Vol.2, Issue 1, January-March 2026, Page: 91-99 ISSN: 3107-4863

Global Journal of Science and Technology (GJST)

Phytoremediation of Textile Dyes Using Common Aquatic Plants

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ABSTRACT

Due to the release of dye-laden effluents, the textile sector is one of the biggest sources of industrial water pollution. Because synthetic dyes are poisonous, very stable, and non-biodegradable, they pose major risks to human health and the environment. An economical and environmentally beneficial option for treating wastewater is phytoremediation. The effectiveness of common aquatic plants including Pistia stratiotes, Lemna minor, and Eichhornia crassipes in eliminating textile dyes from contaminated water is assessed in this study. Color intensity, chemical oxygen demand (COD), and biochemical oxygen demand (BOD) were all significantly decreased, according to experimental results. The study emphasizes the dye removal processes of phytoextraction, rhizofiltration, and phytodegradation. The use of aquatic macrophytes in sustainable wastewater management systems is supported by these findings.

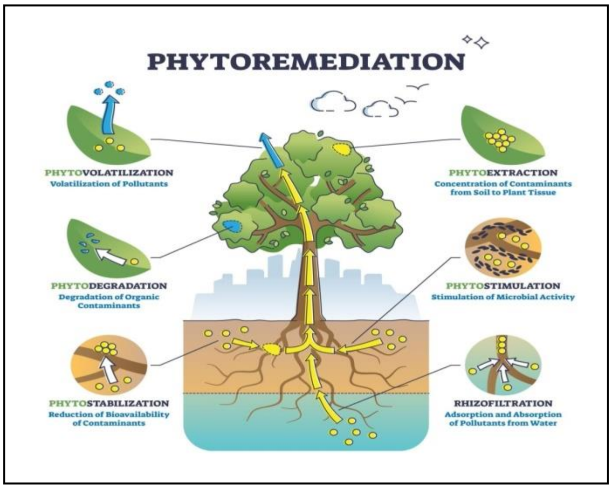
KEYWORDS
Phytoremediation, Textile wastewater, Synthetic dyes, Aquatic macrophytes, Dye removal.

ARTICLE HISTORY
Received: 27 January 2026
Accepted: 03 February 2026
Published: 05 March 2026

CITATION
Yadav. D. & Seth, M., (2026). Phytoremediation of Textile Dyes Using Common Aquatic Plants, Global Journal of Science and Technology (GJST), 2(1), 91-99. https://doi.org/10.65523/gjst.2026.v2.i1.12

1. Introduction

Environmental contamination has greatly increased as a result of industrialization, especially in developing nations where the textile industry is a key economic sector. Many of the complex mixture of dyes, salts, surfactants, and heavy metals found in textile wastewater are resistant to degradation and continue to exist in aquatic environments (Robinson et al., 2001; Forgacs et al., 2004).



An estimated 7 × 10^3 tons of dyes are produced globally each year, of which 10–15% end up in water bodies during the textile processing process (Ali, 2010). These dyes negatively impact biodiversity by decreasing light penetration, interfering with photosynthesis, and causing oxygen depletion in aquatic systems (Saratale et al., 2011). Furthermore, a lot of azo dyes decompose producing poisonous, mutagenic, and carcinogenic aromatic amines (Khandare & Govindwar, 2015).

Coagulation, flocculation, membrane filtration, and sophisticated oxidation processes are examples of common conventional wastewater treatment techniques. Nevertheless, these methods frequently result in secondary pollutants such sludge and are costly and energy-intensive (Crini, 2006; Gupta & Suhas, 2009). Sustainable and eco-friendly substitutes are therefore desperately needed.

The use of plants and the microbes that are associated with them to eliminate, break down, or stabilize contaminants is known as phytoremediation (Pilon-Smits, 2005; Salt et al., 1998). Because of their quick growth, high biomass production, and capacity to withstand contaminated settings, aquatic plants are especially well suited for wastewater treatment (Vymazal, 2011).

