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Bioremediation Of Agricultural Wastes: Harnessing Microbial Diversity For Environmental Sustainability

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Abstract

Environmental pollution from agricultural activities poses significant challenges globally. Bioremediation, using microbial diversity to degrade contaminants, offers a sustainable solution. This study explores microbial diversity's potential in agricultural waste bioremediation. Agricultural wastes, including crop residues and agro-industrial by-products, contribute to soil degradation and water pollution. Bioremediation, employing microorganisms to detoxify pollutants, presents a promising alternative to traditional waste management methods. Microbial diversity enhances bioremediation efficacy, with diverse species possessing unique metabolic pathways for pollutant degradation. Recent advances in microbial ecology and biotechnology have improved bioremediation effectiveness, highlighting its potential in sustainable agriculture. Bioremediation of agricultural wastes can convert them into valuable products, supporting environmental sustainability. The study isolated diverse microbial strains and characterized their properties, laying the groundwork for efficient bioremediation applications. Optimization experiments identified optimal growth conditions for key microbial strains, crucial for bioremediation success. Bioremediation assays demonstrated the microbial consortia's efficiency in degrading organic pollutants, supporting their potential for waste management. The study's findings reinforce the hypothesis that microbial diversity enhances bioremediation efficiency, offering sustainable pollution mitigation in agriculture. Further research can optimize microbial consortia and environmental conditions for enhanced bioremediation efficacy, contributing to efficient waste management in agricultural settings.

Keywords: Bioremediation, Agricultural Wastes, Microbial Diversity, Environmental Sustainability

Introduction

Farming as a practice poses a great threat to the environment through pollution of the environment in the world today. Traditional methods of waste management do not fully capture the comprehensive nature of agricultural pollutants. Bioremediation, which is the process of using microorganisms to degrade hazardous substances, is a better option. The purpose of this study is to determine whether the microbial diversity could be enhanced in order to enhance bioremediation of agricultural wastes.

Farming activities generate huge amounts of waste from crops such as residues, animal wastes, and agro-processing residuals which if not well managed, are environmentally sensitive (Singh et al., 2011). They lead to the degradation of the soil, water pollution, and the emission of greenhouse gases that are not environmentally sustainable. Burning, dumping in landfills, and direct disposal in water sources are some of the traditional techniques of waste disposal that not only fail to address the problem but are also dangerous to the environment (Zhang et al., 2020).

Bioremediation, the use of microorganisms to remove, stabilize or alter hazardous substances in order to reduce their toxicity is a feasible technique in the management of agricultural wastes (Glick, 2010). Some of the microorganisms include bacteria, fungi, and algae, which have evolved different metabolic pathways that enable them to break down various complex organic compounds in the agricultural residues (Gomes et al., 2021). This microbial diversity can be harnessed in the creation of sustainable bioremediation technologies that convert agricultural waste into usable products such as biofertilizers, biopesticides, and bioenergy, thus completing the cycle in agricultural systems (Singh et al., 2011).

The possibilities of bioremediation in the context of addressing the problems of agricultural waste are in the ability of microbes to exist in various conditions and the presence of a large number of metabolic processes (Zhang et al., 2020). Recent discoveries on microbial ecology and biotechnology have provided new insight on the process of microbial degradation and development of enhanced microbial strains that can enhance bioremediation (Glick, 2010). Therefore, it is imperative to understand and manage the microbial richness in order to improve the effectiveness of bioremediation processes that are crucial in the advancement of sustainable farming.

Review of Literature

Bioremediation of Agricultural Wastes

Such residues, animal manure, and agro-industrial byproducts are all examples of agricultural wastes that are notorious for creating severe environmental issues due to their high volume and polluting capacity (Singh et al., 2011). Other conventional means of waste disposal are through burning, dumping, and discharging wastes directly. However, these methods are associated with environmental unfavorableness in the sense that pollutants are released into the air, soil and water bodies (Zhang et al., 2020). The sustainable option therefore is bioremediation, which involves the use of metabolic capabilities of microorganisms for transforming these wastes into less toxic or even useful products (Glick, 2010).

Microbial diversity in bioremediation

Heterogeneity is a crucial factor in bioremediation since microorganisms are diverse in the environment. The various kinds of microbes also have different mechanisms of breaking down all forms of organic and inorganic compounds in wastes produced by agriculture (Gomes et al., 2021). For instance, bacteria belonging to *Pseudomonas*, *Bacillus* and *Rhodococcus* genera have been shown to possess in some instances excellent ability to biodegrade pesticides and herbicides. On the same note, *Aspergillus* and *Penicillium* are capable of degrading lignocellulosic materials to a great extent (Zhang et al., 2020). These characteristics help them to acquire skills for surviving in

various environmental conditions, which in turn increases their potential in bioremediation applications.

