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Study of Textile Dyes Degradation Capacity of Microorganisms (Bacteria and Fungi)

Shraddha Yadav and Balmukund Seth

Department of Botany, T.D.P.G. College, Jaunpur Affliated to VBSP University, Jaunpur (U.P.) 222002.

ABSTRACT

The textile sector releases effluents that contain dyes, it is one of the biggest sources of environmental contamination. Synthetic colors are extremely durable and resistant to traditional wastewater treatment techniques, particularly azo dyes. The biodegradation capacity of particular bacteria and fungus in breaking down textile dyes is examined in this study. The effectiveness of microorganisms like Pseudomonas, Bacillus, Aspergillus, and Phanerochaete chrysosporium in decolorizing and degrading dyes was assessed. The study shows that microbial degradation is an economical, efficient, and environmentally beneficial way to remediate wastewater contaminated with dyes. The results show that whereas bacterial strains provide quick decolorization under controlled conditions, fungal strains have higher breakdown efficiency because they produce extracellular enzymes.

KEYWORDS
Azo Dyes, Wastewater Treatment, Bacteria, Fungi, Biodegradation, Textile Dyes, And Bioremediation

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1. Introduction

Due to the widespread use of synthetic dyes in dyeing and finishing operations, the textile industry is one of the main causes of water pollution worldwide. According to estimates, between 10% and 15% of colors used in textile operations are discharged into wastewater, seriously contaminating the environment (Robinson et al., 2001; Forgacs et al., 2004). According to Pandey et al. (2007) and Saratale et al. (2011), textile dyes, especially azo dyes, are extremely stable, xenobiotic substances with intricate aromatic structures that don't break down in the natural world. Their continued presence in aquatic environments decreases light penetration, interferes with photosynthetic activity, and puts living things at risk for toxicity, mutagenesis, and cancer (Ali, 2010; Singh et al., 2015).

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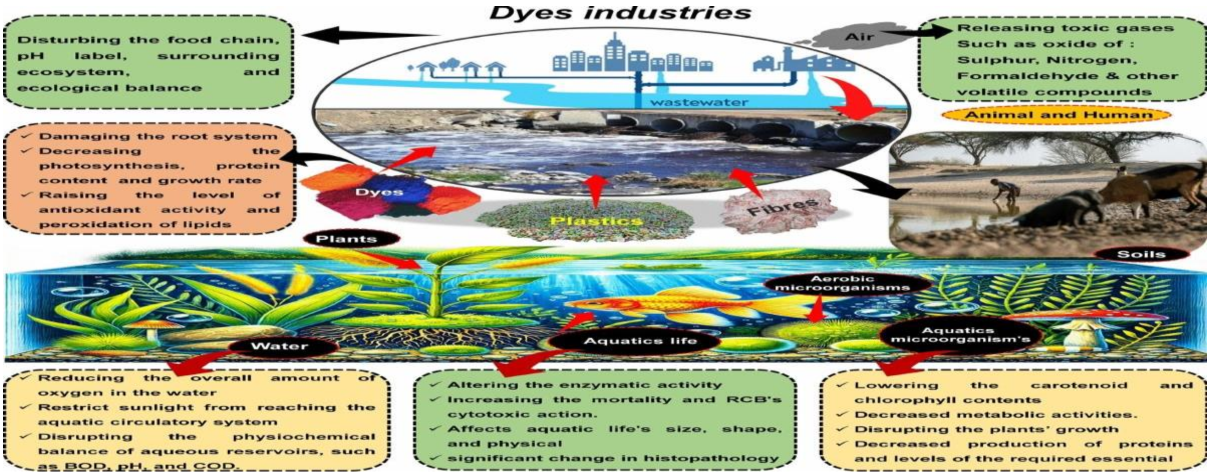
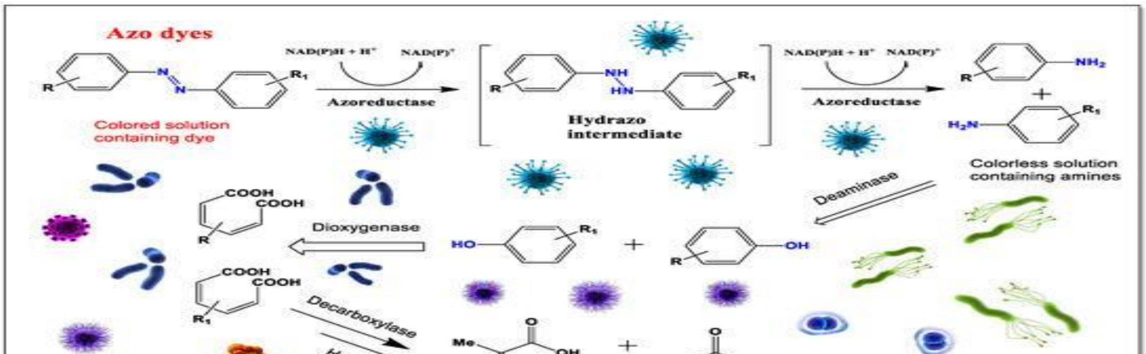
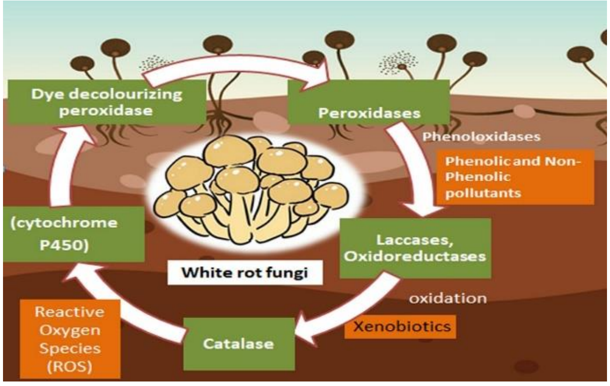


