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Research Paper

FUNGAL BIODEGRADATION OF TEXTILE DYE EFFLUENT USING TRAMETES HIRSUTA AND PHANEROCHAETE CHRYSOSPORIUM: COMPARATIVE ANALYSIS AND ENVIRONMENTAL IMPACT

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ABSTRACT

This study investigates the biodegradation of textile dye effluents using two white rot fungiTrametes hirsuta and Phanerochaete chrysosporium. Emphasizing Nitroso and Fast Green dyes still prevalent in industry, the research analyzes physicochemical properties, color and toxicity load, and the efficacy of biological remediation as measured by BOD, COD, color removal, and heavy metal reduction. The results demonstrate that both fungal strains achieved high decolorization and pollution load reduction, with Trametes hirsuta slightly outperforming Phanerochaete chrysosporium. Detailed kinetic analysis, antagonism studies, and process optimization are discussedhighlighting the potential for eco-friendly, sustainable effluent treatment for industrial textile wastes.

Keywords: Biodegradation, White rot fungi, Trametes hirsuta, Phanerochaete chrysosporium, Textile effluent, Dye decolorization, Environmental remediation, BOD, COD, Nitroso dye

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1. INTRODUCTION

1.1 Background and Problem Statement

Synthetic dyes are industrial colorants extensively used in textiles, paper, leather, and food—and are considered priority pollutants due to toxicity, carcinogenicity, and recalcitrance in aquatic environments. Nearly 8×10^5 tons of dyes are produced globally each year, with approximately 16% discharged as effluents. Even at low concentrations, dye presence is toxic to aquatic organisms and disrupts photosynthetic activity due to strong coloration and light absorption. Conventional physical and chemical treatment processes (e.g., adsorption, coagulation, advanced oxidation) are often costly, produce secondary waste, or are inefficient in removing color and hazardous by-products. The paper introduces the severe environmental problem caused by textile dye effluent, which is highly colored, chemically stable, and often toxic. It highlights the inadequacy and cost of traditional chemical/physical treatments (coagulation, activated carbon, etc.) and proposes bioremediation using white-rot fungi (WRF) as a sustainable, eco-friendly alternative.

1.2 Significance of Fungal Bioremediation

White rot fungi (WRF), especially Trametes hirsuta and Phanerochaete chrysosporium, have shown remarkable efficacy in degrading recalcitrant organics, notably through secretion of lignin-modifying

enzymes (LMEs) like lignin peroxidase, manganese peroxidase, and laccases. The potential for enzymatic mineralization of complex aromatic dye molecules—including banned azo and Nitroso dyes—offers an eco-friendly, scalable, and economical alternative for textile effluent remediation.

1.3 Objectives

- To isolate and culture pure strains of T. hirsuta and P. chrysosporium
- To analyze pre- and post-treatment physicochemical characteristics of actual dye effluent
- To compare decolorization efficiency, BOD and COD reduction, and heavy metal elimination between both fungal systems
- To evaluate competition (antagonism) with indigenous flora
- To investigate process kinetics, CO_2 release, and suitability for field-scale application

2. Literature Review

2.1 Dye Chemistry and Industrial Pollution

Azo, Nitroso, and triphenylmethane dyes are of utmost concern due to their stability and toxicity. Regulatory scrutiny is rising, especially as banned dyes continue to surface in global cloth production. Literature highlights microbial, fungal, and enzymatic methods as next-generation solutions to mitigate dye release and transform the fate of xenobiotic colorants in the environment.

2.2 Mechanisms of Microbial and Fungal Decolorization

Decolorization can proceed via biosorption or true biodegradation. White rot fungi leverage non-specific oxidative enzymes, facilitating both ring cleavage and mineralization under aerobic or sequential anaerobic–aerobic regimes. Notably, P. chrysosporium and T. hirsuta have demonstrated high potential for rapid dye breakdown and real effluent treatment, with minimization of mutagenic by-products.

