

Application of Polysaccharide-Based Biosorbent Derived from Agricultural Waste for Removal of Dye and Pharmaceutical Pollutants from Effluents

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Abstract: *This study evaluated a polysaccharide-based biosorbent prepared from agricultural waste for the removal of dye and pharmaceutical pollutants from simulated effluents. Cellulose, starch, and pectin were extracted from fruit and vegetable peels, cross-linked using citric acid, and stabilized by lyophilization. Part of the biosorbent was encapsulated in calcium alginate beads using ionotropic gelation. Pollutant removal efficiency for safranin, aspirin, and paracetamol was assessed spectrophotometrically. The encapsulated biosorbent showed improved removal efficiency, achieving 61% for safranin, 40% for aspirin, and 85.2% for paracetamol, compared with the non-encapsulated form. Reusability performance was also better in the encapsulated system. Microbial combination experiments produced selective improvement only for aspirin with *E. coli*, while *Corynebacterium diphtheriae* showed limited effectiveness for paracetamol removal. The findings indicate that agricultural waste-derived biosorbents offer a promising, sustainable, and economical strategy for pollutant removal in wastewater treatment applications.*

Keywords: Biosorption; Agricultural waste valorization; Wastewater treatment; Pharmaceutical pollutants; Dye removal; Calcium alginate encapsulation

1. Introduction

Biosorbents are biologically originated materials, which have the capability of passively removing pollutants from contaminated environments. The process is called biosorption [1]. Several biosorbents are prepared from various biological sources including herbaceous materials, agricultural waste, animal waste, bacteria, and algae. Given their versatile physicochemical properties, a wide range of biosorbents has been investigated for environmental contaminant removal, including dyes, pharmaceutical compounds, heavy metals, and radionuclides [2]. Their large surface area, low cost, high sensitivity to pollutants, environmental compatibility, ease of application and reusability make them efficient for sustainable effluent treatment.

Agricultural waste, growing at an average annual rate of 5–10% has become a significant contributor to environmental pollution, with rapid population growth and intensified agricultural activity further exacerbating soil, water and air contamination [3]. Valorisation of agricultural residues through separation and processing technologies offers an environmentally friendly and cost-effective solution for waste management [4]. Traditionally used for fertilizers, animal feed and biofuels, these residues also serve as promising raw materials for biosorbent synthesis thereby reducing waste accumulation while enabling efficient pollutant removal from industrial effluents.

Polysaccharides-rich agricultural wastes particularly those containing cellulose, starch and pectin are abundant especially suitable for biosorbent preparation. Cellulose, the most abundant biopolymer in nature provides biocompatibility and functional groups for adsorption and can be engineered into membranes, foams, aerogels and filters [5]. Pectin, a negatively charged heteropolysaccharide facilitates pollutant adsorption via electrostatic attraction. Starch, though biodegradable and non-toxic demonstrates enhanced adsorption efficiency upon chemical modification of its hydroxyl groups. These polysaccharides demonstrate potential in pollutant removal.

The harmful effects of pollutants such as safranin, aspirin and paracetamol further emphasize the need for research on biosorption. Safranin, commonly used in textiles and bio-staining accumulates in aquatic organisms, inhibits photosynthesis by blocking sunlight penetration and exhibits carcinogenic and mutagenic properties. Aspirin and paracetamol which are frequently discharged from pharmaceutical industries persist in the environment due to their non-biodegradability. Their bioaccumulation in aquatic organisms leads to oxidative stress, tissue damage and hypersensitivity reactions, highlighting the need for efficient removal strategies.

Conventional effluent treatment methods such as ultrafiltration, ion exchange and precipitation bear high operational costs and environmental concerns [6]. In contrast

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to these, biosorbent offers a cost-effective, eco-friendly alternative with minimal environmental drawbacks. Recent studies have demonstrated the efficiency of biosorbents ranging from alginate bio composites and gellan gum/bacterial cellulose hydrogels [7] to low-cost agricultural residues such as banana peel powder [8].

