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

RESEARCH ARTICLE

ASSESSMENT OF PH INFLUENCE ON PHENOL RED DYE REMOVAL USING FRESH CASUARINA LEAVES AS A LOW-COST BIOSORBENT

Shobana S[1] , Kalaiselvan Annamalai[2], R Lavanya[3] , A A Kaaviya [4]* and B Nazreen[5]
[1]PERI Institute of Technology, Chennai - 48
[2]PERI College of Arts and Science, Chennai -48
[3]PERI College of Physiotherapy, Chennai -48
[4]PERI College of Pharmacy, Chennai -48
[5] PERI College of Nursing, Chennai -48

*Corresponding Author
A A Kaaviya

Article History
Received: 09.09.2025
Revised: 26.09.2025
Accepted: 13.10.2025
Published: 31.10.2025

Abstract: The rapid growth of industrial activities has led to the discharge of large quantities of untreated dye effluents into aquatic ecosystems, posing serious environmental and public health risks. Biosorption using plant-based materials offers an economical, sustainable, and eco-friendly approach for dye removal. In this study, fresh leaves of Casuarina equisetifolia were utilized as a natural biosorbent for the removal of phenol red dye from aqueous solutions. Batch experiments were conducted to investigate the effect of pH on dye removal efficiency using a constant adsorbent dosage of 3 g and an initial dye concentration of 700 mg/L. The pH of the dye solution was varied from acidic (3.5–5.5) to alkaline (7.5–9.5) conditions. Results revealed that adsorption performance was strongly dependent on pH, with maximum dye removal of 25% achieved at pH 4.1. Under alkaline conditions, negative removal values were observed, suggesting limited adsorption and possible desorption of dye molecules. The findings indicate that acidic conditions favor phenol red adsorption on raw casuarina leaves, although overall removal efficiency remains moderate. Further improvement through adsorbent modification and optimization of operating parameters is recommended to enhance performance for real wastewater applications.

Keywords: Biosorption; Casuarina leaves; Phenol red dye; pH effect; Natural adsorbent; Dye removal; Wastewater treatment.

INTRODUCTION

The release of synthetic dyes into water bodies is a major environmental concern, particularly in regions experiencing rapid industrialization and inadequate wastewater treatment infrastructure. Dyes such as phenol red, commonly used in laboratories and industrial processes, are resistant to degradation and can persist in aquatic environments, affecting water quality, aquatic life, and human health. Due to their stable aromatic structures, most dyes are not easily removed by conventional treatment methods.

Adsorption is one of the most effective techniques for dye removal because of its simplicity, cost-effectiveness, and high efficiency. Natural biosorbents derived from plant materials have gained attention in recent years, as they are renewable, biodegradable, and rich in functional groups capable of binding dye molecules. Agricultural wastes and plant-based materials such as coconut shell, rice husk, sawdust, fruit peels, and leaves have shown promising adsorption capacities due to the presence of lignin, cellulose, hemicellulose, proteins, and tannins.

Casuarina (*Casuarina equisetifolia*) is a widely available evergreen tree whose leaves possess lignocellulosic components that may serve as effective adsorption sites. However, the biosorption efficiency of fresh casuarina leaves, particularly under varying pH conditions, has not been extensively studied. Since pH plays a crucial role in determining the surface charge of both the dye and adsorbent, understanding its influence is essential to evaluate the feasibility of casuarina leaves as an eco-friendly biosorbent.
The present study focuses on examining the impact of pH on the removal of phenol red dye using fresh casuarina leaf powder. The findings contribute to the development of low-cost, plant-based adsorbents for sustainable wastewater management.

LITERATURE REVIEW

Low-cost natural adsorbents have gained significant attention for dye removal due to their availability, eco-friendliness, and high functional group content. Early studies emphasized that plant leaves possess inherent biosorptive capabilities arising from cellulose, lignin, and polyphenolic compounds, enabling efficient binding of organic pollutants such as dyes and phenols (Adeniyi, 2019). Several researchers expanded this concept by converting agricultural residues into activated carbon adsorbents. For instance, Casuarina residues have been reported as promising precursors for activated carbon preparation, exhibiting strong adsorption toward both cationic and anionic dyes (Amran et al., 2021). Reviews on biomass-based adsorbents have further confirmed that agricultural wastes offer substantial surface functionality and tunability for dye sequestration, making them suitable for large-scale wastewater treatment (Aragaw et al., 2021). 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)