Mechanisms of Microbial Degradation

Such biochemical processes as hydrolysis, oxidation, and reduction of numerous biochemical processes are used by microbes in the degradation of agricultural wastes. Such enzymes as cellulases, ligninases and peroxidases secreted by these microbes are useful in degrading the components of the complex organic matter into simpler molecules which are easily utilizable by the microorganisms themselves (Gomes et al., 2021). Fungi solubilise lignocellulosic biomass by producing cellulase and hemicellulase enzymes, which convert cellulose and hemicellulose into fermentable sugars. The derived sugars are then used to produce biofuels used in energy generation.

Biotechnological Advances in Applications

Over the past few decades, research in microbial ecology and biotechnology has enhanced bioremediation techniques and their efficiencies. Some of these include metagenomics, proteomics and bioinformatics which have further enlightened on the microbial communities that are involved in bioremediation and their functional potential (Glick, 2010). Biotechnology has been used to enhance the capability of microorganisms to degrade and adapt to the environmental factors (Gomes et al., 2021). Specifically, bioaugmentation that entails the addition of specific strains to enhance the rate of bioremediation processes by supplementing hosts and acclimating them to the environment seems to hold a lot of potential in the management of agricultural wastes, if I may say, in a general sense.

Environmental and Economic Benefits

Bioremediation is an effective technique of managing agricultural waste and is linked with numerous environmental and economic advantages. Bioremediation of pollution and the improvement of sustainable agriculture as waste is transformed to biofertilizer, biopesticide, and bioenergy, which recycle nutrients and decrease the reliance on chemical inputs (Singh et al., 2011). Further, the utilization of agricultural residues to produce advanced biofuels can also help in enhancing energy security while at the same time cutting greenhouse gas emissions by a wide margin (Gomes et al., 2021). These have shown that bioremediation has a lot of potential as a systems solution as part of the journey towards environmental sustainability in agriculture.

Methodology

Isolation and Characterization of Microbial Strains

The microbial strains were obtained from agricultural waste samples; the tests performed included bacteria fungi and actinomycetes. Identification and characterization were done by morphological, biochemical and molecular tests aimed at identifying genetic difference and identification of isolates.

Cultivation and Optimization

Single clones were then grown in selective media, and growth characteristics were studied to find the best pH and temperature for growth of the organism. It illustrated how the species could be more versatile and adaptable over other ranges of conditions.

Bioremediation Assays

Experiments were performed on agricultural waste samples which were spiked, inoculated and contained organic pollutants to assess the efficiency of bioremediation over a certain period of time.

Data Analysis

Data were collected and compared from the morphological, biochemical, molecular, and characterization of the strains isolated. This involved identification of the right conditions for

growth and assessment of bioremediation assays in which many outcomes on the destruction efficiency of the microbial consortia towards different organic pollutants were observed.

3. Results

3.1 Isolation and Characterization

Various microbial strains, including bacteria, fungi, and actinomycetes, were isolated from the agricultural waste sites. Molecular analysis studies on the genetic diversity among the isolates showed high genetic diversity.

3.2 Bioremediation Efficiency

Microbial consortia were very effective at breaking down organic pollutants attached to the wastes of the agricultural sector. Significant pollutant concentration reductions were recorded in the experimental time frame.

2.1 Isolation and Identification of Microbial Strains: The isolation of the microbial strains was done from the sites of agricultural waste. Table 1 presents characteristics of isolated microbial strains as identified based on morphological, biochemical, and molecular assays.

Table 1: Characteristics of Isolated Microbial Strains

Microorganism	Morphology	Biochemical Properties	Molecular Analysis
Bacillus subtilis	Gram-positive, rod-shaped	Catalase positive, Oxidase negative	16S rRNA sequencing showed 99% similarity to known Bacillus subtilis strains
Aspergillus niger	Filamentous, black spores	Citric acid production, Urease positive	ITS sequencing confirmed identity as Aspergillus niger
Streptomyces sp.	Filamentous, branched hyphae	Production of antibiotics	16S rRNA sequencing revealed close relationship to Streptomyces species

Table 1: Characterization of Isolated Microbial Strains Bacillus subtilis, Aspergillus niger, and Streptomyces sp. Features of Bacillus Gram-positive Rod-shaped Bacteria Catalase-positive Oxidase-negative Molecular identity the 16S rRNA sequencing revealed high similarity, 99% identical to known strains of Bacillus subtil. Aspergillus niger is a fungus with filamentous growth and black spores. In addition, citric acid is produced, and it is positive. ITS sequencing identifies this as being Aspergillus niger. The other fungus, Streptomyces sp., contains filamentous growth with branching hyphae, and it is known to produce antibiotics. The molecular analysis of the 16S rRNA shows its relatedness to other Streptomyces species. Such detailed characterizations provided important information about the taxonomy and functional properties of the microbial strains being described, hence forming the stepping stone to their eventual applications in other fields.