On this basis, the present study explores the preparation and application of polysaccharides-based biosorbents derived from agricultural waste for the removal of pollutants safranin, aspirin and paracetamol from effluents. The findings from this study are also expected to make a meaningful contribution to the field of bioremediation by delivering scalable, economical and environmentally responsible alternatives for managing industrial effluents.

2. Literature Review

Various studies have been conducted on the use of biosorbents as an eco-friendly method for the removal of toxic pollutants. A study by Farias et al. (2023) on the use of banana peel powder for the removal of hazardous organic pollutants demonstrated that banana peel powder is a low-cost and effective biosorbent for eliminating hazardous organic pollutants such as methylene blue, atrazine and glyphosate from wastewater, thus leading to green and environment friendly wastewater treatment [8].

Studies on alginate-based materials for removal of pollutants have also been carried out. Thakur (2020) undertook research providing an overview of alginate-based bio-composite materials for the removal of toxic contaminants such as heavy metals, dyes, antibiotics and phenolic compounds from water. The findings of this study indicated that alginate-based bio-composites are effective, low-cost adsorbents for diverse contaminants in water. In addition, the reusability of alginate-based bio composites was demonstrated through this study [13]. The use of microbes in the degradation of hazardous dyes in textile industry effluents has also been explored through various studies. One such study conducted by Das et al. (2023) revealed that microbial enzymes such as peroxidase, azoreductase and laccase are highly effective in breaking down various dyes under optimized conditions. It was found that certain strains, including *Bacillus subtilis* DS and *Klebsiella pneumoniae* GM-04, achieved over 90% dye removal [14].

3. Methodology

3.1 Collection of agricultural waste

The agricultural waste used in this study comprised peels of various fruits and vegetables, including pomegranate, banana, cucumber, potato and green peas in appropriate quantities sufficient for polysaccharides extraction and biosorbent preparation which were found through literature review as containing the polysaccharides cellulose, starch and pectin.



Figure 1: Agricultural waste, including fruit and vegetable peels and groundnut shells, was collected and processed to obtain extracts for biosorbent preparation.

3.2 Extraction of polysaccharides cellulose, starch and pectin

The polysaccharides cellulose, starch and pectin were extracted from the collected agricultural waste using acid and alkaline hydrolysis methods. The procedure involved fragmentation of the collected waste, washing of the waste in hot water for 10 minutes followed by subsequent washing in 0.5 M HCl for 30 minutes (two cycles) at 75°C and in 1 M NaOH for 30 minutes (three cycles) at 75°C [9].

3.3 Screening of the extract for the presence of the polysaccharides cellulose, starch and pectin by rapid tests

The crude extract obtained from agricultural waste was subjected to rapid qualitative screening for the presence of polysaccharides cellulose, starch and pectin. The rapid tests performed included the Schulz test for detection of cellulose, the Iodine test for detection of starch and the NaOH test for detection of pectin.

Table 1: Procedure for rapid tests for cellulose, starch and pectin

	Test performed	Procedure	Expected Results
Detection of cellulose	Schulz Test	1 ml of extract + 1 ml of Schulz reagent	Blue or violet coloration indicates the presence of cellulose
Detection of starch	Iodine Test	1 ml of extract + 1 ml of Gram's iodine	Blue-black coloration indicates the presence of starch
Detection of Pectin	NaOH Test	1 ml of extract + 1 ml of NaOH solution + heat	Yellow coloration indicates the presence of pectin.

3.4 Crosslinking of the extract

The extract obtained was cross-linked by the addition of 30 ml of 1 N citric acid [7]. The mixture was manually stirred to ensure uniform interaction and kept in a refrigerator to stabilize the cross-linking reaction.



