



Cationic Dyes Removal From Textile Effluents Using Plant-Based Bioadsorbents

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ABSTRACT

Synthetic dyes, especially cationic dyes, are poisonous, persistent, and non-biodegradable, the discharge of dye-laden wastewater from textile businesses has become a significant environmental concern. Because these colors reduce light penetration and introduce harmful substances into water bodies, they pose substantial dangers to human health and aquatic ecosystems. Despite their effectiveness, conventional treatment techniques are frequently costly and produce secondary contaminants. In this regard, plant-based bioadsorbents have become a viable and affordable color removal option.

Because they contain lignocellulosic components and functional groups like hydroxyl and carboxyl, plant-derived materials including banana peels, rice husk, tea trash, and sugarcane bagasse have a substantial adsorption potential. A number of factors, including pH, contact time, adsorbent dosage, and initial dye concentration, affect the adsorption process. High removal efficiencies, frequently over 90%, have been reported in numerous experiments, and adsorption behavior generally follows pseudo-second-order kinetics and Langmuir and Freundlich isotherms.

The efficiency of plant-based bioadsorbents in eliminating cationic dyes from textile effluents is demonstrated in this work, which also underlines the benefits of these bioadsorbents, such as their affordability, availability, and environmental friendliness. These materials have a lot of potential for large-scale wastewater treatment applications, despite some drawbacks like performance fluctuation and regeneration difficulties. To increase their effectiveness and usefulness, future studies should concentrate on modification strategies and industrial use.

KEYWORDS

Methylene Blue, Bioadsorption, Plant-Based Bioadsorbents, Cationic Dyes, Textile Effluents, Wastewater Treatment, Agricultural Waste, Adsorption Isotherms, Sustainable Remediation, and Environmental Pollution.