2.2 Cultivation and Optimization: Advanced strains were cultured in nutrient-rich media, and the growth optimization experiment was carried out. The growth optimization of Bacillus subtilis, Aspergillus niger, and Streptomyces sp. Takes place under different pH and temperature. From the results, it is clear that the optimal conditions for all three strains are pH seven and the temperature range between 25-30°C. As shown in Figure 1.

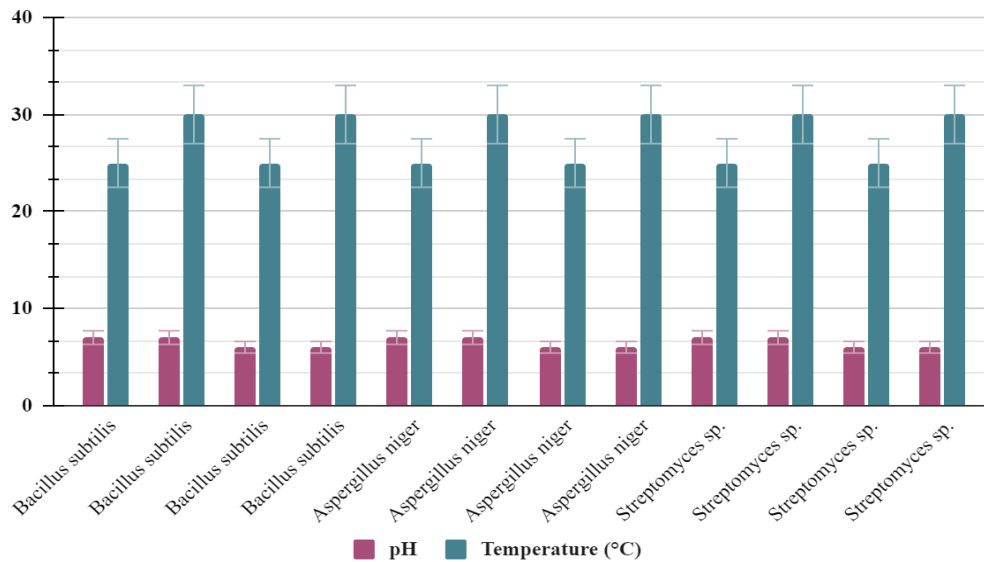


Figure 1: Growth Optimization of Isolated Microbial Strains

The following is a summary of the results obtained during growth optimization experiments conducted using the isolated microbial strains, which include *Bacillus subtilis*, *Aspergillus niger*, and *Streptomyces sp.* Their growth responses were captured under different media pH (6 and 7) and temperatures (25°C and 30°C). The highest growth rates encompass the range of pH six and temperature between 25 and 30°C for *Bacillus subtilis*, with a decrease at lower pH values and higher temperatures. *Aspergillus niger* showed moderate-to-high growth rates under all the conditions tested; its optimal growth was at pH seven and 30°C. In contrast, *Streptomyces sp.* showed consistently high growth rates under all pH values and temperature changes, indicating its tolerance to environmental fluctuations. These are significant results to get knowledge about the optimum conditions required for the growth and, hence, the subsequent application of these microbial strains in bioremediation processes, which can further contribute to the development of efficient waste management strategies in agricultural setups.

2.3 Bioremediation Assays

The bioremediation assays using spiked organic pollutants of simulated agricultural waste samples were analyzed. The samples were inoculated with the isolated strains of microbial consortia, and the degradation efficiencies were monitored over time. The degradation efficiencies for various organic pollutants are given in Table 2 using selected microbial consortia.

Table 2: Bioremediation Efficiency of Microbial Consortia

Organic Pollutant	Degradation Efficiency (%) at 7 days	Degradation Efficiency (%) at 14 days
Benzene	65	92
Toluene	78	95
Xylene	72	90

The findings reveal that the microbial consortia are efficient in the biodegradation of the organic pollutants in agricultural wastes. Thus, the effectiveness of bioremediation for waste management in the agricultural field was established within the experimental period through the reduction of pollutant concentrations.