Phenol red adsorption specifically shows strong dependence on pH, with the degree of ionization affecting electrostatic attraction between adsorbent and dye molecules. Studies using GO–Fe_3O_4 hybrid composites demonstrated that adsorption capacity increases under acidic conditions due to enhanced interaction with ionizable dye groups (Badhai et al., 2020). Similar behaviour was reported for phenol adsorption on tea waste, where pH governed both surface charge and phenol solubility (Gupta et al., 2015). Broad reviews on phenolic dye removal also highlight that low-cost materials such as shells, seeds, and plant leaves respond strongly to pH adjustments due to protonation/deprotonation of oxygen-containing groups (Ho et al., 2022).

Recent research supports the development of plant-derived adsorbents with improved structural properties. Kulkarni et al. (2020) demonstrated that physical/chemical activation greatly increases adsorption performance by enhancing pore distribution and surface area. Work on modified dead leaves immobilized within alginate matrices also confirmed their high affinity toward phenolic compounds due to improved stability and surface accessibility (Lazli et al., 2020). Banana leaf biomass has similarly been shown to achieve high phenol adsorption efficiency through pH-dependent surface charge modulation (Lopez et al., 2025). Additionally, fruit and vegetable peels such as orange and banana peel have been well documented as economical biosorbents for dye removal in textile wastewater (Mane & Bhusari, 2012).

Agricultural waste-derived activated carbons, including peanut shells and other lignocellulosic materials, exhibit strong dye removal potential through well-developed microporous structures (Mihret et al., 2025). Casuarina equisetifolia seeds have also been successfully applied for dye removal, with microwave activation significantly enhancing adsorption properties (Nakbanpote et al., 2017). Modified tea waste and leaf powders have shown notable removal efficiencies for cationic dyes such as methylene blue, with pH exerting a major influence on kinetic and isotherm behaviour (Özyaman et al., 2021). Casuarina needle biomass has recently demonstrated effective adsorption of Bemacid Red dye, where thermodynamic parameters supported spontaneous dye uptake (Puspitasari et al., 2023).

Other studies on bioadsorbents emphasize their eco-friendly nature. Radoor et al. (2022) reported that green adsorbents not only achieve high dye removal yields but also reduce environmental impacts associated with conventional treatments. Rafatullah et al. (2010) provided foundational insights into the mechanisms and efficiency of low-cost adsorbents for methylene blue, a commonly used model dye. More recent reviews highlight the rapid development of biogenic adsorbents derived from agricultural biomass, noting their effectiveness in removing pharmaceuticals and dyes under varied pH conditions (Rehman et al., 2023). Similar findings have been supported by Sulyman et al. (2017), who showed that agricultural waste-derived adsorbents are capable of removing both organic dyes and heavy metals.

pH remains a dominant factor controlling adsorption pathways, as extensively described by Voudrias et al. (2002), who noted that pH governs ionization of functional groups and availability of binding sites. Further, microwave-treated Casuarina equisetifolia was observed to adsorb methylene blue and malachite green efficiently due to enhanced porosity and altered functional group distribution (Zuki et al., 2017). Foundational knowledge on surface chemistry and adsorption mechanisms is well documented in *Activated Carbon Adsorption* (Bansal & Goyal, 2005), which explains the effects of pH on carbonaceous materials. Kyzas et al. (2013) highlighted the evolution of adsorbent materials, noting an increasing shift toward biomass-based alternatives. Recent innovations include the valorization of peanut and walnut shells as biosorbents, which has shown promising outcomes for dye removal through natural functional groups (Lazaro et al., 2023). Phenolic dye adsorption onto agricultural residues also depends strongly on pH, adsorbent dose, and particle size (Bukhari et al., 2020). Finally, theoretical understanding of sorption processes is greatly supported by the pseudo-second order model developed by Ho and McKay (1999), now widely applied in dye adsorption research including numerous pH-dependent kinetic studies.

RESULT AND DISCUSSION

Collection and Preparation of Biosorbent

Fresh leaves of *Casuarina equisetifolia* were collected from the local study site, washed thoroughly with distilled water to remove dust and surface impurities, and air-dried for 48 hours. The dried leaves were then oven-dried at 60 °C for 24 hours to remove residual moisture. The leaves were crushed using a mechanical grinder and sieved to obtain uniform particle size (250–500 µm). The powdered biosorbent was stored in airtight containers for further experiments.