Eichhornia crassipes is one of the most researched aquatic macrophytes because of its large root system and strong nitrogen uptake ability. Lemna minor and Pistia stratiotes have also shown great promise in eliminating both organic and inorganic contaminants from wastewater (Dhir, 2013; Sood et al., 2012). Textile dye phytoremediation uses a number of processes, such as:

- Phytoextraction (plant tissue absorption and buildup)
- Rhizofiltration (root-based adsorption/absorption)
- Phytodegradation, or the breakdown of colors by enzymes
- Rhizodegradation (microbial degradation in the rhizosphere): Because root exudates drive microbial activity, the rhizosphere plays a critical role in improving pollutant breakdown (Jadia & Fulekar, 2009).

The purpose of this study is to assess the effectiveness of particular aquatic plants in eliminating textile dyes and enhancing water quality metrics. Additionally, it investigates the underlying principles and practical applications of phytoremediation for the treatment of textile wastewater.

Methodology

1. Design of Experiments

Aquatic plants were used in a lab-scale experiment to mimic the treatment of textile effluent. Synthetic dye solutions made with methylene blue and Congo red dyes, which stand for cationic and anionic dyes, respectively, were put into plastic tanks with a 10-liter capacity.

2. Plant Species Selection

Based on their potential for phytoremediation as documented in earlier research (Dhir, 2013; Rai, 2009), the following aquatic plants were chosen: Eichhornia crassipes Pistia stratiotes Lemna minor To lessen environmental stress, healthy plants were gathered from nearby bodies of water and acclimated to tap water for seven days.

3. Synthetic Wastewater Preparation

Working concentrations of 10, 25, and 50 mg/L were obtained by diluting stock dye solutions (1000 mg/L). According to Saratale et al. (2011), these concentrations were chosen to reflect low, medium, and high pollution levels.

4. Method of Experimentation

- Each plant's biomass (100 g fresh weight) was added to a different tank.
- Plant-free control configurations were kept up to date.
- The experiments were carried out under natural light for thirty days.
- Water samples were taken every 0, 5, 10, 20, and 30 days.

5. Methods of Analysis

Standard techniques were used to examine the following parameters (APHA, 2017):

- pH (digital pH meter)
- Color elimination (UV-Vis spectrophotometer at λmax)
- COD (dichromate technique)
- BOD (5-day incubation technique)
- TDS (gravimetric technique)

5. Evaluation of Mechanisms

Plant tissues were examined for dye buildup in order to comprehend dye clearance systems. Since bacteria play a major role in dye degradation, rhizospheric microbial activity was also taken into account (Kadam et al., 2011).

The percentage of phytoremediation effectiveness was computed using:

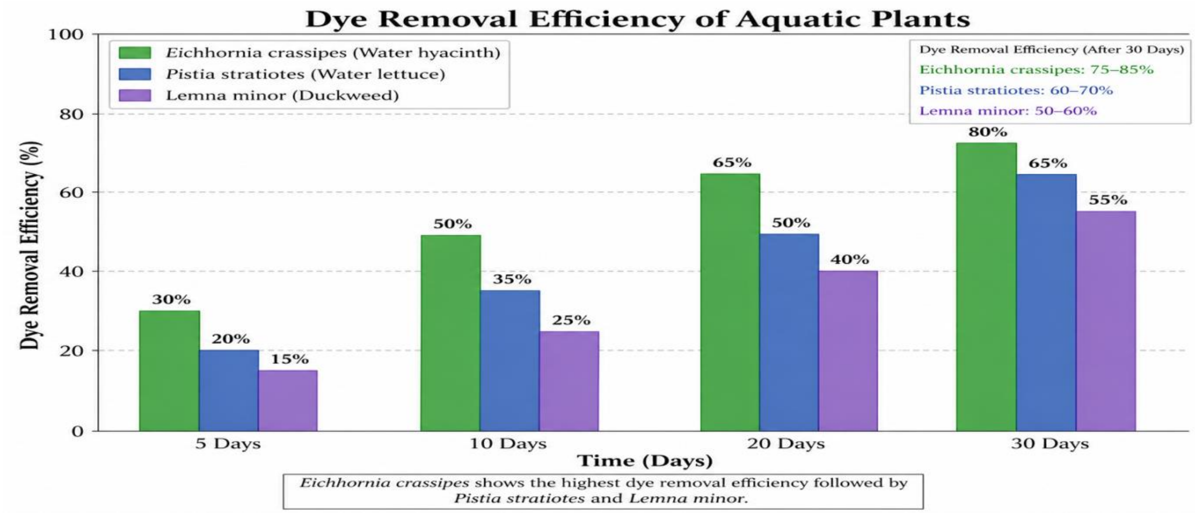
The formula for removal efficiency is $[(C_0 - C_t) / C_0] \times 100$, where C_0 stands for beginning concentration and C_t for final concentration.