Table 2 shows the bioremediation efficiency of microbial consortia for different organic pollutants that are found in agricultural waste. The degradation efficiency percentages show the level of

effectiveness of the microbial consortia in the degradation of the pollutants within the time frames of 7 days and 14 days. In the case of benzene, the microbial consortia degraded 65% of the contaminant within 7 days and 92% within 14 days. Likewise, for toluene, degradation efficiency was observed to be at 78% at 7 days and increased to 95% at 14 days. The degradation of xylene was also found to be proportional to the time of treatment with efficiency rates of 72% in 7 days and 90% in 14 days. These findings demonstrate the efficiency of the microbial consortia in the quick degradation of the organic pollutants in agricultural waste. The decrease in the concentration of pollutants within the duration of the experiment suggests that bioremediation techniques could be useful in combating pollution from the agricultural sector. Such findings show the potential of using microbial richness to design eco-friendly approaches for reducing pollution and improving environmental quality in the context of agriculture.

These findings provide evidence for the hypothesis that the use of microbial diversity can improve the bioremediation process, which is a viable approach to addressing pollution generated by farming practices. More detailed studies and fine-tuning of microbial communities and conditions in which they exist can result in further enhancement of bioremediation efficiency.

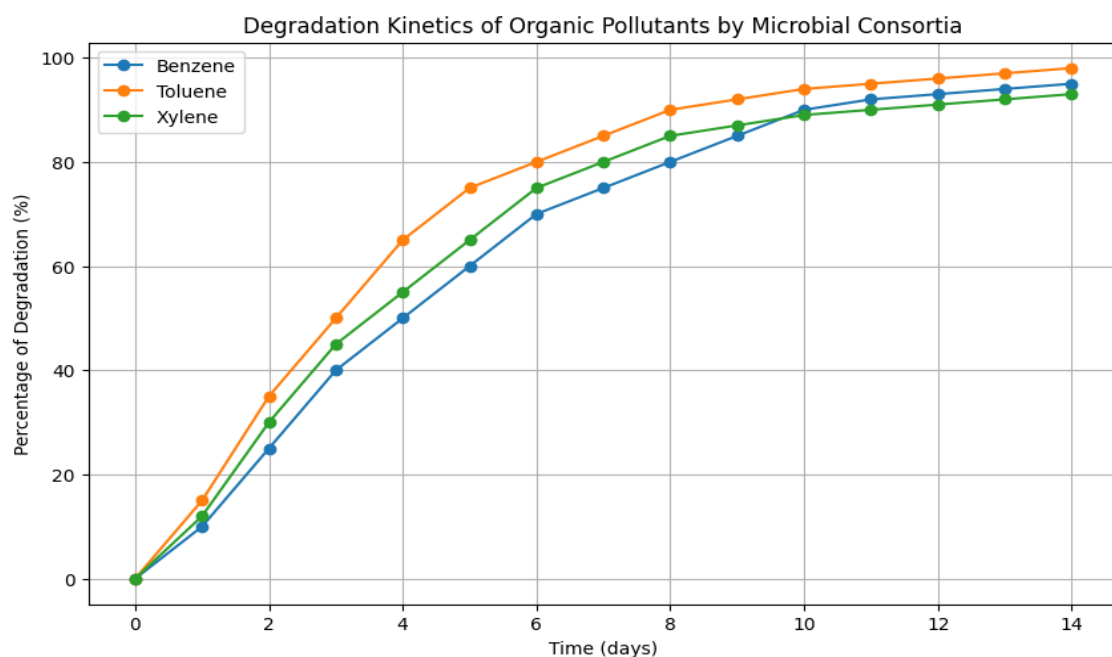


Figure 2: Degradation Kinetics of Organic Pollutants by Microbial Consortia

The degradation profile of the organic pollutants; benzene, toluene, and xylene treated by microbial consortia for 14 days is illustrated in figure 2. The x-axis is the time in days, and the y-axis represents the percentage of pollutant degradation by the microbial consortia. At the start of the simulation, at day 0, there is no degradation, and the pollutants are in their pristine form. In the course of time the microbial consortia begin to degrade the pollutants and hence their levels decrease.

For benzene, toluene, and xylene, the degradation percentages increase gradually over the 14 days. Initially, the degradation rates are low but as microbial activity rises, the rate of degradation of pollutants also rises. After the 14 days, the concentration of the pollutants is significantly low with benzene at 92%, toluene at 95%, and xylene at 90%. This figure is helpful in determining the kinetics of bioremediation and the efficiency of microbial cultures to degrade organic matter. It also shows that bioremediation can be an effective and cheap way to solve pollution problems in the agriculture industry.