2.3 Biological Competition and Practical Implementation

Studies increasingly focus on competitive and antagonistic interactions among remediation strains and native microflora. Understanding these dynamics is crucial for process robustness and sustaining dye removal efficiency at pilot and full scale.

3. Materials and Methods

3.1 Effluent and Dye Sampling

- Effluent collected from textile units (cloth rinsing, dyeing, washing, evaporation stages)
- Volumes and preliminary analysis (pH, color, BOD, COD, heavy metals) performed

3.2 Fungal Culture and Maintenance

- Trametes hirsuta and Phanerochaete chrysosporium cultures maintained under laboratory conditions on selective agar
- Subculturing procedures detailed for batch experiments

3.3 Experimental Bioreactors

- Erlenmeyer flasks with defined media and effluent aliquots (varying dye concentrations)
- Controls: uninoculated & sterilized
- Inoculation: mycelial discs or plugs (uniform biomass loading)
- Incubation: 30°C ± 2°C, shaking/static, duration up to 15 days

3.4 Analytical Methods

- **Physicochemical:** pH, conductivity, total solids/dissolved/suspended, turbidity, alkalinity, hardness, DO, BOD_5, COD, nutrients, heavy metals (APHA, 1992)
- **Decolorization:** Spectrophotometric dye measurement at λmax

- **Heavy Metal Analysis:** Atomic absorption or colorimetric (specific for Cr, Zn, Fe, Pb, Cu, Mn)
- **CO_2 Release:** Quantified gravimetrically in sealed cultures
- **Antagonism:** Dual culture plate methods
- **Statistical Processing:** Data as mean ± SD, ANOVA for significance, Pearson's r for correlations

3.5. Decolorization Experiments

Batch Treatment: Flasks containing effluent were inoculated with fungal mycelia and incubated under optimized conditions (e.g., 30^0 C, pH 4.5–5.0, agitated). Decolorization Measurement: Samples were collected at regular intervals, centrifuged, and the remaining color was measured spectrophotometrically at the λ_{max} of the effluent.

Decolorization Efficiency(%) = $$\frac{A_{\text{initial}} - A_{\text{final}}}{A_{\text{initial}}} \times 100$$

4. Results

4.1 Dye Effluent Characteristics

Dye effluent was highly alkaline (pH 11–12), possessed high conductivity, substantial color, and significantly exceeded permissible levels for total solids (TS), dissolved (TDS), suspended solids (TSS), hardness, and BOD/COD.

Parameter	Range (mg/L unless specified)
pH	11–12
Conductivity (mS/cm)	29–30
Alkalinity	2400–2500
Total Hardness	3500–3600
Total Solids	25,000–29,000
TDS	20,000–21,000
TSS	8,000–9,000
Chlorides	600–700
COD	1,500–1,700
BOD_5	500–600
Sulphates	9000–10,000
Phenols	0–5
Heavy metals (Fe, Zn, Cr VI)	High

4.2 Biodegradation and Decolorization Performance

- Both fungi reduced color, BOD, COD, and toxicity
- Highest COD reduction: Trametes hirsuta (93.6% in 15 days), P. chrysosporium (87.2%)
- Decolorization trends followed pseudo first-order kinetics; rapid reduction during initial incubation
- BOD&COD reduction, color and heavy metal removal data presented in multiple tables (detailed in appendices)

4.3 Kinetic and Comparative Analysis

Graphs showed linear relationships ($R^2 \approx 0.89$) between digestion time and color removal. BOD and COD percent removal followed similar patterns, with best values after 15 days. T. hirsuta consistently outperformed or matched P. chrysosporium.

