Journal of Rare Cardiovascular Diseases
ISSN: 2299-3711 (Print) | e-ISSN: 2300-5505 (Online)
www.jrcd.eu
RESEARCH ARTICLE

ASSESSMENT OF ADSORBENT DOSAGE ON THE OF METHYLENE REMOVAL EFFICIENCY BLUE DYE USING LOW-COST NATURAL ADSORBENTS

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Article History
Received: 12.08.2025
Revised: 09.09.2025
Accepted: 28.10.2025
Published: 12.11.2025

Abstract: The discharge of dye-contaminated effluents from textile and allied industries poses significant environmental challenges due to the persistence, toxicity, and visibility of synthetic dyes. In this study, low-cost agricultural wastes—groundnut shell and spent tea waste—were evaluated as natural adsorbents for the removal of methylene blue dye from aqueous solutions. The adsorbents were prepared through washing, boiling, oven-drying, and sieving to obtain uniform particle sizes. Batch adsorption experiments were performed at a constant initial dye concentration of 500 mg/L to assess the influence of adsorbent dosage. Groundnut shell at 0.4 g demonstrated the highest removal efficiency of 94%, while spent tea waste at 0.7 g achieved a maximum of 74%. Results indicate that adsorption efficiency varies with adsorbent dose and adsorbent type, highlighting the potential of natural waste-derived materials as cost-effective alternatives for dye removal. Further optimization of parameters such as contact time, pH, and temperature could enhance color removal efficiency for practical wastewater treatment applications.

Keywords: Adsorption; Methylene blue; Groundnut shell; Tea waste; Low-cost adsorbent; Dye removal; Wastewater treatment..

INTRODUCTION

Synthetic dyes, especially those used in textile, leather, paper, and plastic industries, are among the major pollutants discharged into aquatic environments. Methylene blue (MB), a widely used cationic dye, is known for its high solubility, stability, and resistance to biodegradation. However, its uncontrolled release into water bodies can cause severe environmental and health issues, including irritation to the eyes, skin, and gastrointestinal system. Due to their structural complexity and strong chromophoric groups, conventional treatment methods often fail to completely remove dyes from wastewater.

Several treatment techniques—such as chemical oxidation, coagulation, ion exchange, membrane filtration, and biological degradation—have been explored, but many of them are costly, energy-intensive, or produce secondary pollutants. Among these, adsorption has emerged as a promising technique due to its simplicity, cost-effectiveness, and high efficiency in dye removal. Increasing attention has been focused on converting low-cost agricultural wastes into functional adsorbents, thereby promoting sustainable waste utilization.

Groundnut shell and tea waste, abundantly available biodegradable byproducts, possess significant adsorption potential due to their porous structure and surface functional groups. Utilizing such low-cost materials not only offers an economical solution for dye remediation but also helps in effective waste valorization. This study investigates the effect of adsorbent dosage on the adsorption of methylene blue dye using groundnut shell and spent tea waste, comparing their efficiency to identify the more effective natural adsorbent for practical wastewater treatment applications.

LITERATURE REVIEW

Reviews and broad surveys. Several comprehensive reviews have summarized the state of dye removal by low-cost adsorbents and identified major research directions and knowledge gaps. Rafatullah et al. (2010) provided an early systematic review of methylene blue adsorption on low-cost materials, comparing adsorbent types, treatment methods, and common experimental protocols. Kyzas, Fu, and Matis (2013) surveyed trends in adsorbent materials for dyeing wastewaters and emphasized the increasing interest in green, waste-derived adsorbents. More recent review articles also underline the persistent research focus on optimizing adsorption performance while minimizing costs and environmental footprints (Khan et al., 2022; Khan, Al-Asadi et al., 2025). These reviews collectively establish the rationale for converting abundant agricultural byproducts into adsorbents and for studying parameters such as adsorbent dose, contact time, pH, and temperature (Rafatullah et al., 2010; Kyzas et al., 2013; Khan et al., 2022). Vickneswari M et al (2025), Revathi K et al (2025), Revathi K et al (2025), Vickneswari M et al (2025), Vickneswari M et al (2025), P