ARTICLE HISTORY

Received: 27 January 2026

Accepted: 03 February 2026

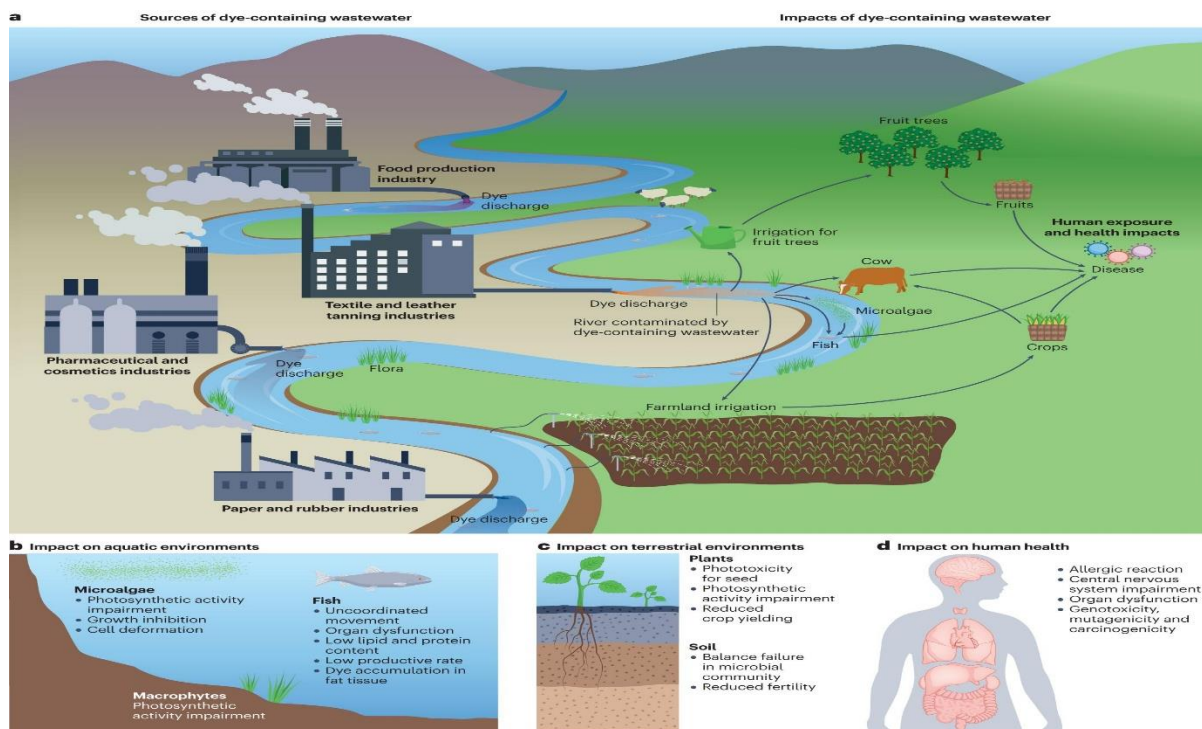
Published: 05 March 2026

CITATION

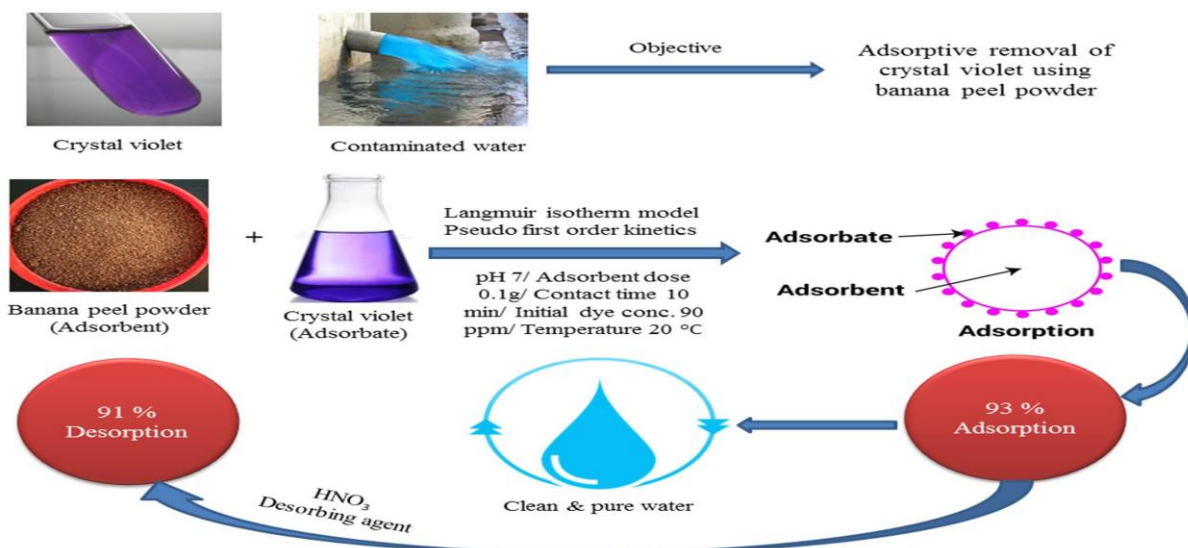
Mishra. A. & Seth. B., (2026). Cationic Dyes Removal From Textile Effluents Using Plant-Based Bioadsorbents, Journal of Science and Technology (GJST), 2(1), 186-194. <https://doi.org/10.65523/gjst.2026.v2.i1.23>

1. Introduction

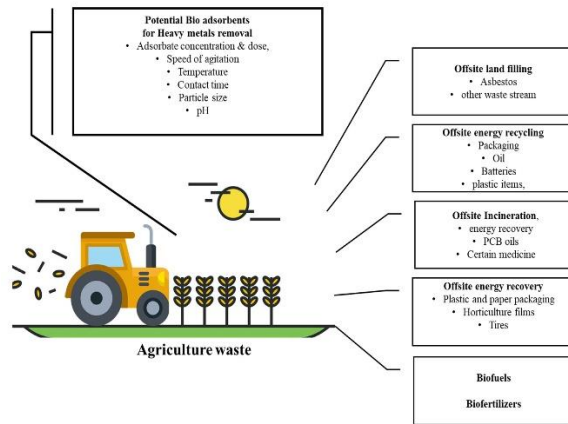
Wastewater containing dyes has been released into the environment as a result of the textile industry's explosive development. Because of their high tinctorial strength and affinity for synthetic fibers, cationic dyes, including methylene blue, are widely utilized among the several types of dyes. However, these dyes are persistent pollutants in aquatic ecosystems due to their toxicity, carcinogenicity, and resistance to biodegradation (Gupta & Suhas, 2009; Bhatnagar & Sillanpää, 2017). Dyes have a detrimental impact on aquatic ecosystems and human health by reducing light penetration and interfering with photosynthesis (Crini, 2006; Rafatullah et al., 2010).