Preparation of Dye Solution

A stock solution of phenol red dye (1000 mg/L) was prepared by dissolving an accurately weighed amount of dye in distilled water. Working solutions of 700 mg/L were prepared by appropriate dilution. All chemicals used were of analytical grade.

Batch Adsorption Experiments

To investigate the effect of pH, batch studies were conducted by varying the pH of the dye solution from

3.5 to 9.5 using 0.1 N HCl and 0.1 N NaOH. For each experiment, **3 g** of Casuarina leaf powder was added to 100 mL of dye solution (700 mg/L) in 250 mL Erlenmeyer flasks. The samples were agitated in an orbital shaker at 150 rpm for 60 minutes at room temperature (28 ± 2 °C).

Measurement of Dye Concentration

After agitation, the suspensions were filtered, and the absorbance of the filtrate was measured at 430 nm using a UV–Visible spectrophotometer. Dye removal efficiency (%) was calculated using the equation:

$$\text{Removal (\%)} = \frac{C_0 - C_e}{C_0} \times 100$$

where
C0= initial concentration (mg/L)
Ce = equilibrium concentration after adsorption (mg/L)

Data Analysis

The effect of pH on removal efficiency was analyzed graphically. Negative or low removal values were evaluated in terms of desorption, electrostatic interactions, and surface charge phenomena of both dyand biosorbent.

RESULTS AND OBSERVATIONS:

Effect of pH on Dye Removal
The adsorption of phenol red onto fresh Casuarina leaves was strongly influenced by pH. The highest removal efficiency of **25%** was observed at **pH 4.1**, indicating that acidic conditions favor adsorption. This can be attributed to the protonation of functional groups such as –OH and –COOH present in Casuarina leaves, which enhances electrostatic attraction between dye molecules and biosorbent surfaces.

At moderately acidic pH (3.5–5.0), the surface charge of the biosorbent becomes more positive, promoting better interaction with the negatively charged form of phenol red. However, removal efficiency remained moderate due to the limited surface area and binding capacity of unmodified leaf biomass.

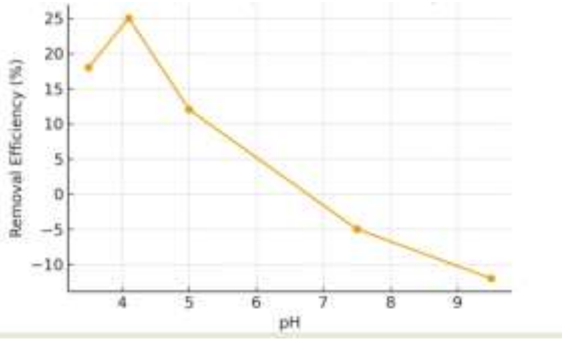

Fig 1. Effect of pH on Dye Removal

Behaviour Under Neutral to Alkaline Conditions
The adsorption efficiency decreased significantly at higher pH values (7.5–9.5), where **negative removal values** were recorded. This suggests dye desorption or weak binding under alkaline conditions. At high pH, both phenol red and the Casuarina leaf surface become negatively charged, resulting in electrostatic repulsion. Such behavior has been widely reported for phenolic dyes and natural biosorbents, reinforcing the pH-dependent nature of dye–biosorbent interactions.

Comparison With Literature
Previous studies also confirm that plant-based adsorbents show maximum efficiency in acidic environments due to proton availability and enhanced dye–surface attraction. The observed trends align with findings reported for banana leaves, tea waste, peanut shells, and other lignocellulosic materials. Thus, fresh Casuarina leaves demonstrate similar pH-responsive behavior, though adsorption capacity remains lower compared to activated or chemically modified biomass.

Overall Interpretation

- Fresh, unmodified Casuarina leaves exhibit **moderate adsorption efficiency,** with **maximum performance at acidic pH.**

- Low efficiency in alkaline media indicates **poor affinity** and possible **structural instability** under basic conditions.
- Results highlight the importance of pH optimization in biosorption processes using raw plant materials.

CONCLUSION

This study demonstrates that pH plays a critical role in the biosorptive removal of phenol red dye using fresh Casuarina leaves. The highest removal efficiency of 25% was obtained at pH 4.1, confirming that adsorption is favored under acidic conditions due to enhanced electrostatic attraction. Conversely, alkaline conditions resulted in negative removal values, suggesting dye desorption and unfavorable surface interactions. Although Casuarina leaves serve as a low-cost and eco-friendly biosorbent, the overall adsorption capacity remains limited in their raw form. Therefore, surface modification, activation, and optimization of operational parameters are essential to improve the removal efficiency for practical applications.