Figure 2: Extract obtained from agricultural waste cross-linked for biosorbent preparation

3.5 Preservation of the bioactivity of the extract

The bioactivity of the cross-linked extract was preserved by lyophilization. In this process, the cross-linked extract was frozen and placed in a lyophilizer at -40°C . Within the instrument, ice gets removed from the extract as vapor and to remove the bound water molecules the temperature in the chamber of this instrument rises which allows the bound water molecules to convert into gaseous phase.



Figure 3: Lyophilized Biosorbent

3.6 Encapsulation of the biosorbent

The biosorbent formed after lyophilization of the extract was encapsulated using the ionotropic gelation technique. In this method, 0.98 g of the biosorbent was dispersed in a sodium alginate solution and the mixture was extruded drop wise into a calcium chloride solution. The biosorbent is incorporated in beads composed of calcium alginate [10].



Figure 4: Biosorbent encapsulated within calcium alginate beads via ionotropic gelation technique

3.7 Determination of the removal efficiency of the pollutants safranin, aspirin and paracetamol by the non-encapsulated and encapsulated biosorbent

The solutions of pollutants safranin (250 mg/ml) aspirin (0.1 mg/ml) and paracetamol (0.1 mg/ml) were prepared using distilled water for safranin and 1:1 methanol:HCl mixture for aspirin and paracetamol. The initial concentrations of these pollutants were determined spectrophotometrically at wavelengths of 520 nm, 230 nm and 256 nm respectively without generating calibration curves for spectrophotometric quantification [11, 12]. Following the addition biosorbents and after a contact period of 48 hours at 37°C , the concentrations of the solutions were re-measured spectrophotometrically.

3.8 Determination of removal efficiency of only calcium alginate beads (Control)

The pollutants removal efficiency by calcium alginate beads was determined as control in this experiment. This helped in separating the effect of the biosorbents from the effect of the calcium alginate itself. The beads were tested under the same experimental conditions and pollutants concentrations as those used for non-encapsulated and encapsulated biosorbents.

3.9 Evaluation of the reusability of the non-encapsulated and encapsulated biosorbent

The non-encapsulated and encapsulated biosorbents were recovered from the solutions of pollutants. After washing them with distilled water, they were reused to evaluate their pollutant removal efficiency.

3.10 Combination of pollutant-degrading microbes with the biosorbent

The biosorbent was combined with non-pathogenic strain of *E. coli* by encapsulation to assess its removal efficiency for the all the three pollutants safranin, aspirin and paracetamol. For paracetamol specifically, the biosorbent was also combined separately with non-pathogenic strain of *Corynebacterium diphtheriae* to assess its individual performance. These microorganisms were chosen as literatures highlight their effectiveness in pollutant removal and also due to their ready availability in the laboratory where the present study was conducted.

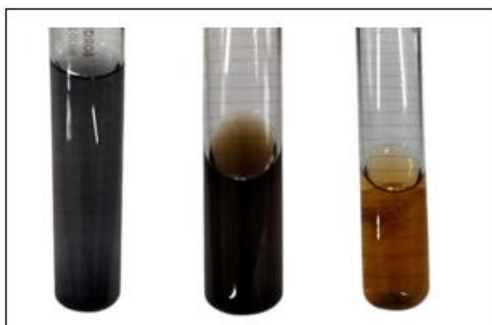
4. Results and Discussion

4.1 Preliminary screening of the extract obtained from agricultural waste.

The extract obtained from agricultural waste was preliminarily screened for the presence of polysaccharides cellulose, starch and pectin via rapid qualitative tests namely Schulz, Iodine and NaOH tests respectively.

Table 2: Results of preliminary screening of the extract obtained from agricultural waste for presence of polysaccharides cellulose, starch and pectin

Test	Observation	Inference
Schulz test for detection of cellulose	Violet coloration observed.	Cellulose present
Iodine test for detection of starch	Blue-black coloration observed.	Starch present
NaOH test for detection of pectin	Yellow coloration observed.	Pectin present

**Figure 5:** Positive Schulz, Iodine and NaOH tests

4.2 Determination of removal efficiency of pollutants safranin, aspirin and paracetamol by non-encapsulated and encapsulated biosorbent.