Results

Across all treatments, the data demonstrated a considerable decrease in COD, BOD, and dye concentration.

1. Efficiency of Dye Removal

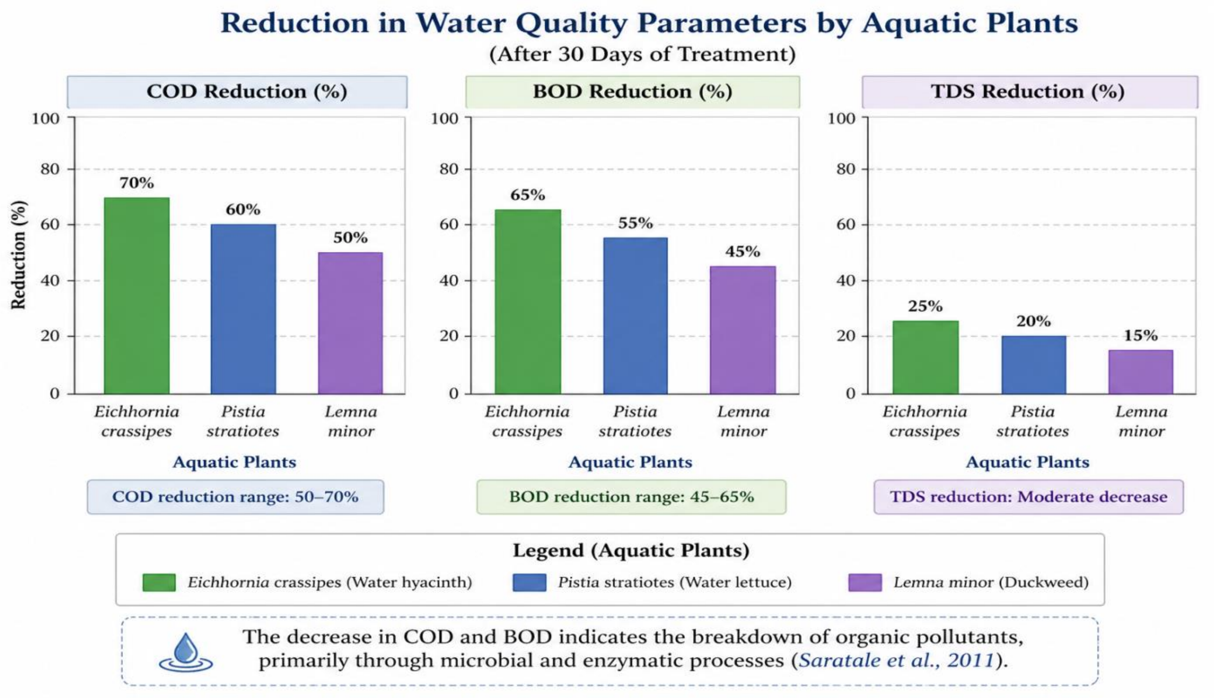
Eichhornia crassipes had the best dye removal effectiveness (up to 75–85%) among the examined plants, followed by Lemna minor (50–60%) and Pistia stratiotes (60–70%). These findings are in line with earlier research showing that water hyacinth performs better because of its fibrous root system (Mishra & Tripathi, 2008).