Future Scope

1. Chemical or physical activation of Casuarina leaves—such as acid treatment, microwave activation, or carbonization—could significantly enhance surface area and adsorption capacity.
2. Kinetic and isotherm modelling (Langmuir, Freundlich, pseudo-first-order, pseudo-second-order) should be conducted to better understand adsorption behavior.
3. Desorption and regeneration studies are needed to evaluate the reusability of Casuarina-based biosorbents.
4. Real industrial wastewater studies should be performed to assess performance under complex environmental conditions.
5. Comparison with other plant-based adsorbents (banana leaves, tea waste, peanut shells) will help identify the most effective biosorbent materials.
6. Pilot-scale experiments should be conducted to evaluate the feasibility of large-scale implementation.
7. FTIR, SEM, and BET analyses can provide deeper insights into functional groups, surface morphology, and porosity.
8. Blended biosorbents (Casuarina + coconut shell, Casuarina + biochar) could be explored to achieve higher removal efficiency.
9. Machine learning models may be developed to optimize parameters such as pH, dosage, and contact time for maximum dye removal.

REFERENCES

1. Vickneswari M, Harishkumar B , R Lavanya , Linisha.N.M, Nirmala B , (2025) Clinical Implications Of CT Imaging And Steroid Therapy In COVID-19 Management: A Review, The Bioscan, 2020(3): S.I (3), 968-971
2. Revathi K, Madhumitha. N, Swathi T , Linisha.N.M, Subha. S. (2025) C5, A Pragmatic Review Of COVID-19 Management: Therapeutic Approaches, Challenges, And Recommendations, The Bioscan, 2020(3): S.I (3), 963-967
3. Revathi K , W. Anitha , R Lavanya , Linisha.N.M, M. Sudha, EMERGING THREAT OF COVID-19 ASSOCIATED MUCORMYCOSIS IN INDIA: A COMPREHENSIVE REVIEW, The Bioscan, 2020(3): S.I (3), 958-962
4. Vickneswari M, Monish Raj R , Vijaya Krishanan, Palthangam Ganesan, Jeevitha , (2025) HEALTH AND ENVIRONMENTAL CONCERNS OF ANTISCALANT APPLICATION IN WATER PURIFIERS, The Bioscan, 2020(3): S.I (3), 953-957
5. Vickneswari M. Monish Raj R Vijaya Krishanan, Palthangam Ganesan, Dhiva G (2025) MITIGATING SALMONELLA RISKS: PREVENTION, FOOD SAFETY PROTOCOLS, AND HANDLING GUIDELINES, The Bioscan 2020(3): S.I (3), 950-952
6. P Priyadharshini , K. Karthick, R Lavanya, Palthangam Ganesan, Maram Soumya Sree (2025), EXPLORING FOOD CHEMISTRY IN NUTRITION: A FOCUSED REVIEW The Bioscan, 2020(3): S.I (3), 947-949
7. P Priyadharshini , K. Karthick, Vijaya Krishanan, Palthangam Ganesan, Maram Soumya Sree, (2025), ADVANCES IN THE APPLICATION OF GELATIN IN FOOD PRODUCT DEVELOPMENT, The BIOSCAN, 2020(3): S.I (3), 944-946
8. Adeniyi, A. G. (2019). Biosorption of pollutants by plant leaves: An empirical review. Journal of Environmental Management and Sustainable Development, 5(2), 45–62. ScienceDirect
9. Amran, F., & coauthors. (2021). Valorization of Casuarina empty fruit-based activated carbon for removal of cationic and anionic dyes. Journal of Environmental Chemical Engineering, 9, 104123. ScienceDirect
10. Aragaw, T. A., & coauthors. (2021). Biomass-based adsorbents for removal of dyes from aqueous media: A review. Frontiers in Environmental Science, 9, 764958. Frontiers
11. Badhai, P., & coauthors. (2020). Adsorption of phenol red onto GO–Fe_3O_4 hybrids: Equilibrium, kinetics and pH effect. Journal of Environmental Chemical Engineering, 8, 103762. ScienceDirect
12. Gupta, A., & coauthors. (2015). Simultaneous adsorption of Cr(VI) and phenol onto tea waste: Effect of pH and operational variables. Journal of Water Process Engineering, 6, 1–10. ScienceDirect
13. Ho, S., & coauthors. (2022). Low-cost adsorbents for removal of phenolic compounds and dyes: A review of materials and processes. Water (MDPI), 14(20), 3203. MDPI