Table 3: Percentage removal efficiency of non-encapsulated biosorbent for pollutants removal

Pollutants	Initial Absorbance	Absorbance after treatment	Percentage removal of pollutants
Safranin	1.454	0.872	40%
Aspirin	1.694	1.058	37.50%
Paracetamol	1.14	0.869	23.80%

Table 4: Percentage removal efficiency of encapsulated biosorbent for pollutants removal

Pollutants	Initial Absorbance	Absorbance after treatment	Percentage removal of pollutants
Safranin	1.454	0.567	61%
Aspirin	1.694	1.012	40%
Paracetamol	1.140	0.169	85.2%

The encapsulated biosorbent demonstrated the highest removal efficiency for paracetamol as compared to safranin and aspirin. Overall, it was more effective in removing all three pollutants safranin, aspirin and paracetamol as compared to the non-encapsulated biosorbent.

4.3 Determination of removal efficiency of calcium alginate beads (Control)

Table 5: Percentage removal efficiency of calcium alginate beads for pollutants removal

Pollutants	Initial Absorbance	Absorbance after treatment	Percentage removal of pollutants
Safranin	1.454	1.103	24%
Aspirin	1.694	1.651	2.5%
Paracetamol	1.140	1.069	6%

4.4 Evaluation of the reusability of the biosorbent

Table 6: Percentage removal efficiency of reused non-encapsulated biosorbent for pollutants removal

Pollutants	Initial Absorbance	Absorbance after treatment	Percentage removal of pollutants
Safranin	1.454	0.502	65.5%
Aspirin	1.694	1.058	37.6%
Paracetamol	1.140	0.896	21.5%

Table 7: Percentage removal efficiency of reused encapsulated biosorbent for pollutants removal

Pollutants	Initial Absorbance	Absorbance after treatment	Percentage removal of pollutants
Safranin	1.454	0.415	71.5%
Aspirin	1.694	0.928	45.3%
Paracetamol	1.140	0.262	77%

The reused encapsulated biosorbent was found to be more effective for the pollutants safranin and aspirin. Overall, the encapsulated biosorbent depicted better reusability for the removal of pollutants safranin, aspirin and paracetamol as compared to the non-encapsulated biosorbent.

4.5 Combination of the biosorbent with a pollutant degrading microbe by encapsulation and evaluation of its removal efficiency of pollutants.

Table 8: Percentage removal efficiency of biosorbent combined with *E. coli* for pollutants removal

Pollutants	Initial Absorbance	Absorbance after treatment	Percentage removal of pollutants
Safranin	1.454	0.770	47%
Aspirin	1.694	0.747	55%
Paracetamol	1.140	1.025	10%

The biosorbent combined with *E. coli* by encapsulation was found to be more effective than the non-encapsulated, encapsulated, reused non-encapsulated and reused encapsulated biosorbents for the removal of pollutant aspirin, though its efficiency was lower for safranin and paracetamol.

Table 9: Percentage removal efficiency of biosorbent combined with *Corynebacterium diphtheriae* for pollutant paracetamol removal

Pollutants	Initial Absorbance	Absorbance after treatment	Percentage removal of pollutants
Paracetamol	1.140	0.992	12.98%

The biosorbent combined with *Corynebacterium diphtheriae* was found to be far less effective for paracetamol removal than the non-encapsulated, encapsulated, reused non-encapsulated and reused encapsulated biosorbents. However, it was slightly more effective than the biosorbent combined with *E. coli*.

4.6 Comparison of the removal efficiency non-encapsulated, encapsulated, reused biosorbent along with combination of the biosorbent with a pollutant degrading microbe for the pollutants screened

The removal efficiencies of non-encapsulated, encapsulated, reused biosorbents along with biosorbents combined with

pollutant-degrading microbes *E. coli* and *Corynebacterium diphtheriae* were compared and represented graphically.

