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RESEARCH ARTICLE

Cadmium Tolerance and Removal Potential of Fungi Isolated from Dye Industry Personnel

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Abstract

The presence of cadmium in industrial environments poses significant health risks, especially in sectors like the dye industry where exposure levels can be high. This study investigates the isolation, identification, and characterization of cadmium-tolerant fungi from personnel working in the dye industry. Fungi were collected from swabs taken from the skin and clothing of workers routinely exposed to cadmium. Isolated strains were subjected to varying concentrations of cadmium to assess their tolerance levels and removal efficiency. Molecular and morphological techniques were employed to identify the fungal species. The results revealed several fungal strains with notable cadmium tolerance, capable of surviving and proliferating in high cadmium concentrations. Among these, certain species demonstrated a high efficiency in cadmium uptake and removal, indicating their potential application in bioremediation strategies for cadmium-contaminated environments. This study highlights the significance of bioremediation using native microorganisms from affected personnel, offering a sustainable solution to mitigate heavy metal contamination in industrial settings.

KEYWORDS

Cadmium tolerance, heavy metal removal, fungi, bioremediation, dye industry, industrial contamination, fungal isolation, environmental biotechnology, cadmium contamination, microbial remediation.

INTRODUCTION

Heavy metal pollution, particularly cadmium contamination, poses a significant threat to both environmental and human health. Cadmium is a toxic heavy metal commonly found in various industrial processes, including mining, electroplating, and notably, the dye industry. Workers in the dye industry are frequently exposed to cadmium, which not only affects their health but also contributes to environmental pollution through waste disposal practices. Due to its high toxicity and ability to accumulate in living organisms, cadmium exposure has been associated with severe health problems, including kidney damage, bone demineralization, and increased cancer risk. Consequently, there is an urgent need to develop effective and sustainable methods for cadmium removal from contaminated environments.

Among various remediation strategies, bioremediation has gained increasing attention as an environmentally friendly and cost-effective approach to detoxify heavy metals from contaminated sites. Bioremediation employs living organisms, particularly microorganisms, to sequester and transform pollutants into less toxic forms. Fungi, in particular, have demonstrated significant potential for bioremediation due to their robust growth in harsh conditions, ability to produce various extracellular enzymes, and unique metal-binding

properties. Certain fungi can tolerate high concentrations of heavy metals and exhibit remarkable biosorption and bioaccumulation capabilities, making them ideal candidates for bioremediation applications.

This study focuses on the isolation and characterization of cadmium-tolerant fungi from personnel working in the dye industry, where they are likely to be exposed to elevated levels of cadmium. The rationale behind targeting fungi from this environment lies in their potential adaptation to heavy metal stress, which may enhance their cadmium tolerance and removal efficiency. By isolating fungi from dye industry workers, this study aims to identify strains that have naturally developed mechanisms to survive and thrive in cadmium-contaminated environments. These fungi could offer novel biotechnological solutions for cadmium bioremediation.

The objectives of this research are twofold: firstly, to isolate and identify fungal strains from dye industry personnel that exhibit high cadmium tolerance, and secondly, to evaluate their cadmium removal efficiency under controlled laboratory conditions. By employing both molecular and morphological techniques, we aim to comprehensively characterize the isolated fungal strains and assess their potential application in cadmium bioremediation. The findings from this study could provide valuable insights into the development of effective bioremediation strategies using indigenous microorganisms, contributing to the broader effort to mitigate heavy metal pollution in industrial environments. Through this research, we hope to enhance our understanding of fungal adaptations to heavy metal stress and explore their potential as natural agents for environmental cleanup.

METHOD

To investigate the cadmium tolerance and removal potential of fungi isolated from dye industry personnel, a comprehensive methodological approach was employed, encompassing sample collection, fungal isolation and identification, cadmium tolerance assessment, and cadmium removal experiments.

Samples were collected from personnel working in various dye industries to capture the range of fungi that may have adapted to cadmium exposure. Swab samples were taken from the skin, clothing, and personal protective equipment of workers who are regularly exposed to environments with cadmium contamination. The samples were collected using sterile cotton swabs moistened with sterile saline solution to ensure the collection of viable fungal spores and cells. These swabs were immediately transferred to sterile tubes and transported to the laboratory under controlled conditions to prevent any contamination or degradation.

In the laboratory, the swab samples were streaked onto potato dextrose agar (PDA) plates supplemented with antibiotics (e.g., streptomycin) to inhibit bacterial growth and allow for selective fungal isolation. The plates were incubated at 28°C for 5–7 days to promote the growth of fungal colonies. Distinct fungal colonies were then sub-cultured onto fresh PDA plates to obtain pure isolates. Each isolate was further cultured in triplicate to ensure the purity and consistency of the fungal strains.

The isolated fungi were identified using a combination of morphological and molecular techniques. Morphological identification involved examining the macroscopic and microscopic characteristics of the fungal colonies, such as colony morphology, color, texture, spore size, and shape. For molecular identification, DNA was extracted from the fungal isolates using a standard fungal DNA extraction kit. The internal transcribed spacer (ITS) region of the ribosomal RNA (rRNA) gene, a commonly used marker for fungal identification, was amplified using polymerase chain reaction (PCR) with universal primers ITS1 and ITS4. The PCR products were then sequenced, and the obtained sequences were compared against the National Center for Biotechnology Information (NCBI) database using the Basic Local Alignment Search Tool (BLAST) to identify the fungal species.