For the removal of dyes, conventional wastewater treatment techniques such as coagulation, flocculation, oxidation, and membrane filtering have been used extensively. However, these techniques frequently result in sludge production, high operating expenses, and insufficient dye removal (Ali, 2012; Wang & Zhu, 2007). Adsorption has drawn a lot of interest among different treatment methods because of its ease of use, great efficiency, and versatility (Foo & Hameed, 2012; Malik, 2004). The most efficient adsorbent is activated carbon, but its high cost and challenges with regeneration prevent it from being used widely (Demirbas, 2009; Hameed, 2009).



Plant-based bioadsorbents made from agricultural waste have shown promise as dye removal substitutes in recent years. These materials, which include sugarcane bagasse, banana peels, rice husks, and tea debris, are rich in lignocellulosic components such as cellulose, hemicellulose, and lignin, which include functional groups that can bind dye molecules (Ngah & Hanafiah, 2008; Salleh et al., 2011). Electrostatic interaction between negatively charged surface groups and positively charged dye ions is the main factor controlling the adsorption of cationic dyes onto these bioadsorbents (Mohan et al., 2007; Ahmad et al., 2020).



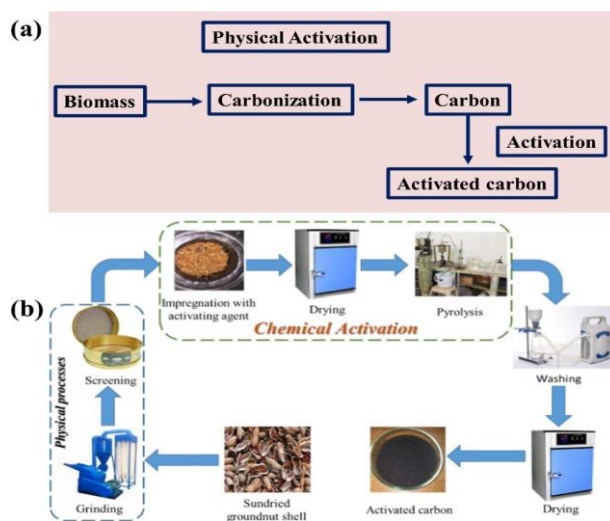
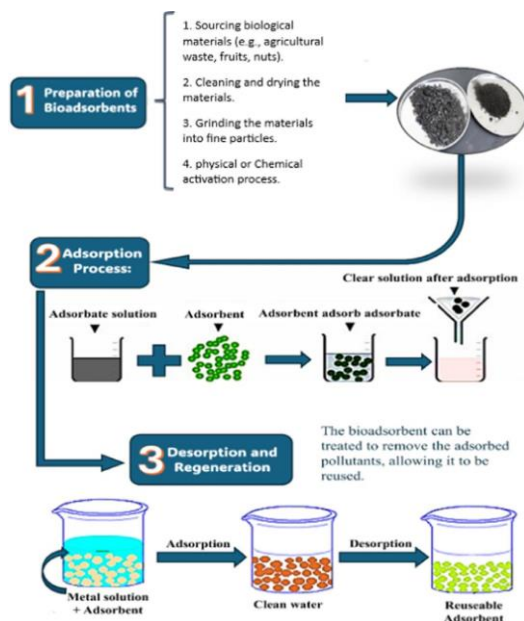
Numerous studies have shown how effective plant-based bioadsorbents are at removing dyes. For example, rice husk shows improved adsorption following chemical treatment (Sharma et al., 2009), whereas banana peel has demonstrated great adsorption ability due to its high pectin content (Annadurai et al., 2002). Because of its polyphenolic nature, tea waste has also been described as an efficient adsorbent (Tan et al., 2008). Additionally, the high surface area and porosity of biochar made from plant biomass have drawn interest because they improve adsorption efficacy (Mohan et al., 2007; Ahmad et al., 2020).

pH, contact time, adsorbent dosage, and initial dye concentration are some of the variables that affect adsorption efficiency. The increasing negative charge on the adsorbent surface, studies show that adsorption of cationic dyes is preferred at higher pH (Ho & McKay, 1999; Bhattacharyya & Sharma, 2005). Chemisorption is the predominant mechanism in the adsorption process, which is typically explained using Langmuir and Freundlich isotherms and pseudo-second-order kinetics (Ho & McKay, 1999; Foo & Hameed, 2012).