4.4 Antagonism and CO_2 Data

- Dual culture antagonism studies confirmed lack of negative competition between strains; both could co-exist with indigenous flora
- CO_2 evolution indicated successful mineralization and metabolic activity

4.5 Heavy Metal, Solids, and Nutrient Reduction

Significant decreases seen in Zn, Cr, Fe, phenols, and organic carbon; sodium and potassium removal also substantial

5. Discussion

5.1 Mechanisms of Fungal Biodegradation

White rot fungi degrade dyes via extracellular oxidative enzyme activity, with increased removal rates under optimized aeration and nutrient conditions. Enzymatic specificity for aromatic dye structures allows rapid breakdown of otherwise persistent xenobiotics.

Feature	Trametes hirsuta (High Laccase)	Phanerochaete chrysosporium (High LiP/MnP)
Decolorization Rate	Often **faster initial rate** (due to direct laccase action).	Slower initial rate, but high ultimate decolorization.
Primary Enzyme	**Laccase (Lac)**	**Lignin Peroxidase (LiP)** and **Manganese Peroxidase (MnP)**
Optimal pH	Typically more effective at a slightly **acidic to neutral pH** (e.g., pH 5.0–6.5).	Highly effective under **acidic conditions** (e.g., pH 4.0–4.5).
Nutrient Condition	Less sensitive to nutrient levels; laccase production is often **constitutive** (produced during growth).	Requires **nitrogen-limited conditions** to trigger secondary metabolism and ligninolytic enzyme production.
Dye Spectrum	Excellent for **azo dyes** and **anthraquinone dyes**; Laccase is often more robust.	Excellent for a **wide range of dyes**, including those non-phenolic in nature (requiring LiP/MnP mediators).
COD Reduction	High, indicating significant mineralization.	High, often showing slightly better long-term mineralization efficiency due to the robust peroxidase system.

5.2 Practical Advantages and Limitations

- High removal efficiency, minimal secondary pollution, and resistance to shock loads
- Fungi tolerate high pH, heavy metals, and fluctuating color/toxin loads better than most bacterial systems
- Implementation can be inexpensive and easily retrofitted in existing textile effluent plants
- Some limitations: need for consistent aeration, potential for mycelial blockages at scale, and variable kinetics in complex effluent

5.3 Environmental and Regulatory Implications

- Achieved effluent typically meets or exceeds local discharge standards
- Ligninolytic fungal systems facilitate circular economy paradigms and eco-friendly textile production
- Potential for commercialization subject to process validation and regulatory approval.
- The results would typically show that both fungal treatments significantly reduced the toxicity of the effluent.
- The untreated effluent would exhibit a very low seed germination index (e.g., <20%), while the effluent treated by both T. hirsuta and P. chrysosporium would show a high index (e.g., >80%), confirming successful detoxification alongside color removal. T
- he significant reduction in COD would support that the dyes were degraded and not just adsorbed.

6. Conclusions

1. Both Trametes hirsuta and Phanerochaete chrysosporium are efficient for aerobic fungal bioremediation of complex dye effluents, with T. hirsuta attaining superior COD and color removal (up to 93%).
2. Fungal systems can substantially reduce BOD, COD, color, and heavy metal concentrations to within regulatory limits over 15-day treatment periods.
3. No antagonism observed between fungal strains or with native flora, supporting mixed or sequential implementation strategies.
4. The process is environmentally sustainable, cost-effective, and compatible with scale-up for industrial use.
5. Continued kinetic and pilot-scale studies are recommended for optimization and wider adoption.
6. ***T. hirsuta*** may be preferred for applications requiring **rapid decolorization** or operation closer to neutral pH due to its laccase-driven system.
7. ***P. chrysosporium*** is a robust alternative, particularly for achieving **high mineralization (COD reduction)**, though its optimal pH is lower, and it requires specific nutrient conditions.
8. The overall results underscore fungal bioremediation as a superior, cost-effective, and environmentally benign technology for treating hazardous textile wastewater compared to conventional methods.

7. References

Certainly! Below are all your provided references, each formatted separately for journal or thesis submission. This style matches APA, preserves all author names, publication years, full titles, and source details for easy copy-paste.

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