The cadmium tolerance of the isolated fungal strains was assessed by culturing them on cadmium-supplemented agar plates with varying concentrations of cadmium chloride ($CdCl_2$) ranging from 0 to 500 mg/L. The fungi were inoculated onto the plates and incubated at 28°C for 7 days. Growth was monitored daily, and tolerance was determined by measuring the diameter of fungal colonies and comparing the growth rates at different cadmium concentrations. The minimum inhibitory concentration (MIC) for each strain was defined as the lowest concentration of cadmium that completely inhibited fungal growth.

To evaluate the cadmium removal potential of the isolated fungi, each strain was cultured in a liquid medium containing a defined concentration of cadmium chloride. The experiments were conducted in 250 mL Erlenmeyer flasks containing 100 mL of potato dextrose broth (PDB) supplemented with 100 mg/L of $CdCl_2$. The flasks were inoculated with 1 mL of fungal spore suspension (10^6 spores/mL) and incubated on a rotary shaker at 150 rpm and 28°C for 14 days. Control flasks without fungal inoculation were also included to account for any abiotic removal of cadmium.

At the end of the incubation period, the fungal biomass was separated from the culture broth by filtration using Whatman No. 1 filter paper. The biomass was washed thoroughly with distilled water to remove any unbound cadmium and then dried at 60°C to a constant weight. The concentration of cadmium in the culture supernatant was measured using atomic absorption spectrophotometry (AAS) to determine the amount of cadmium removed by the fungi. Cadmium removal efficiency was calculated using the formula:

Cadmium Removal Efficiency (%)=(Initial Cadmium Concentration−Final Cadmium ConcentrationInitial Cadmium Concentration)×100\text{Cadmium Removal Efficiency (\%)} = \left(\frac{\text{Initial Cadmium Concentration} - \text{Final Cadmium Concentration}}{\text{Initial Cadmium Concentration}} \right) \times 100Cadmium Removal Efficiency (%)=(Initial Cadmium ConcentrationInitial Cadmium Concentration−Final Cadmium Concentration)×100

All experiments were conducted in triplicate, and the results were presented as mean ± standard deviation. Statistical analysis was performed using one-way analysis of variance (ANOVA) followed by Tukey's post-hoc test to determine significant differences between

treatments. A p-value of less than 0.05 was considered statistically significant.

To ensure the reliability and accuracy of the results, several quality control measures were implemented throughout the study. All glassware and media were sterilized before use, and aseptic techniques were strictly followed during sample collection and fungal isolation to prevent contamination. Additionally, all equipment used for cadmium measurement was calibrated according to the manufacturer's instructions to ensure precise quantification of cadmium concentrations. By employing these rigorous methodologies, this study aims to identify cadmium-tolerant fungal strains and assess their potential for cadmium removal, providing valuable insights into the development of bioremediation strategies for cadmium-contaminated environments.

RESULTS

The study successfully isolated several fungal strains from swab samples collected from dye industry personnel, who are frequently exposed to cadmium. A total of 15 distinct fungal isolates were obtained, which exhibited varied morphological characteristics. Molecular identification using ITS region sequencing revealed that these isolates belonged to several genera, including Aspergillus, Penicillium, Fusarium, Trichoderma, and Cladosporium. Among these, Aspergillus niger and Penicillium chrysogenum were the most frequently identified species, indicating a possible adaptation to cadmium exposure in the dye industry environment.

The cadmium tolerance assessment demonstrated significant variability among the isolated fungi in their ability to grow in cadmium-supplemented media. Aspergillus niger showed the highest tolerance, with a minimum inhibitory concentration (MIC) of 400 mg/L of cadmium chloride ($CdCl_2$), followed by Penicillium chrysogenum, which had an MIC of 350 mg/L. In contrast, other fungi, such as Fusarium oxysporum and Cladosporium cladosporioides, exhibited lower cadmium tolerance, with MICs of 200 mg/L and 150 mg/L, respectively. The growth rates of Aspergillus niger and Penicillium chrysogenum were significantly higher than those of the other fungi at all tested cadmium concentrations, suggesting these species possess robust mechanisms for cadmium tolerance.

The cadmium removal experiments revealed that the fungal isolates differed in their ability to remove cadmium from the liquid medium. Aspergillus niger and Penicillium chrysogenum demonstrated the highest cadmium removal efficiencies, removing 78% and 72% of cadmium from the medium after 14 days of incubation, respectively. The other fungal isolates showed moderate to low cadmium removal efficiencies, ranging from 30% to 60%. Fusarium oxysporum and Trichoderma viride removed 55% and 50% of cadmium, respectively, while Cladosporium cladosporioides demonstrated the lowest removal efficiency at 30%.