According to the literature, plant-based bioadsorbents provide an economical, efficient, and environmentally acceptable method of removing cationic dyes from textile effluents. They are suitable for sustainable wastewater treatment due to their abundance and biodegradability, but more research is needed to improve their adsorption capability, regeneration, and large-scale applicability.

Materials and Methods

Bioadsorbent Preparation



Plant materials, including rice husks, banana peels, and tea trash, were gathered, completely cleaned with distilled water, and dried at 60 to 80 degrees Celsius. To achieve a consistent particle size, the dried materials were crushed into a fine powder and sieved. To improve their adsorption qualities, several samples underwent chemical treatment or activation.

Making the Dye Solution

For experimental investigation, a stock solution of a cationic dye (such as methylene blue) was made and diluted to the appropriate quantities.

Experiments on Batch Adsorption

In order to conduct adsorption tests, a dye solution and a known quantity of bioadsorbent were combined under carefully monitored circumstances.

Among the parameters examined were:

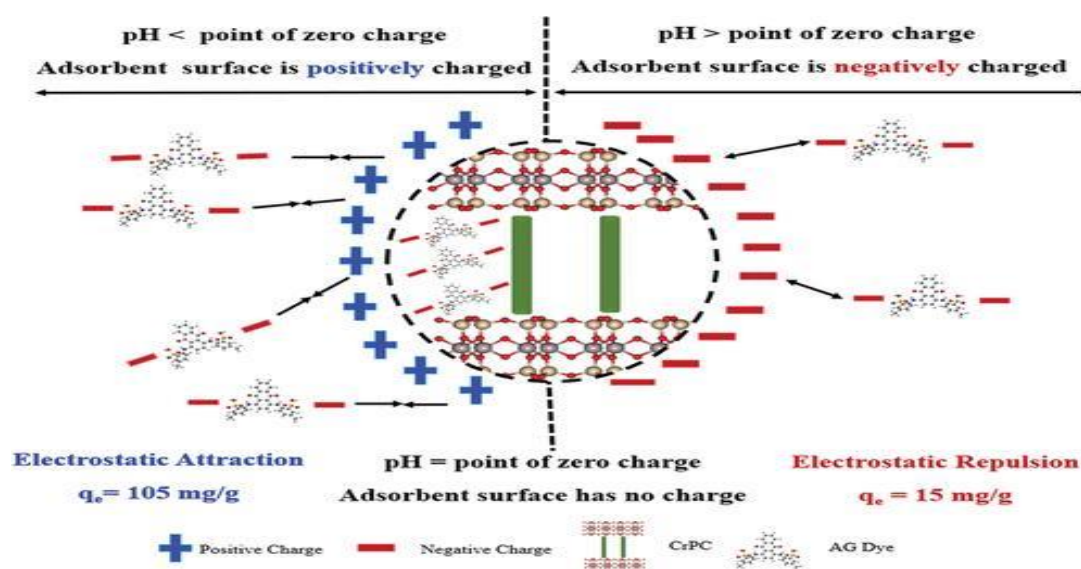
- pH ranges from 2 to 10
- Time spent in contact (0–120 minutes)
- Dosage of adsorbent (0.1–2 g)
- The initial concentration of dye (10–200 mg/L)

Analytical Techniques

A UV-visible spectrophotometer was used to detect the dye concentration both before and after adsorption. Calculations were made for removal efficiency and adsorption capacity.