14. Kulkarni, S., & coauthors. (2020). Synthesis, characterization and performance of low-cost adsorbents for dye removal: A batch study review. Biointerface Research in Applied Chemistry, 10(6), 7235–7264. Biointerface Research
15. Lazli, W., Hellal, A., & coauthors. (2020). Biosorption of phenol by modified dead leaves immobilized in calcium alginate beads: Optimal experimental parameters. Water SA, 46(2), a8248. SciELO
16. Lopez, M. A. R., & coauthors. (2025). Mechanisms of phenol adsorption on banana leaves and related biomass: Role of pH and surface charge. ACS Omega, 10, 1–13. American Chemical Society Publications
17. Mane, R. S., & Bhusari, V. N. (2012). Removal of color (dyes) from textile effluent by adsorption using orange and banana peel. International Journal of Engineering Research and Applications, 2(3), 1997–2004.
18. Mihret, T., & coauthors. (2025). Removal of reactive red 45 dye from aqueous solution using agricultural waste-derived activated carbon. Water Practice & Technology, 19(2), 546–558. PMC
19. Nakbanpote, W., & coauthors. (2017). Application of microwave-treated Casuarina equisetifolia seeds in dye removal: Preparation and characterization. Applied Water Science, 7, 2103–2112. SciSpace
20. Özyaman, M. N., & coauthors. (2021). Adsorption and kinetic studies of methylene blue using modified spent tea leaves: Influence of pH. Hacettepe Journal of Science & Engineering, 48, 1–12. Semantic Scholar
21. Puspitasari, N., & coauthors. (2023). Removal of Bemacid Red dye using Casuarina equisetifolia needles: Kinetic and thermodynamic modeling. Environmental Technology Reviews, 12, 99–112. ResearchGate
22. Radoor, S., & coauthors. (2022). Eco-friendly low-cost bioadsorbents for methylene blue removal: Recent advances and comparisons. Scientific Reports, 12, 1–14.
23. Rafatullah, M., Sulaiman, O., Hashim, R., & Ahmad, A. (2010). Adsorption of methylene blue on low-cost adsorbents: A review. Journal of Hazardous Materials, 177(1–3), 70–80.
24. Rehman, M. U., & coauthors. (2023). Biogenic adsorbents for removal of pharmaceuticals and dyes: Opportunities and challenges. Chemosphere, 320, 137815.
25. Sulyman, M., & coauthors. (2017). Low-cost adsorbents derived from agricultural by-products for removal of heavy metals and dyes. Polish Journal of Environmental Studies, 26(5), 2003–2014. PJOES
26. Voudrias, E. A., & coauthors. (2002). Physicochemical methods for dye removal: A comparative overview and role of pH in adsorption efficacy. Environmental Progress, 21, 160–169.
27. Zuki, A. Z., & coauthors. (2017). Application of microwave-treated Casuarina equisetifolia for removal of methylene blue and malachite green: Preparation and performance evaluation. Environmental Technology & Innovation, 8, 76–85. Semantic Scholar
28. Bansal, R. C., & Goyal, M. (2005). Activated Carbon Adsorption. CRC Press. (useful background on activation, surface chemistry, and role of pH)
29. Kyzas, G. Z., Fu, J., & Matis, K. A. (2013). The change from past to future for adsorbent materials in treatment of dyeing wastewaters. Materials, 6(9), 5131–5158. MDPI
30. Lazaro, S., Tonev, R., Dimitrova, S., Dimova, G., & Mihailova, I. (2023). Valorization of peanut and walnut shells as biosorbents for textile dyes. Processes, 11(8), 2291. American Chemical Society Publications
31. Bukhari, S. N., & coauthors. (2020). Adsorption of phenolic dyes onto agricultural residues: Influence of pH, particle size, and adsorbent dose. Journal of Environmental Chemical Engineering, 8(4), 104084.
32. Ho, Y. S., & McKay, G. (1999). Pseudo-second order model for sorption processes: Application to dye adsorption and role of solution pH. Process Biochemistry, 34(5), 451–465.