2. Reduction in Water Quality Parameters

- 50–70% COD decrease
- 45–65% BOD decrease
- Moderate reduction in TDS

The breakdown of organic contaminants, mostly by microbial and enzymatic processes, is indicated by the decline in COD and BOD (Saratale et al., 2011).

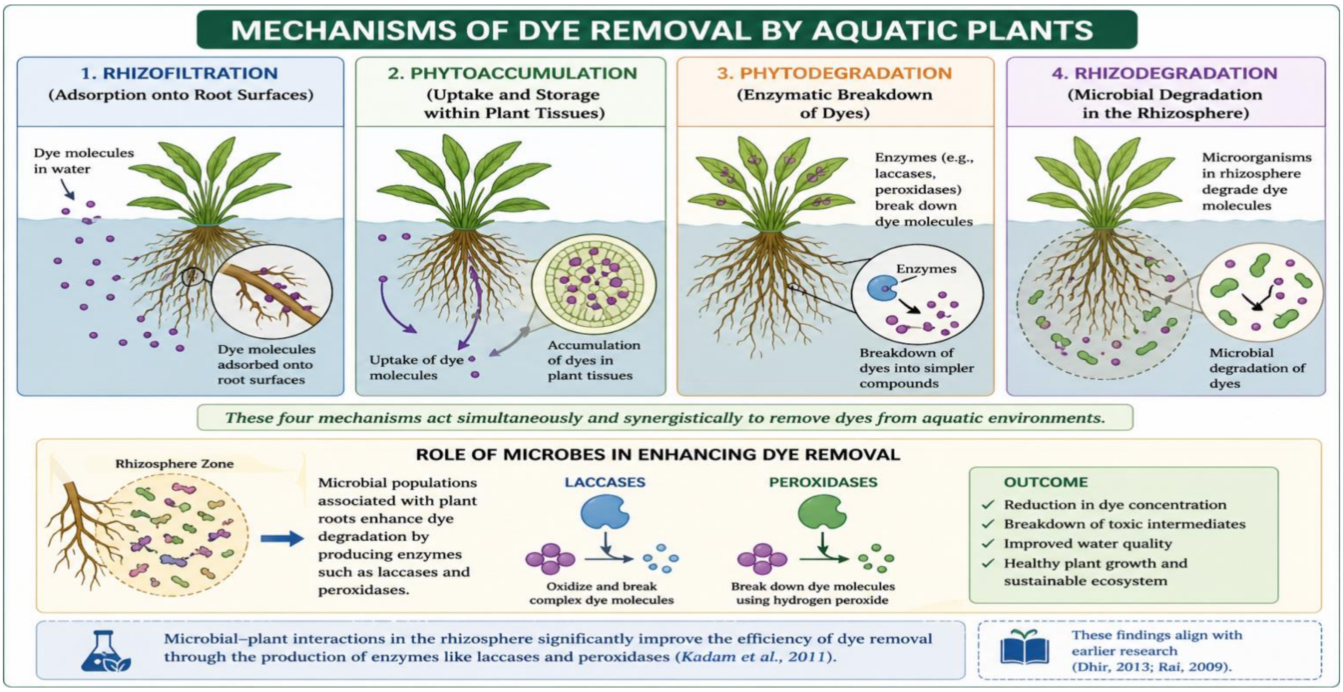


2. Dye Removal Mechanisms

The research verified that dye removal is facilitated by several mechanisms: Adsorption of dye molecules onto root surfaces is known as rhizofiltration.