Results and Discussion

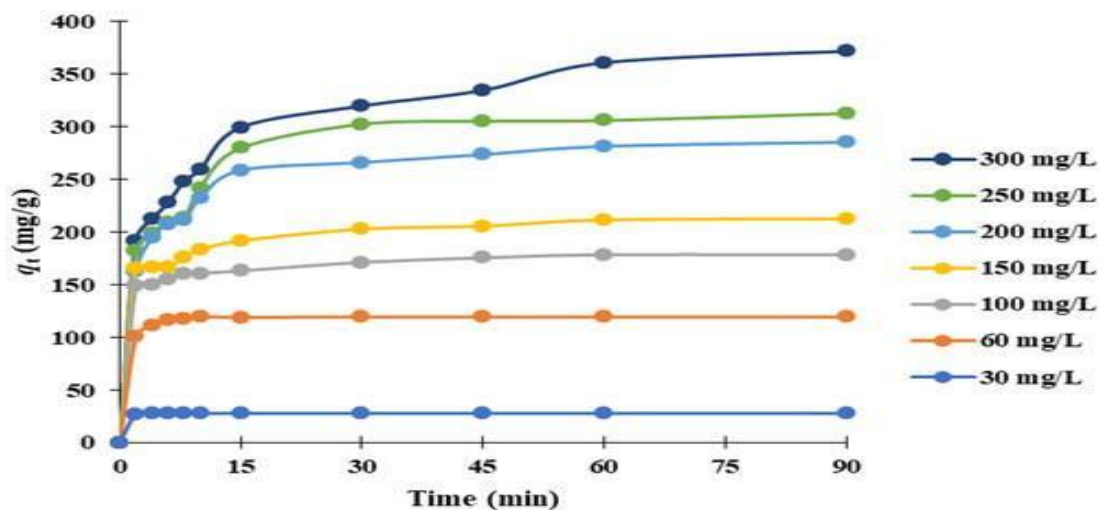
Effect of pH



Increased negative charge on the adsorbent surface at higher pH levels enhanced electrostatic interaction with cationic dyes, increasing adsorption efficiency.

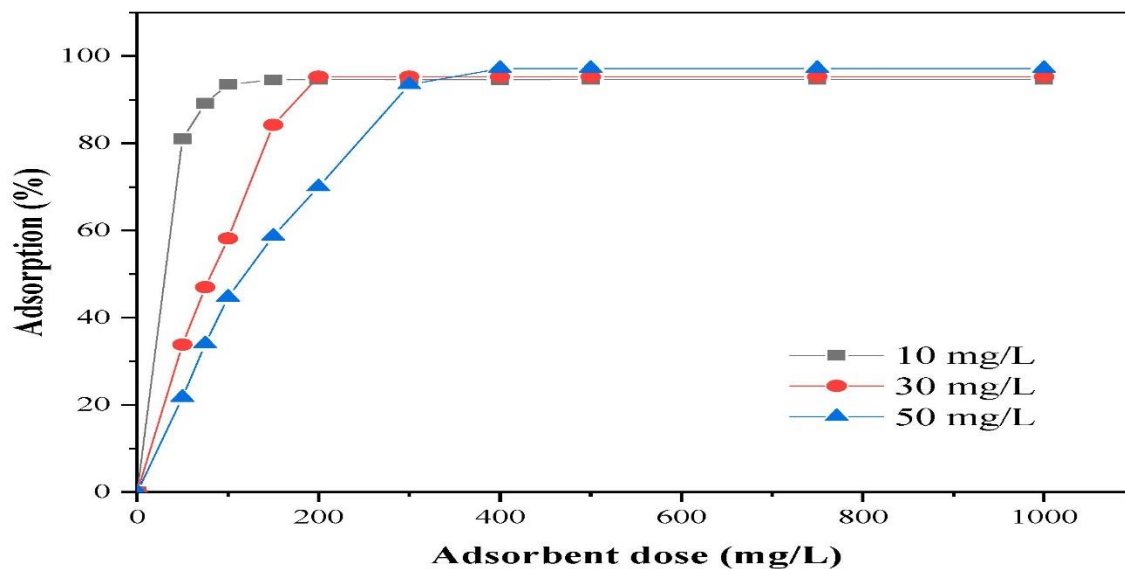
Impact of Contact Duration

There were many active sites in the early phases, rapid adsorption was seen. It took 60 to 90 minutes to attain equilibrium.