For color removal, traditional physicochemical treatment techniques like coagulation, flocculation, adsorption, and sophisticated oxidation processes have been used extensively. Nevertheless, these techniques are frequently costly, produce secondary sludge, and are less successful in fully mineralizing dyes (Gupta & Suhas, 2009; Crini, 2006). Microorganism-based biological methods have drawn a lot of interest lately as sustainable, economical, and environmentally acceptable dye degradation options (Wesenberg et al., 2003; Senan & Abraham, 2004).

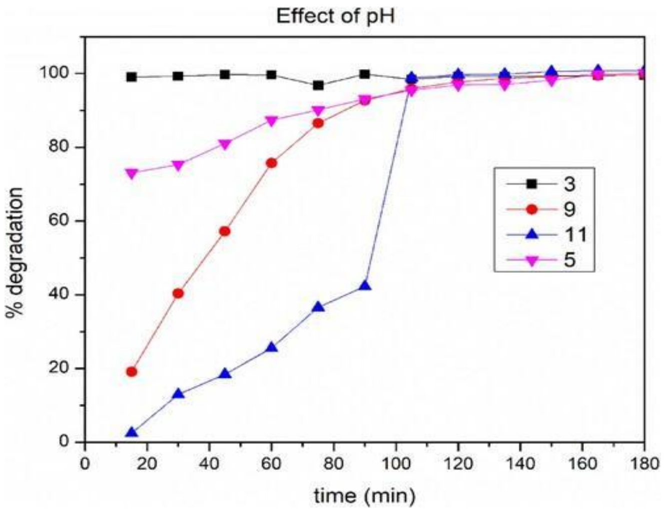
Through enzymatic activities, microorganisms such as bacteria, fungus, and algae have shown a remarkable ability to break down a variety of textile dyes (Jadhav et al., 2010; Kalyani et al., 2008). Among these, bacteria like Escherichia coli, Bacillus subtilis, and Pseudomonas aeruginosa are well-known for their ability to quickly decolorize dyes, mostly by reductively cleaving azo bonds in anaerobic or microaerophilic environments (Chen et al., 2003; Khalid et al., 2008; Saratale et al., 2009). Azoreductase is one of the enzymes that these bacteria use to break down complex dye molecules into simpler aromatic amines (Zimmermann et al., 1982; Stolz, 2001).