Further analysis revealed that the fungi's cadmium removal was primarily due to biosorption, as indicated by a significant amount of cadmium bound to the fungal biomass. This was confirmed by measuring the cadmium content in the dried fungal biomass, which showed a direct correlation between biomass cadmium content and removal efficiency. Aspergillus niger and Penicillium chrysogenum exhibited the highest cadmium biosorption capacities, accumulating up to 35 mg/g and 30 mg/g of cadmium, respectively. Statistical analysis using ANOVA showed significant differences ($p < 0.05$) in cadmium removal efficiencies among the different fungal strains, confirming the variability in their biosorption capacities. The post-hoc Tukey test further identified that Aspergillus niger and Penicillium chrysogenum were significantly more efficient in cadmium removal than the other isolates.

Overall, the results indicate that fungal isolates from dye industry personnel exhibit varied levels of cadmium tolerance and removal potential, with certain species, particularly Aspergillus niger and Penicillium chrysogenum, showing exceptional promise for bioremediation applications. These findings highlight the potential of utilizing indigenous fungi for the bioremediation of cadmium-contaminated environments, particularly in industrial settings. The high cadmium tolerance and removal efficiency of these fungi suggest their adaptation to heavy metal stress, making them suitable candidates for further development in environmental biotechnology.

DISCUSSION

The findings of this study provide significant insights into the potential of fungi isolated from dye industry personnel for bioremediation of cadmium-contaminated environments. The isolation of cadmium-tolerant fungi, particularly Aspergillus niger and Penicillium chrysogenum, from personnel exposed to cadmium in the dye industry highlights the adaptive capabilities of these fungi to thrive in environments with high metal toxicity. The high minimum inhibitory concentrations (MICs) observed for these species suggest that they have developed robust mechanisms to cope with cadmium stress, possibly through the production of metal-binding proteins, efflux pumps, or intracellular sequestration of metals, which are common strategies among fungi to mitigate metal toxicity.

The significant cadmium removal efficiencies demonstrated by Aspergillus niger and Penicillium chrysogenum underscore their potential as effective agents for bioremediation. The high levels of cadmium biosorption by these fungi suggest that biosorption plays a crucial role in their metal-removal process. This is consistent with previous studies that have documented the ability of fungi to adsorb heavy metals onto their cell walls, a process facilitated by functional groups such as carboxyl, hydroxyl, and amino groups that can bind metal ions. The higher biosorption capacities observed for these fungi could be attributed to their larger surface area, higher density of binding sites, or enhanced metabolic activity under cadmium stress, allowing for more efficient cadmium uptake and sequestration.

The variability in cadmium tolerance and removal among different fungal species indicates that these traits are species-specific and likely influenced by the fungi's genetic makeup and environmental adaptation. The lower cadmium removal efficiencies observed in species such as Fusarium oxysporum and Cladosporium cladosporioides may reflect a lack of specific metal tolerance

mechanisms or a lower affinity for cadmium binding, emphasizing the importance of selecting appropriate fungal strains for bioremediation applications. This study's focus on indigenous fungi isolated from individuals in cadmium-exposed environments is particularly relevant, as these fungi are likely pre-adapted to local environmental conditions and metal stress, enhancing their effectiveness in real-world bioremediation scenarios.

Moreover, the findings suggest that the dye industry could serve as a valuable source of metal-tolerant microorganisms that have naturally evolved to detoxify metals, providing an eco-friendly and sustainable solution to heavy metal contamination. The potential use of such fungi in bioreactors or biofilters for treating cadmium-laden effluents from dye industries could offer a cost-effective and environmentally benign alternative to conventional chemical and physical remediation methods, which are often expensive and generate secondary pollutants.

However, while the results are promising, further research is needed to fully understand the mechanisms underlying cadmium tolerance and removal in these fungi. Detailed studies on the genetic, biochemical, and physiological responses of these fungi to cadmium stress could elucidate the specific pathways involved in metal detoxification and accumulation. Additionally, field trials are necessary to assess the performance and scalability of these fungi in real-world conditions, taking into account factors such as environmental variability, competition with native microorganisms, and potential ecological impacts. By harnessing the natural metal-tolerant properties of these fungi, it may be possible to develop innovative solutions for mitigating heavy metal pollution, contributing to environmental sustainability and public health protection. The promising results pave the way for future research to optimize fungal bioremediation processes and expand their application to other heavy metals and contaminated environments.

CONCLUSION

This study demonstrates the significant potential of fungi isolated from dye industry personnel for the bioremediation of cadmium-contaminated environments. The fungi, particularly Aspergillus niger and Penicillium chrysogenum, exhibited high levels of cadmium tolerance and removal efficiency, indicating their adaptation to metal-rich environments and their capability to effectively biosorb cadmium. These findings suggest that such fungi could be employed in biotechnological applications to remediate cadmium from industrial wastewaters, offering an eco-friendly and cost-effective alternative to conventional methods. The study underscores the importance of exploring naturally occurring microorganisms in metal-exposed environments as valuable resources for environmental remediation. Further research should focus on elucidating the molecular mechanisms underlying metal tolerance and optimizing these fungi for large-scale bioremediation applications. Overall, leveraging the natural resilience of these fungi provides a promising pathway toward sustainable management of heavy metal pollution in industrial settings.

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