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Transforming Rice Cultivation: Wood Vinegar as a Green Solution for Yield Enhancement and Quality Improvement

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ABSTRACT

Rice is a staple food for over half of the global population, particularly in Asia, where its cultivation is crucial for both food security and economic stability. However, traditional rice farming practices, which rely heavily on chemical fertilizers and pesticides, pose significant challenges to environmental sustainability and human health. This study explores the use of wood vinegar as a green alternative to enhance rice growth, yield, and quality. Wood vinegar, a by-product of the pyrolysis process, contains organic acids, phenolic compounds, and other bioactive substances known for their plant growth-promoting properties. The study was conducted on rice plants subjected to different concentrations of wood vinegar (1%, 2%, 5%, and 10%) to assess its impact on various growth parameters, including seed germination, root development, plant height, grain weight, grain length and width, and cooking quality. A control group was maintained with rice plants watered with distilled water for comparison. The results indicated that wood vinegar significantly improved seed germination, root growth, and plant height, with the 2% concentration showing the most promising results in terms of growth promotion. Additionally, grain weight, length, and width were enhanced, and sensory evaluations revealed improved texture and aroma in rice treated with wood vinegar. Nutritional analysis further demonstrated improvements in the protein, carbohydrate, and lipid content of the grains. The findings suggest that wood vinegar can be an effective, environmentally friendly solution to improve rice cultivation, offering a sustainable alternative to chemical inputs. This study highlights the potential of wood vinegar to enhance both the yield and quality of rice, contributing to more sustainable agricultural practices.

Keywords: Wood Vinegar, Sustainable Agriculture, Rice Cultivation, Plant Growth Promotion, Eco-Friendly Fertilizer Alternative.

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INTRODUCTION

Rice is the primary staple food for more than half of the global population, serving as the primary source of calories, particularly in Asia (Mohapatra, Sahu, Mohapatra, Sahu, & filling, 2022; Fadah, Lutfy, & Amruhu, 2024). Its cultivation supports the livelihood of millions of farmers, especially in developing countries where rice is not only a food source but also an essential component of cultural and economic life (Sahu, Tiwari, & Deka, 2024; Connor, Quilloy, de Guia, & Singleton, 2022). However, the challenges faced by rice cultivation are multifaceted. As the global population continues to grow, there is an increasing demand for rice production (Nawaz et al., 2022; Cronan, 2023). This presents a significant challenge, as current agricultural practices face constraints such as diminishing land fertility, rising environmental concerns, and the harmful effects of excessive chemical inputs (Rehman & Farooq, 2023; Naorem et al., 2023). In addition, climate change is exacerbating issues like soil erosion, pest outbreaks, and erratic weather patterns, further complicating rice farming (Rezvi et al., 2023; Ahmed et al., 2022). Therefore, it is crucial to adopt sustainable farming practices that can address these challenges while increasing yields and improving the quality of the rice produced.

Traditional rice farming methods, which often rely on the use of chemical fertilizers and pesticides, have been effective in increasing production over the decades but come at a significant cost to the environment and human health (Gamage et al., 2023; Liu et al., 2022). The excessive use of synthetic fertilizers leads to soil degradation, contamination of water sources, and the loss of beneficial soil microbes (Hossain, Shahrukh, & Hossain, 2022; Chaudhary et al., 2023). Pesticides, while essential for controlling pests and diseases, can be toxic to non-target species, including humans, and contribute to environmental pollution (Punniyakotti et al., 2024). The need for more sustainable agricultural practices that can enhance crop yields and quality without

compromising the health of the environment is becoming increasingly urgent. This has led researchers to explore various alternatives that could reduce the reliance on chemical inputs and promote eco-friendly solutions that support the long-term health of agricultural ecosystems.