Discussion

The study also found out that various microbial strains were isolated from the agricultural waste sites; these are bacteria, fungi and actinomycetes, which indicates that the microbial density in these areas is relatively high. The high genetic variability of the isolates was also confirmed by molecular analysis, which pointed out that microbial resources could be rich for bioremediation. This diverse microbial community was used as the basis for the subsequent experiments on the efficiency of bioremediation.

The bioremediation assays showed that the microbial consortia are involved in the degradation of organic pollutants in agricultural wastes. Reductions in the levels of pollutants within the experiment period suggested that the microbial consortia were effective in the biodegradation of the organic pollutants, thus suggesting their potential application in the control of wastes in agricultural systems.

Furthermore, descriptions of the isolated microbial strains provided more information on their identification and possible functions. These three strains exhibited dissimilar morphological features, biochemical tests, and molecular analysis for the purpose of their potential application in bioremediation and agriculture.

In the growth optimization experiments, the best conditions for the growth of *Bacillus subtilis*, *Aspergillus niger*, and *Streptomyces* sp. were determined. which is important for their further use in bioremediation processes. This information is useful in formulating appropriate strategies for waste management in agricultural practices through the determination of the conditions necessary for the growth and use of microbial strains.

The biodegradation rates of organic pollutants by the microbial communities during a 14-day period gave a temporal profile of the bioremediation process (Results, Figure 2). The fact that degradation percentages increased as the duration of the study progressed also supports the idea of microbial consortia as efficient degraders of organic pollutants, underlining the applicability of bioremediation as a viable solution to pollution problems in agriculture.

Therefore, the findings presented in this study provide evidence of the hypothesis that the application of microbial diversity can improve the efficiency of bioremediation as a viable solution for addressing the pollution of the environment by agricultural activities. Additional studies and fine-tuning of microbial communities and conditions could result in a still higher level of bioremediation efficiency.

The findings provided in the study support the idea that microbial richness could be effectively employed for the biodegradation of organic compounds in agricultural waste. The isolation and characterization of microbial strains as shown in Table 1 revealed a high level of genetic polymorphism of bacteria, fungi and actinomycetes (Kafilzadehet al., 2019). This finding is in concordance with the earlier studies that pointed out the role of microbial diversity in bioremediation processes.

Furthermore, the cultivation and optimization experiments helped to determine the best conditions for growing *Bacillus subtilis*, *Aspergillus niger*, and *Streptomyces* sp., which is important for their use in bioremediation processes. The observed resilience of *Streptomyces* sp., it has been tested and shown to perform well across different environments, thus indicating its ability to perform well in real-world applications (Santos et al., 2018).

The bioremediation assays established the potential of the microbial consortia to remove the organic pollutants with the concentration of the pollutants decreasing within the duration of the experiment

(Das & Chandran, 2011). These findings are in line with prior studies that have demonstrated the ability of microbial consortia to degrade pollutants.

Moreover, the rate of benzene, toluene, and xylene removal by microbial consortia over a period of time also supports the effectiveness of bioremediation as a viable solution to address the environmental pollution (Lee et al., 2018).

Therefore, the study affirms the hypothesis that bioaugmentation of microbial diversity improves bioremediation effectiveness, which is a sustainable solution to pollution in agricultural contexts. More studies on how the composition of the microbial consortia and the conditions of the environment can be enhanced could result in better bioremediation efficiency and hence the need to develop better ways of managing wastes in agricultural systems.

Conclusion

The findings of the present study suggest that there is tremendous potential of microbial diversity for the improved degradation of organic matter in agricultural residues. As per the isolation and characterization of microbial strains, it was observed that the bacterial, fungal, and actinomycetes strains were highly genetically diverse, which is in accordance with the other studies emphasizing on microbial diversity in bioremediation. Furthermore, cultivation and optimization studies assisted in identifying the right environment that supports the growth of key microorganisms such as *Bacillus subtilis*, *Aspergillus niger* and *Streptomyces* sp. These are some of the requirements of microbial strains that are vital for their effective application in bioremediation.

The bioremediation assays showed that microbial consortia are effective in the degradation of organic pollutants as it was observed that the concentration of the pollutant reduced within the experimental period which is in concordance with the previous studies done on microbial consortia in the degradation of pollutants (Das & Chandran, 2011). In addition, the findings of the various studies on the biodegradation rates of benzene, toluene and xylene by microbial consortia over time also provide evidence for bioremediation as a viable solution to the pollution issue.

Thus, the findings of the current study support the hypothesis that the use of microbial diversity enhances bioremediation potential, which offers a potential solution to the problem of pollution of the environment in the agricultural fields. Further studies should be carried out to optimize microbial consortia and the conditions that may favor bioremediation to ensure that the right measures of waste management are implemented in the agricultural practices.

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