Priyadharshini et al (2025) and P Priyadharshini et al (2025)

Spent tea / tea waste as adsorbent. Spent tea leaves and tea waste are among the most frequently studied low-cost adsorbents for methylene blue. Hameed (2009) introduced spent tea leaves as an effective non-conventional adsorbent and reported notable dye uptake under batch conditions. Uddin and Ahsan (2009) and later studies (Liu et al., 2018; Özyaman et al., 2021/2022) examined adsorption capacities, kinetic behavior, and proposed mechanisms for dye binding on tea-derived biomass. Collectively, these works show that tea waste is readily available, requires minimal pretreatment, and often exhibits favorable adsorption kinetics and isotherm behavior, making it a practical option for small-scale or decentralized treatment systems (Hameed, 2009; Uddin & Ahsan, 2009; Liu et al., 2018; Özyaman et al., 2021).

Groundnut / peanut shell based adsorbents. Peanut (groundnut) shell has been widely investigated either as raw biosorbent or after activation/modification. Studies that prepared and characterized groundnut shell-based adsorbents report good removal efficiencies for cationic dyes and describe optimization of dose, particle size and activation methods (Kamaraj et al., 2017; Ahmad et al., 2021). Lazarova et al. (2023) and Hashem et al. (2024) explored valorization and preparation of activated carbon from peanut shells, demonstrating that thermal or chemical activation substantially enhances surface area and dye uptake. These studies support the potential of peanut shell both as a direct biosorbent and as a precursor for higher-performance activated carbons (Kamaraj et al., 2017; Lazarova et al., 2023; Hashem et al., 2024).

Other agricultural wastes and comparative studies. Several authors have compared a variety of agricultural byproducts—orange peel, banana peel, rice husk, water hyacinth, neem leaf, etc.—to identify the most promising low-cost adsorbents for methylene blue and other dyes (Mane & Bhusari, 2012; Mohammed et al., 2014; R. S. Mane & Bhusari, 2012; Meena et al., 2012 as cited in your references). These comparative studies generally find that adsorption performance depends strongly on surface chemistry and porosity, and that pretreatment or activation often levels the performance differences between distinct waste materials. Meta-analyses and review collections (Rafatullah et al., 2010; Kyzas et al., 2013) synthesize these findings and highlight that local availability and cost will usually determine the most suitable biosorbent for a given region.

Adsorption mechanisms, kinetics, and isotherms. A central thread running through experimental studies is the characterization of adsorption behavior by kinetic and isotherm models. Authors working with tea waste and peanut/groundnut shells typically fit experimental data to pseudo-first-order and pseudo-second-order kinetic models and to Langmuir and Freundlich isotherms to infer monolayer vs. multilayer adsorption and possible chemisorption/ physisorption contributions (Uddin & Ahsan, 2009; Hameed, 2009; Liu et al., 2018; Özyaman et al., 2021/2022). While model fits vary by material and experimental conditions, many reports suggest that pseudo-second-order kinetics and Freundlich or Langmuir-type isotherms describe MB adsorption on biomass reasonably well, indicating a mix of surface heterogeneous adsorption sites and possible chemisorptive interactions with functional groups on the biomass surface.

Activated carbon and chemical modification approaches. Chemical activation (e.g., KOH, H3PO4) and thermal activation greatly enhance the adsorption performance of agricultural wastes by increasing surface area and porosity. Several recent studies specifically on peanut/groundnut shell-derived activated carbons show markedly improved dye uptake compared with raw biomass (Ahmad et al., 2021; Hashem et al., 2024; Mani et al., 2023). Chemical functionalization (acid or base treatment) and nano-carbon formation have also been reported to improve kinetics and capacity (Reddy et al., 2024; Aladeokin et al., 2024; Mani et al., 2023). These treatments can render the adsorbents competitive with commercial activated carbons, but they add steps, cost, and environmental considerations that must be weighed against the benefits.