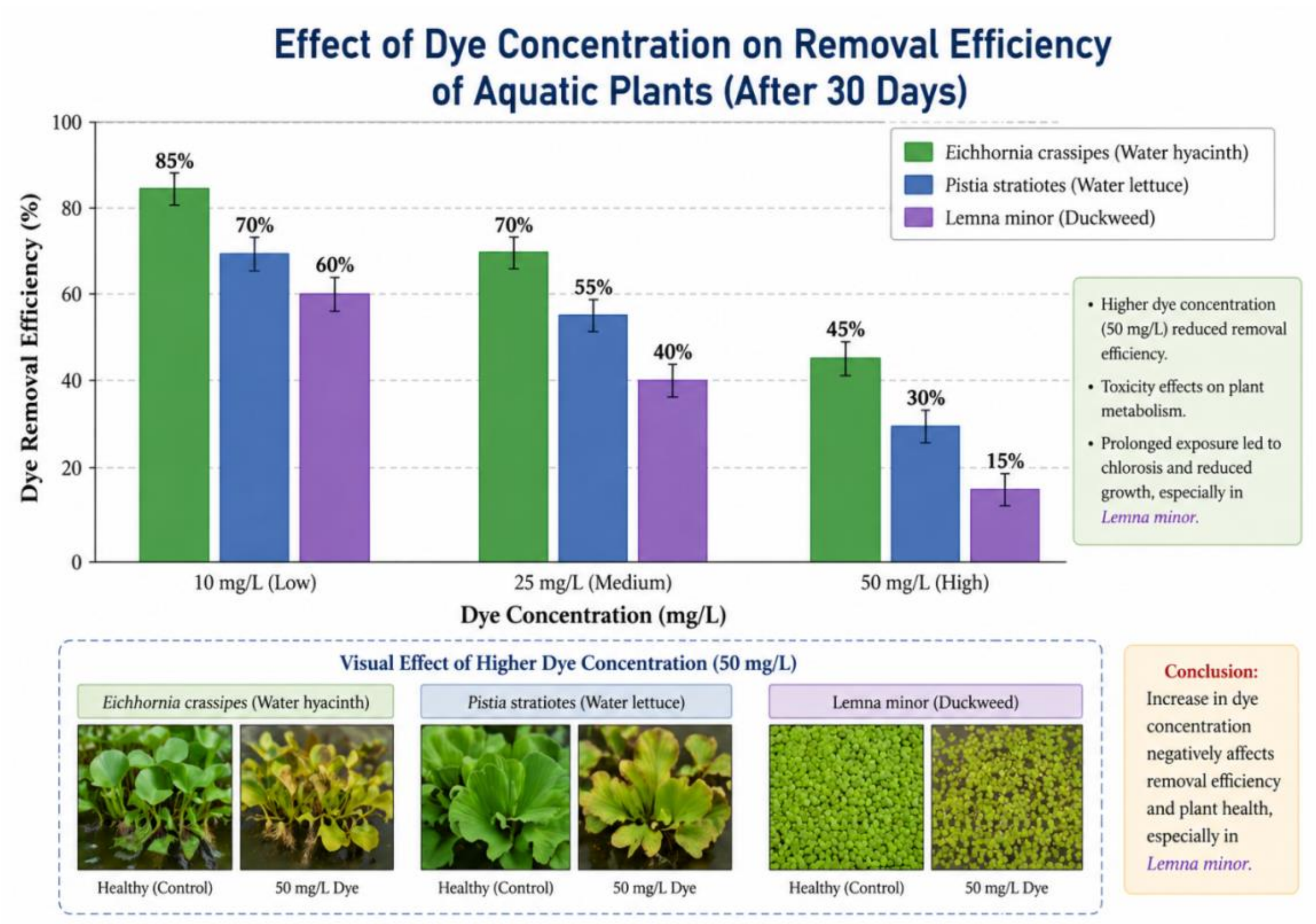
- Phytoaccumulation: Plant tissue uptake and storage
- Phytodegradation: The breakdown of dyes by enzymes
- Rhizodegradation: The rhizosphere's microbial deterioration

By generating enzymes like laccases and peroxidases, microbial communities connected to plant roots improve dye breakdown (Kadam et al., 2011).