Adsorbent Dosage's Effect

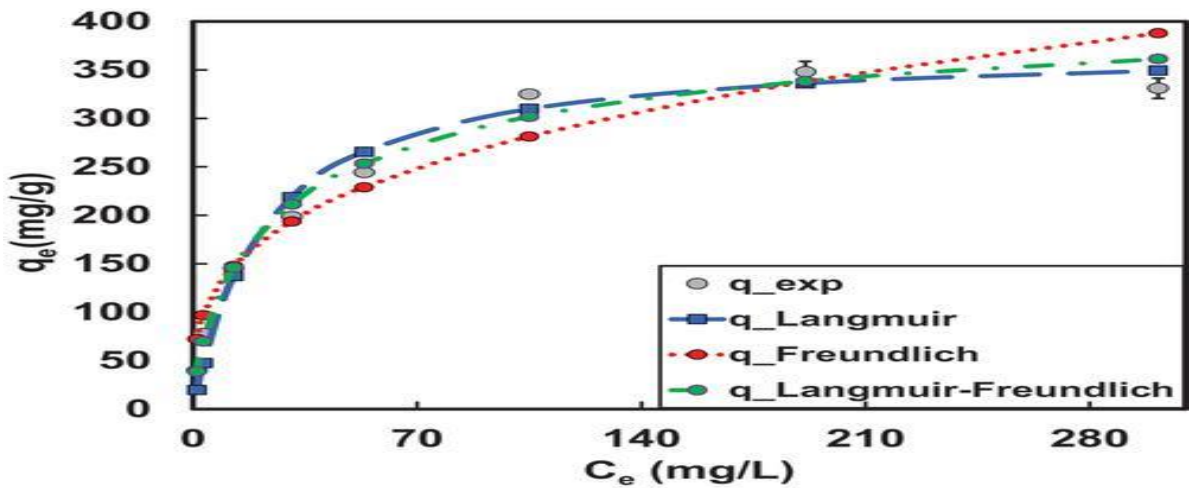
More surface area and binding sites were accessible, higher dosages improved removal efficiency.



Kinetics and Adsorption Isotherms

The following was the adsorption process:

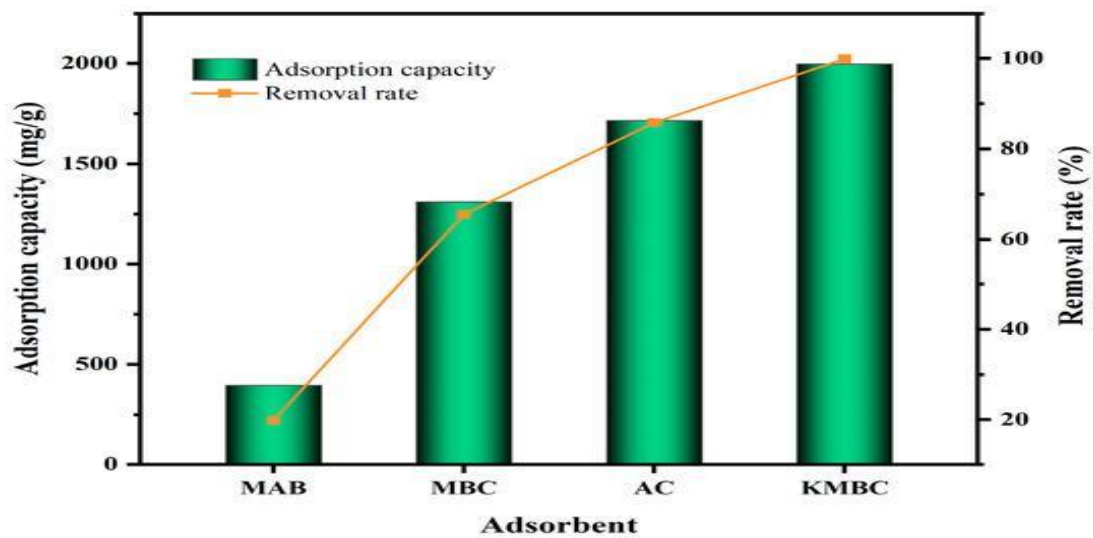
- The Langmuir isotherm for monolayer adsorption
- Heterogeneous surface adsorption, or the Freundlich isotherm
- Chemisorption is indicated by pseudo-second-order kinetics.