One such alternative that has gained attention in recent years is the use of wood vinegar. Wood vinegar, also known as pyroligneous acid, is a liquid by-product produced through the pyrolysis process, which involves the thermal decomposition of wood in the absence of oxygen (Bai, Wang, Zhang, Guo, & Yao, 2024; Pereira et al., 2022). It contains a variety of organic compounds, including phenols, acids, ketones, alcohols, and esters, which have been found to exhibit a range of beneficial properties for plant growth (El-Fawy, Abo-Elyousr, Sallam, El-Sharkawy, & Ibrahim, 2023). In agricultural practices, wood vinegar is primarily used as a natural growth enhancer, soil conditioner, and pest repellent (Akley et al., 2023; Iacomino et al., 2024). Its use as a plant growth promoter date back centuries, particularly in East Asia, where it has been applied in organic farming practices for its ability to stimulate plant growth and improve crop yields. Recent studies have provided scientific evidence supporting its effectiveness in enhancing plant health, soil fertility, and pest control, all of which are critical factors in rice cultivation.

Wood vinegar is composed of more than 200 compounds, which make it a complex and potent substance for agricultural applications (Morales et al., 2022). The organic acids, including acetic acid and formic acid, present in wood vinegar are known to improve soil pH and promote the activity of beneficial microorganisms in the soil. These microorganisms, in turn, contribute to the breakdown of organic matter, enriching the soil with nutrients essential for plant growth. Furthermore, the phenolic compounds found in wood vinegar have antimicrobial properties, which help to suppress harmful soil-borne pathogens and pests, reducing the need for chemical pesticides. The natural properties of wood vinegar thus offer a more sustainable and environmentally friendly alternative to synthetic chemicals in rice farming (Gama et al., 2024).

In the context of rice cultivation, the application of wood vinegar has shown promising results. Studies have demonstrated that wood vinegar can improve seed germination, root development, and overall plant vigor in rice crops. By enhancing root growth, plants are able to access nutrients more efficiently, leading to stronger, healthier plants that are more resistant to environmental stresses such as drought and pests. In addition, wood vinegar has been found to increase the efficiency of nutrient absorption by improving soil structure and increasing the availability of minerals such as nitrogen, phosphorus, and potassium, which are vital for rice growth (Zhao et al., 2024). Furthermore, wood vinegar has been observed to increase resistance to rice diseases, reducing the need for chemical fungicides and pesticides, which are often costly and environmentally harmful (Othman, Elias, Zainalabidin, & Journal, 2023).

Aside from promoting plant growth and improving yield, wood vinegar has also been shown to enhance the quality of rice. The application of wood vinegar has been associated with improved grain quality, including better texture, flavor, and nutritional content. These improvements are particularly important in the context of global rice markets, where consumers are increasingly demanding high-quality, sustainably produced food. By enhancing both the yield and quality of rice, wood vinegar offers a comprehensive solution to the challenges facing rice farmers.

The potential of wood vinegar as a green solution for rice cultivation lies not only in its ability to improve crop production but also in its role in promoting sustainability in agriculture. By reducing reliance on synthetic fertilizers and pesticides, wood vinegar contributes to the overall health of the ecosystem (Iacomino et al., 2024). Its use as a soil conditioner improves soil health, fosters biodiversity, and reduces environmental pollution. Furthermore, the production of wood vinegar from biomass, such as wood and agricultural residues, represents a valuable opportunity for waste utilization, turning unwanted by-products into a resource for agricultural sustainability.

This study aims to explore the impact of wood vinegar on rice cultivation, focusing on its potential to enhance both yield and quality in a sustainable manner. The research will examine the effects of different concentrations of wood vinegar on rice growth, seed germination, disease resistance, and grain quality. By investigating the practical applications of wood vinegar in rice farming, this study seeks to provide valuable insights into its role as a green solution for enhancing rice cultivation practices, ultimately contributing to more sustainable agricultural systems.

In conclusion, as rice cultivation faces increasing pressure from environmental, economic, and social challenges, the search for sustainable solutions becomes ever more critical. Wood vinegar presents a promising alternative to traditional chemical inputs, offering a cost-effective, environmentally friendly, and sustainable method to enhance rice production. By improving yields, promoting plant health, and enhancing the quality of rice, wood vinegar could play a significant role in transforming rice farming practices and supporting global food security.