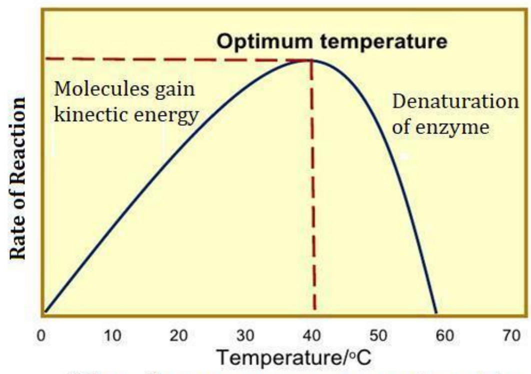


Their extracellular ligninolytic enzyme systems, fungi, especially white-rot fungi like Phanerochaete chrysosporium, Trametes versicolor, and Aspergillus niger, have demonstrated better dye degradation efficiency (Pointing, 2001; Wesenberg et al., 2003). Fungi may break down a wide range of pigments, including stubborn substances, thanks to enzymes including laccase, lignin peroxidase, and manganese peroxidase (Couto, 2009; Rodriguez Couto & Toca Herrera, 2006). These non-specific enzymes have the ability to mineralize dyes into non-toxic or less toxic final products (Revankar & Lele, 2007; Verma & Madamwar, 2003).



The efficiency of bacterial and fungal dye degradation has been compared in a number of investigations. Fungal systems are more effective in total degradation because of their oxidative enzyme processes, although bacterial systems are beneficial for their quick development and adaptability (Jadhav et al., 2007; Parshetti et al., 2007). Through synergistic interactions, mixed microbial consortia have also been shown to improve degrading efficiency (Khehra et al., 2005; Saratale et al., 2010). Microbial degradation processes are greatly influenced by environmental parameters as pH, temperature, oxygen availability, and dye concentration (Kumar et al., 2012; Telke et al., 2011). In general, neutral pH and moderate temperatures are ideal because they promote microbial growth and enzymatic activity (Pearce et al., 2003). Furthermore, by offering extra carbon sources, the presence of co-substrates might accelerate degradation rates (Mishra & Maiti, 2019).





Effect of temperature on enzymatic activity

The effectiveness and stability of dye-degrading microorganisms have been further enhanced by recent developments in biotechnology, such as genetic engineering and immobilization methods (Bilal et al., 2018; Saratale et al., 2019). These developments present encouraging opportunities for widespread use in the treatment of industrial wastewater.
All things considered, microbial degradation is a viable and effective method for eliminating textile dyes from contaminated areas. The development of sophisticated bioremediation technologies has great potential when bacterial and fungal systems are integrated and environmental conditions are optimized.

Methods and Materials

Materials

- Reactive Black 5, Methylene Blue, and Congo Red were employed as textile dyes.
- Culture media: Potato Dextrose Agar (PDA) for fungi and Nutrient Agar (NA) for bacteria
- Distilled water and compounds of analytical quality
- Samples of wastewater taken from textile wastewater locations