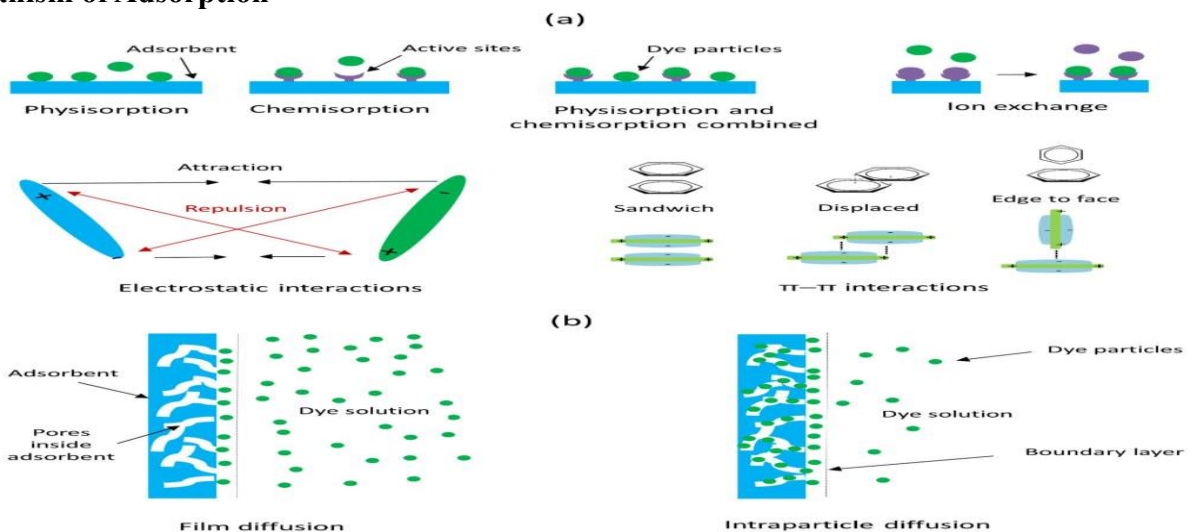
Comparative Efficiency

Among the bioadsorbents that were tested:

- The most efficient waste was tea.
- The effectiveness of banana peels was moderate.
- After alteration, rice husk performed better.



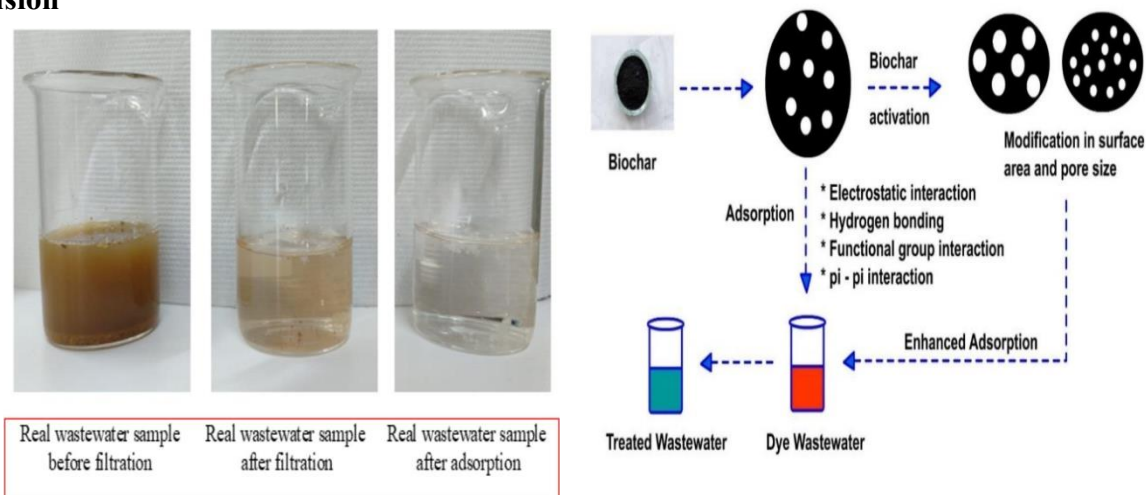
Mechanism of Adsorption



Cationic dyes are adsorbed onto plant-based bioadsorbents by the following processes:

- The dye ions' electrostatic attraction to a negatively charged surface
- The bonding of hydrogen
- The exchange of ions Interactions between π and π
- Functional groups like carboxyl and hydroxyl improve dye binding.

Conclusion



The study demonstrates that cationic dyes may be effectively and sustainably removed from textile effluents using plant-based bioadsorbents. Due to the large number of active sites, adsorption started off quickly and reached equilibrium in 60 to 90 minutes. Although a plateau was seen at higher levels, increasing the adsorbent dosage increased the dye removal effectiveness by providing additional surface area and binding sites.

Both monolayer and heterogeneous adsorption were indicated by the process's Langmuir and Freundlich isotherms, although chemisorption was suggested as the predominant mechanism by pseudo-second-order kinetics. Rice husk performed better after alteration, although tea trash and banana peel were the most effective materials among those evaluated.

All things considered, plant-derived bioadsorbents provide an affordable, environmentally responsible, and effective wastewater treatment option with a great deal of potential for real-world use.

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