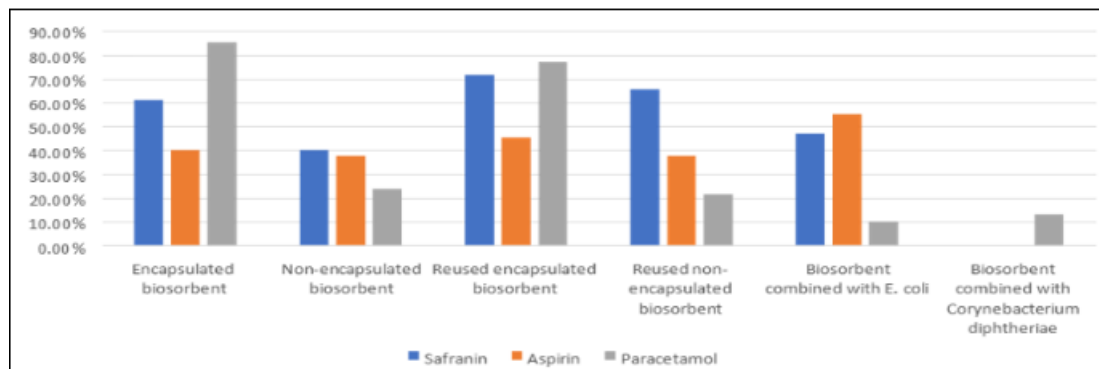


Figure 6: Graph depicting removal efficiency of non-encapsulated, encapsulated, reused biosorbent along with combination of the biosorbent with a pollutant degrading microbe for the screened pollutants safranin, aspirin and paracetamol

The graph shows that the encapsulated biosorbent achieved higher removal efficiency for all three pollutants safranin, aspirin and paracetamol. Its reusability was also superior to that of the non-encapsulated biosorbent. Encapsulation enhanced its performance, enabling the removal of all three screened pollutants, whereas other studies reported biosorbents effective only against a single pollutant like safranin

The reused encapsulated biosorbent showed greater removal efficiency for safranin and aspirin but lower efficiency for paracetamol compared to the encapsulated biosorbent. The combination of the biosorbent demonstrated better removal efficiency than encapsulated and reused encapsulated biosorbents only for the pollutant aspirin. For safranin, the combination of the biosorbent with *E. coli* as the pollutant-degrading microbe by encapsulation showed less removal efficiency than both encapsulated and reused encapsulated biosorbents. For paracetamol, the combinations with *E. coli* and *Corynebacterium diphtheriae* were less effective than encapsulated and reused encapsulated biosorbents.

5. Conclusion

This study demonstrated that agricultural waste-derived polysaccharide-based biosorbents can effectively remove selected dye and pharmaceutical pollutants from simulated effluents. Encapsulation in calcium alginate significantly improved pollutant removal efficiency and reusability compared with the non-encapsulated biosorbent. Microbial integration showed selective benefit only for aspirin removal. These findings support the potential of low-cost agricultural waste valorization as a sustainable strategy for wastewater remediation, though further optimization, mechanistic analysis, and scale-up validation are required.

6. Future Scope

The present study utilized fruit and vegetable peels which are post-harvest agricultural waste for synthesis of a biosorbent useful in pollutant removal. In future, other types of agricultural waste such as rice husks, corn cobs and straws could be explored for biosorbent synthesis to enhance pollutant removal efficiency. In this study, the synthesized

biosorbent was screened for the removal of three pollutants safranin, aspirin and paracetamol. Apart from these, other pollutants such as hydrocarbons and heavy metals commonly found in effluents can also be evaluated for removal using biosorbents.

The biosorbent synthesized here can be further optimized for economical storage conditions. Additionally, improved encapsulation methods may be developed to achieve more effective pollutant removal. The biosorbent was combined with a non-pathogenic strain of *Corynebacterium diphtheriae* through encapsulation to assess its paracetamol removal efficiency. Alternatively, other non-pathogenic microbial strains with similar capabilities could be employed to enhance pollutant removal.

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