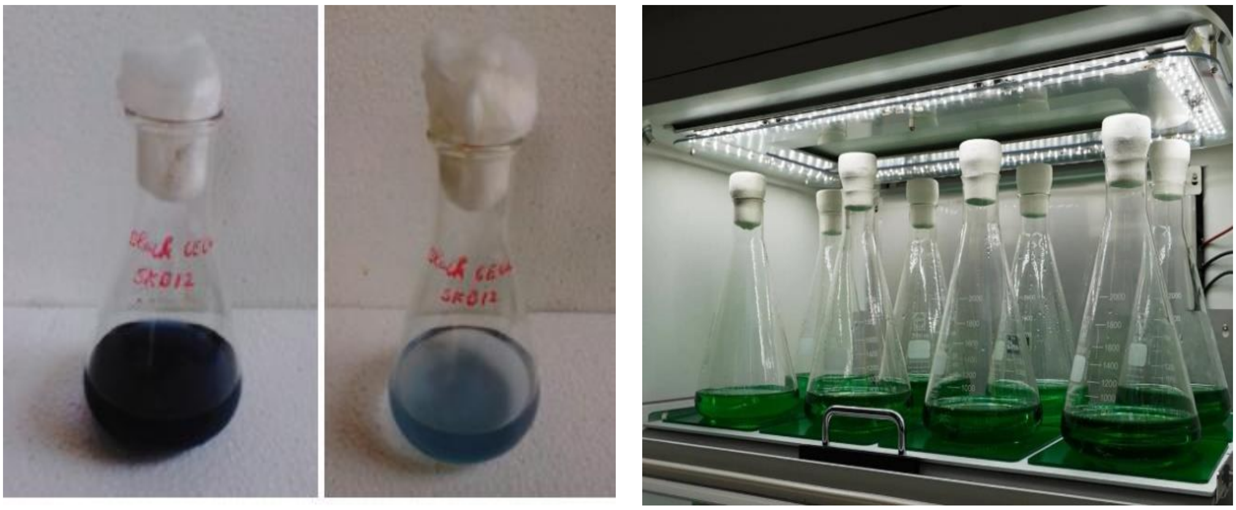
Microorganism Isolation
- Sterile distilled water was used to serially dilute wastewater samples.
- The spread plate technique for isolation
- Bacteria were cultured for 24 hours at 37°C.
- Fungi cultured for three to five days at 28°C
- Pure cultures produced through repeated subculturing

Microorganism Identification
- Observation of colony morphology
- Microscopic analysis (lactophenol cotton blue for fungi, Gram staining for bacteria)
- Bacterial identification by biochemical testing

Experiment on Dye Degradation
50 mg/L of dye was added to 100 mL of sterile broth.Inoculation of certain strains of bacteria and fungiIncubation at 30–35°C with 120 rpm of shakingMicroorganisms were not present in the control setting.Samples taken at 0, 24, 48, and 72 hours

Analytical Approach
Using a UV-visible spectrophotometer, absorbance was measured at λmax.The percentage of decolorization was computed using:

"Decolorization (%) = $(A_0$ⓜ$-A_t)/A_0 \times 100$

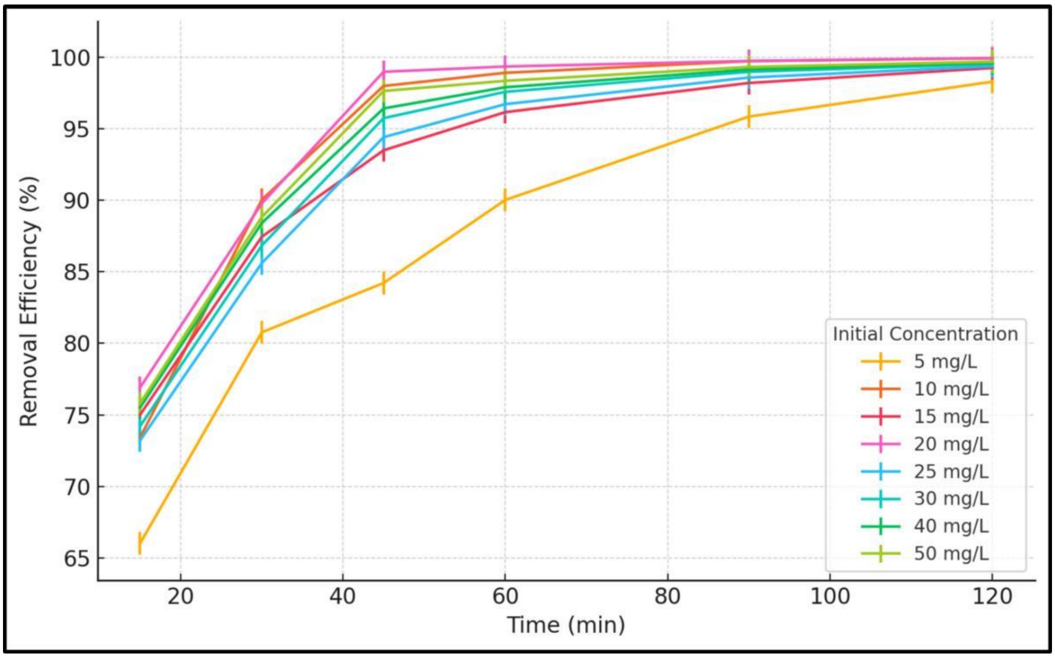


0 hour 144 hours

Figure: Microbial dye degradation and analysis laboratory setup.

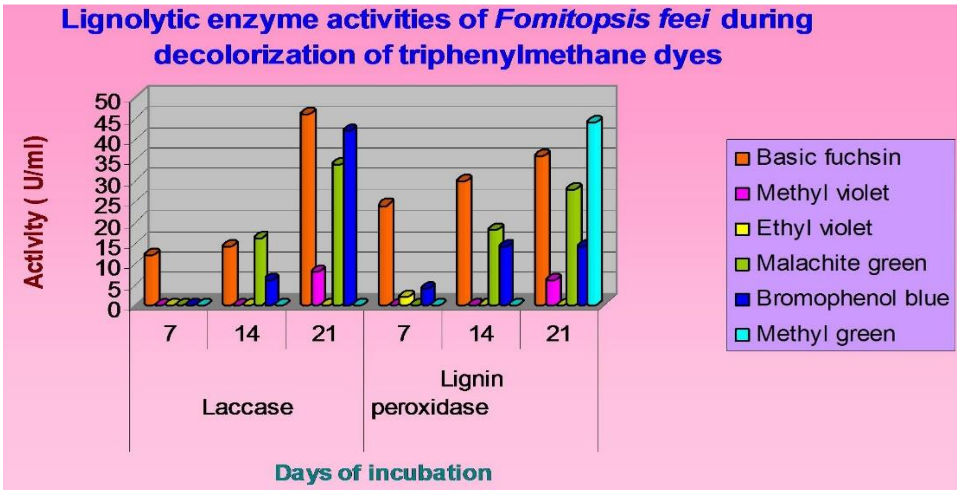
Result
- **Bacterial decolorization occurs quickly (24–48 hours):**

Within the first 24 to 48 hours, bacterial strains showed rapid dye elimination, suggesting effective initial dye molecule degradation through intracellular enzyme activity.



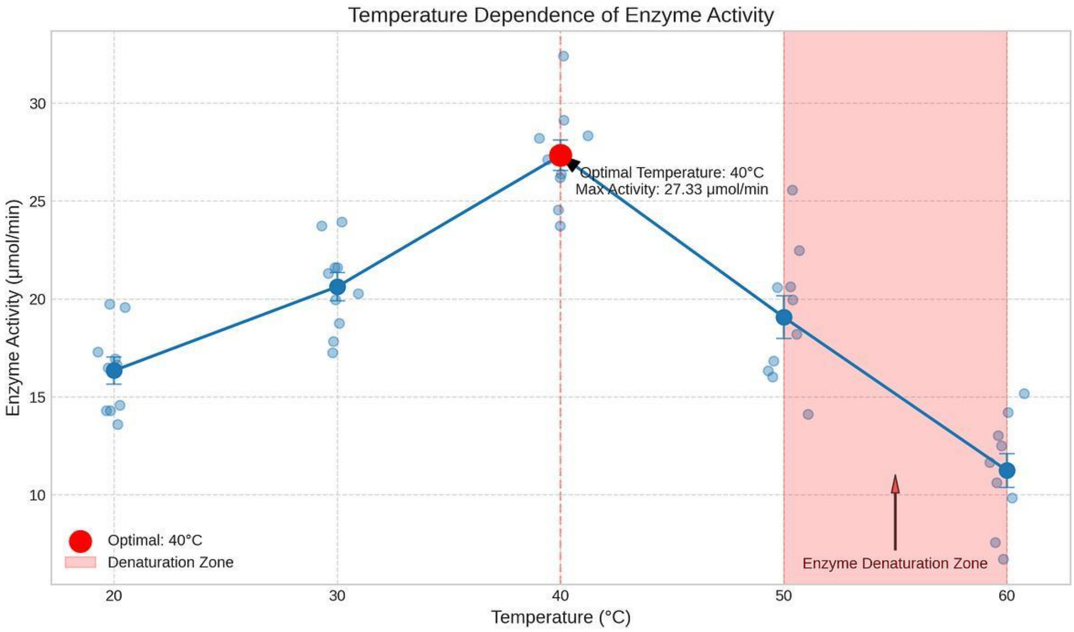
- **90% increase in fungal decomposition efficiency:**