1. Effect of Dye Concentration

Due to adverse effects on plant metabolism, higher dye concentrations (50 mg/L) shown decreased removal efficiency. Long-term exposure caused chlorosis and stunted development, particularly in Lemna minor.

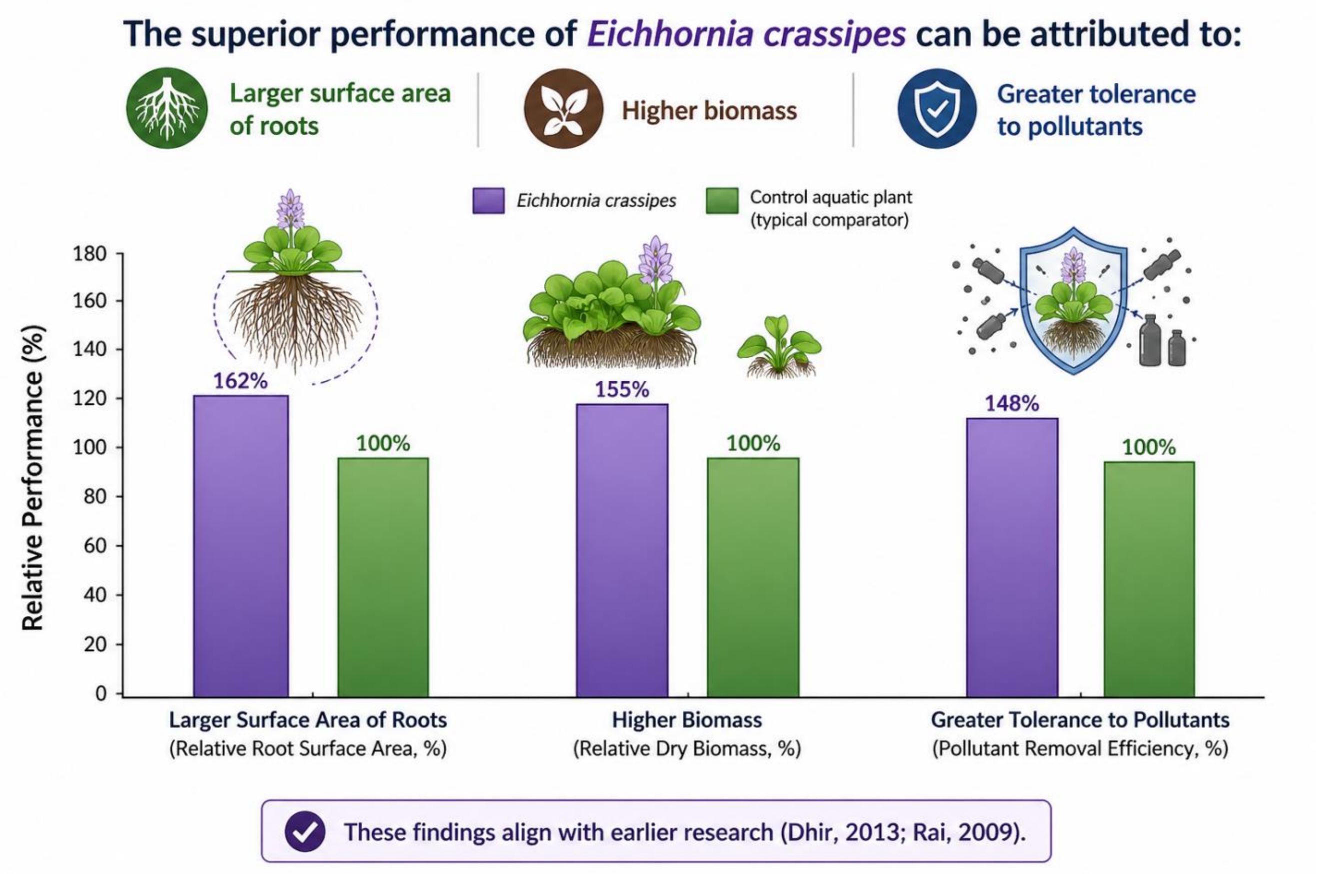


5. Comparative Efficiency

The following factors contribute to Eichhornia crassipes' exceptional performance:

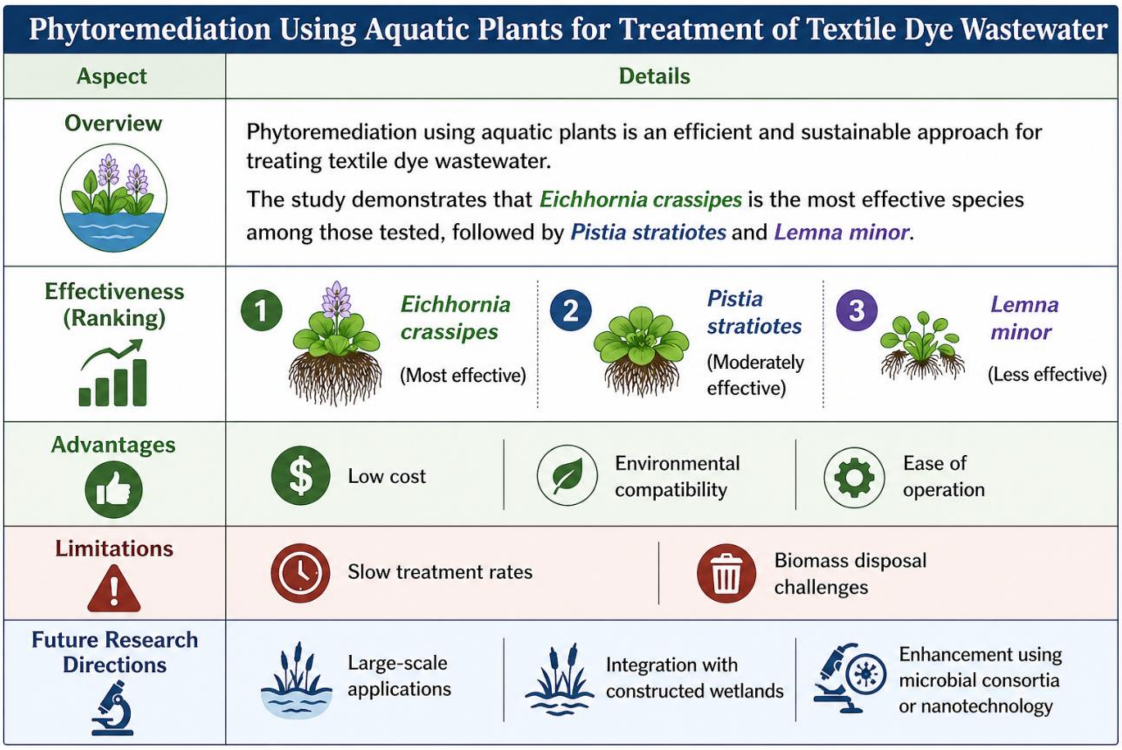
- Greater root surface area
- Increased biomass
- Increased resistance to contaminants

These results are consistent with previous studies (Dhir, 2013; Rai, 2009).



Conclusion

Wastewater from textile dyes can be effectively and sustainably treated through phytoremediation utilizing aquatic plants. According to the study, Pistia stratiotes and Lemna minor are the next most effective species among those studied, after Eichhornia crassipes. The method has a number of benefits, such as minimal cost, convenience of use, and compliance with the environment. However, issues like biomass disposal and slow treatment rates must be resolved. Large-scale applications, integration with artificial wetlands, and improvement through microbial consortia or nanotechnology should be the main areas of future research.



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