Recent advances and novel processing. Newer work continues to refine activation techniques, scale up preparation methods, and explore composite or hybrid adsorbents (Lazarova et al., 2023; Zhai et al., 2024). Some papers report nano-engineered carbons or composites that achieve high capacities in laboratory tests (Reddy et al., 2024; Aladeokin et al., 2024), while others emphasize simple, low-energy pretreatments suitable for decentralized applications (Hameed, 2009; Uddin & Ahsan, 2009). Reviews and recent articles (Khan et al., 2022; Radoor et al., 2022) synthesize these trends and urge attention to regeneration, lifecycle impacts, and pilot-scale testing.

Methodological considerations and variability. Across the literature, methodological variability (dye concentration, adsorbent dose, contact time, pH, temperature, particle size, and reporting units) complicates direct comparison of adsorption capacities. Rafatullah et al. (2010) and Kyzas et al. (2013) emphasize the need for standardized testing protocols and full reporting to allow meaningful benchmarking across studies. Several experimental papers on tea waste and peanut shell therefore report detailed parametric studies and model fitting so that dose-response, optimum dose, and operational windows can be compared (Hameed, 2009; Uddin & Ahsan, 2009; Kamaraj et al., 2017).

Gaps, limitations, and future directions. Despite strong laboratory evidence for the viability of tea waste and peanut shell as low-cost adsorbents, gaps remain in scaling, regeneration, long-term stability, and real effluent testing. Many studies remain at bench scale and use synthetic dye solutions rather than actual textile effluents (Rafatullah et al., 2010; Kyzas et al., 2013). Future work recommended by the literature includes (a) pilot or field testing with real industrial wastewater, (b) techno-economic and lifecycle analyses for activated vs. raw biosorbents, (c) regeneration and reuse studies to assess operational lifespan, and (d) standardization of experimental protocols to improve comparability (Khan et al., 2022; Hashem et al., 2024; Lazarova et al., 2023). Your study on adsorbent dosage directly addresses an important operational parameter highlighted across these papers.

MATERIAL AND METHODS

Preparation of Adsorbents

Low-cost agricultural wastes, namely **groundnut shell** and **spent tea waste**, were selected as natural adsorbents due to their availability and porous structure. The raw materials were washed repeatedly with distilled water to remove dust, tannins, and other impurities. Both materials were then **boiled at 100°C for 30 minutes** to eliminate organic contaminants and enhance surface activation. After boiling, the samples were **oven-dried at 80°C for 48 hours**. The dried samples were crushed and sieved through **25-mesh** to ensure uniform particle size. The prepared adsorbents were stored in airtight containers to prevent moisture absorption prior to experimentation.

Preparation of Adsorbate (Methylene Blue Solution)

A stock solution of methylene blue (MB) was prepared by dissolving **0.5 g of dye in 1 L of distilled water** and stirring continuously using a magnetic stirrer at **400 rpm and 80°C for 1 hour** to ensure uniform mixing. The solution was cooled and filtered to obtain a clear MB stock solution of known concentration.

Batch Adsorption Experiments

Batch studies were conducted to determine the effect of **adsorbent dosage** on MB removal efficiency. Experiments were performed in **250 mL conical flasks**, each containing **100 mL of MB solution (500 mg/L)**. Different masses of adsorbents—**0.4 g, 0.5 g, 0.6 g, 0.7 g, and 0.8 g**—were added to individual flasks. All samples were agitated using a **flask shaker for 100 minutes** at room temperature to maintain uniform contact between the dye and adsorbents.