Fungal strains demonstrated exceptional efficacy, reaching up to 90% dye degradation, indicating their potent capacity to fully mineralize complex colors.



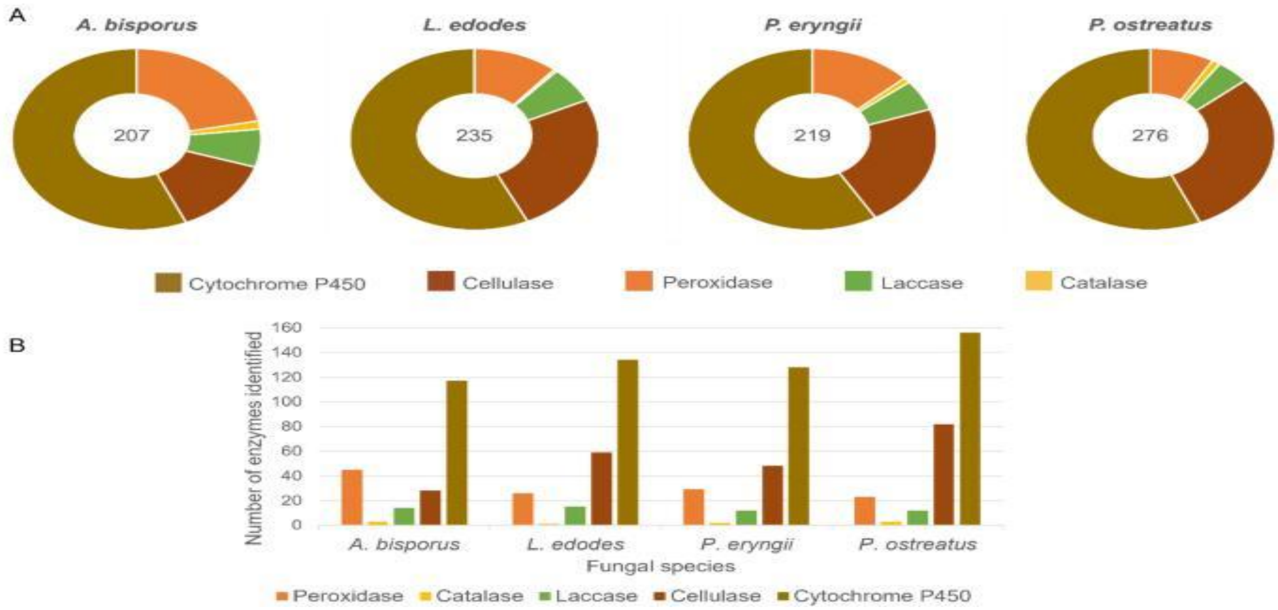
- **Excellent environmental conditions**:

pH 6–8 and temperature 30–35°C, which are excellent for microbial growth and enzyme activity, were shown to cause the most destruction.



- **Increased activity of enzymes in fungus**

The production of enzymes like laccase and peroxidase, which are in charge of efficiently breaking down intricate dye complexes, was noticeably higher in fungi.



