage and settling time were essential for the aggregation and sedimentation of microplastics, suggesting that optimisation is required for large-scale applications. We are leading the way to sustainable plant-based technologies for microplastic pollution removal in wastewater treatment and for the protection of aquatic ecosystems. The use of plant derived bioflocculants for wastewater treatment is more environment friendly and cost effective compared to membrane filtration, electrocoagulation and advanced oxidation processes. They are economical, biodegradable, renewable, and non-toxic and generate less secondary sludge (Kumar et al., 2021; Salehizadeh and Shojaosadati, 2001).

VI. CONCLUSIONS

The present study concluded that okra, fenugreek and tamarind extracts are effective natural bio-flocculants for removal of microplastics from polluted water. Okra was the most effective in removing single extracts. The maximum efficiency of the mixture was 96 %. The authors demonstrated the ability of plant polysaccharides to induce natural coagulation and flocculation resulting in aggregation and sedimentation of microplastic particles. Low cost, biodegradable, eco-friendly, non-toxic. The results indicate a rising worldwide interest in green bioremediation technologies and avenues for sustainable wastewater treatment with the help of plant-based coagulants.

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