Determination of Dye Concentration

After agitation, samples were centrifuged at **7000 rpm for 15 minutes** to remove suspended particles. The absorbance of the supernatant was measured using a **Photoelectric Colorimeter at 315 nm and 515 nm**. The percentage removal of dye was calculated using the formula:

$$\text{\% Removal} = \frac{C_0 - C_f}{C_0} \times 100$$

where

C_0 = initial dye concentration (mg/L)

C_x = final dye concentration after adsorption (mg/L)

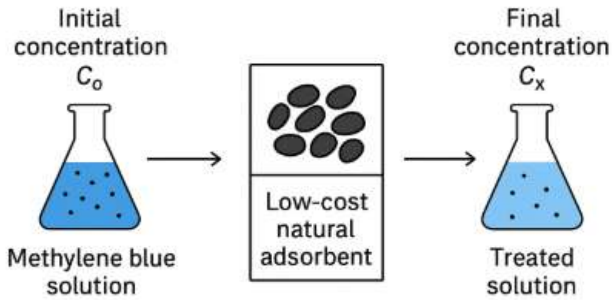

Fig 1. Assessment of adsorbent dosage

RESULTS AND DISCUSSIONS:

Effect of Adsorbent Dosage on Dye Removal

The experimental results clearly demonstrate that adsorbent dosage significantly affects the removal efficiency of methylene blue for both groundnut shell and tea waste. At a constant initial dye concentration of 500 mg/L, the adsorbent masses influenced the number of available surface sites and thereby the adsorption capacity.

For groundnut shell, the maximum dye removal of 94% occurred at 0.4 g, indicating that this dosage provides optimal availability of active binding sites without causing particle saturation or aggregation. As the dosage increased beyond 0.4 g, removal efficiency decreased to 52% at 0.7 g due to possible overlapping of adsorption sites or reduced driving force for mass transfer.

For spent tea waste, the highest removal efficiency of 74% occurred at a dosage of 0.7 g, suggesting that tea waste requires a higher amount to provide sufficient surface area for effective adsorption due to its lower porosity compared to groundnut shell. At lower dosages (0.4–0.6 g), tea waste achieved dye removal between 60–80%, showing moderate but consistent adsorption capabilities.

Overall, the results confirm that adsorbent dosage is a critical parameter and that groundnut shell is more efficient than tea waste at lower dosages, while tea waste achieves moderate efficiency at higher masses. The adsorption behavior is influenced by factors such as pore structure, surface functional groups, and particle aggregation at higher dosages.

CONCLUSION

This study demonstrates that low-cost natural adsorbents, specifically groundnut shell and spent tea waste, are effective for removing methylene blue dye from aqueous solutions. The results reveal that adsorbent dosage plays a vital role in adsorption efficiency. Groundnut shell exhibited a maximum removal of 94% at 0.4 g, making it a highly efficient biosorbent even at low dosage levels. Spent tea waste achieved its highest removal of 74% at 0.7 g, indicating that a higher dosage is required for optimal performance.

Overall, groundnut shell proved to be the more promising adsorbent due to its superior adsorption capacity and structural properties. The study confirms the potential of agricultural waste materials as sustainable and economical alternatives for dye removal in wastewater treatment.

FUTURE SCOPE

Future research can be expanded in the following ways:

- Optimization of Parameters: Investigate the effects of pH, temperature, contact time, and particle size on dye removal efficiency to identify optimal operating conditions.
- Isotherm and Kinetic Modeling: Apply models such as Langmuir, Freundlich, pseudo-first-order, and pseudo-second-order to better understand adsorption mechanisms.
- Thermodynamic Studies: Evaluate adsorption spontaneity, enthalpy, and entropy changes for industrial applicability.
- Desorption and Regeneration: Examine the reusability of groundnut shell and tea waste to determine cost-effectiveness in large-scale operations.
- Characterization Techniques: Utilize FTIR, SEM, BET, and XRD for detailed surface analysis of the adsorbents before and after adsorption.
- Real Effluent Testing: Validate performance using actual textile wastewater to assess practical applicability.
- Development of Activated Carbon: Explore chemical/thermal activation of these wastes to enhance their adsorption capacity further.

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