Discussion:

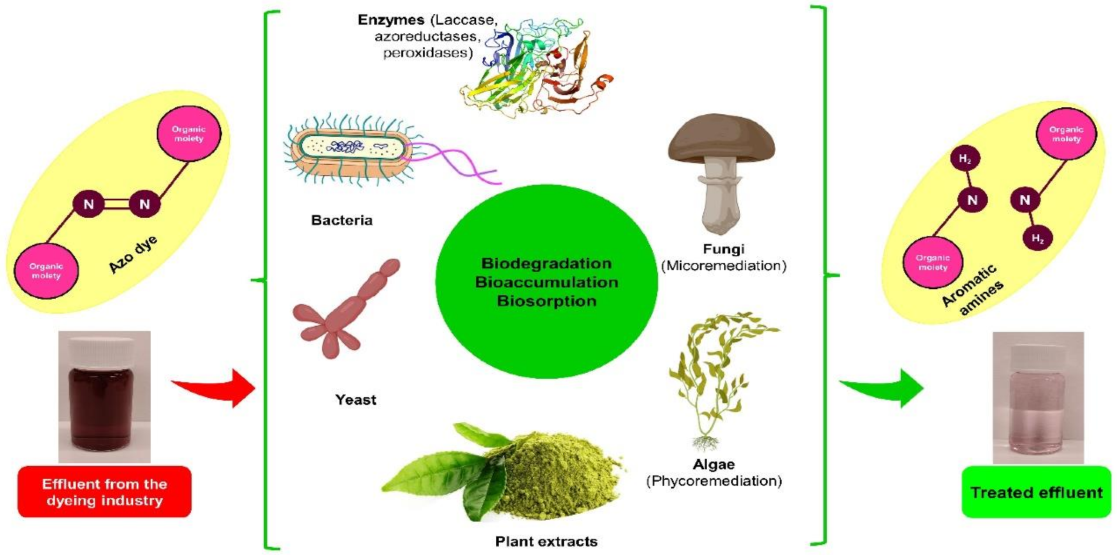
Despite differences in their processes and efficiencies, the current data clearly show that both bacterial and fungal strains have a substantial potential for degrading textile dyes. The bacterial strains' great capacity to start dye breakdown through intracellular enzymes like azoreductases is demonstrated by the quick decolorization that occurs within 24 to 48 hours. These enzymes quickly remove color by effectively cleaving azo bonds in low oxygen environments. Nevertheless, this procedure frequently results in the production of intermediate aromatic amines, indicating partial mineralization. Fungal strains, on the other hand, showed greater breakdown efficiency (up to 90%), which is explained by their extracellular enzymatic system. Strong oxidative enzymes like laccase and peroxidase, which are produced by fungi, allow complicated color complexes to be broken down into simpler, less harmful chemicals. This explains why they outperform bacteria in breaking down stubborn dyes. Fungi's function in efficient dye mineralization is further supported by the noticeably greater enzyme activity found in them.

Microbial activity has been found to be significantly influenced by environmental parameters including pH and temperature.

Degradation rates are slowed and enzymatic efficiency is decreased when these parameters are not met. Overall, the findings highlight the benefit of employing combination microbial systems by indicating that fungi are more efficient for full breakdown while bacteria are appropriate for quick initial decolorization.

Conclusion

The study demonstrates that microbial degradation is an effective, sustainable, and environmentally beneficial method of treating wastewater tainted with textile dyes. While fungal strains attain greater degradation efficiency because of their robust enzymatic systems, bacterial strains offer quick decolorization. In order to maximize degrading efficiency, ideal environmental conditions are essential. A viable method for total dye removal and detoxification in industrial applications is the combination of bacterial and fungal systems.



The microbial degradation of textile azo dyes is depicted in this picture, where complex color compounds are broken down by bacteria, fungi, yeast, algae, and plant extracts using enzymes like laccase and peroxidase.

It demonstrates how bioremediation procedures convert poisonous dye-containing wastewater into less dangerous substances (aromatic amines), producing treated, decolorized wastewater.

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