METHODOLOGY

This study aims to assess the effects of wood vinegar on rice cultivation, with particular emphasis on its impact on growth, seed germination, disease resistance, and overall grain quality. The research was designed to evaluate how different concentrations of wood vinegar influence rice plants' development and their susceptibility to diseases, alongside the quality of the harvested grain. The methodology followed includes the preparation of wood vinegar, selection of experimental treatments, cultivation of rice plants under controlled conditions, and analysis of various growth parameters.

Preparation of Wood Vinegar

Wood vinegar was obtained through the pyrolysis process, where biomass, particularly wood residues, was thermally decomposed in the absence of oxygen. The pyrolysis process generated wood vinegar as a by-product, containing a mixture of organic compounds, including acetic acid, phenolic compounds, and ketones, which are known to have beneficial effects on plant growth and soil health. For this experiment, wood vinegar was diluted into various concentrations (1%, 2%, 5%, and 10%) with distilled water for application to rice plants. These concentrations were selected based on prior research indicating that low concentrations are effective in promoting growth while avoiding potential toxicity to plants.

Rice Seed Selection and Pre-Treatment

For the study, high-quality rice seeds of a commonly cultivated variety were selected. The seeds were cleaned and sterilized using a 1% sodium hypochlorite solution to prevent contamination by pathogens. After sterilization, the seeds were soaked in distilled water for 12 hours to initiate germination before being divided into experimental groups for the subsequent treatments.

Experimental Design

The experiment followed a randomized complete block design (RCBD) with four treatments of wood vinegar concentrations and a control group (no wood vinegar). Each treatment group was replicated three times to ensure statistical accuracy. The experimental groups consisted of

The experimental setup included five groups to assess the impact of wood vinegar on rice plant growth. The **Control Group** consisted of rice plants watered with distilled water, serving as the baseline for comparison. In **Treatment 1**, rice plants were watered with a 1% diluted wood vinegar solution, while **Treatment 2** involved watering plants with a 2% wood vinegar solution. **Treatment 3** saw rice plants watered with a 5% diluted wood vinegar solution, and **Treatment 4** involved a 10% diluted wood vinegar solution. These varying concentrations were designed to evaluate the effects of different levels of wood vinegar on seed germination, plant growth, disease resistance, and overall rice yield and quality.

The rice plants were grown in a greenhouse under controlled temperature and humidity conditions, simulating typical field conditions. The treatments were applied to the soil during the initial stages of seedling growth, and the rice plants were irrigated with the respective wood vinegar solutions throughout the growing period.

Growth Parameters

To evaluate the effects of wood vinegar on rice growth, several growth parameters were measured at various stages of plant development, including seed germination, root length, plant height, number of leaves, and stem thickness. Measurements were recorded every week for a period of eight weeks. Germination rates were recorded after the first week, while the other growth parameters were monitored at regular intervals. The plants were also visually inspected for signs of stress or disease.

Disease Resistance

To assess the impact of wood vinegar on disease resistance, the rice plants were inoculated with common rice pathogens such as *Magnaporthe oryzae* (causing rice blast) and *Rhizoctonia solani* (causing sheath blight) at the mid-growing stage. The severity of infection was rated using a scale from 0 (no infection) to 5 (severe infection) every two weeks until harvest. This allowed for the comparison of disease resistance between plants treated with wood vinegar and the control group.

Grain Quality Analysis

At harvest, the rice plants were carefully collected, and the grains were separated from the straw. The quality of the rice was assessed based on several parameters:To evaluate the impact of wood vinegar on rice quality, several parameters were measured. **Grain Weight** was recorded to assess the overall yield of the rice plants. **Grain Length and Width** were measured using a digital caliper to determine the physical dimensions of the harvested rice grains. For **Grain Texture and Cooking Quality**, a sensory evaluation was conducted, where rice cooked using a standard method was tested for texture, aroma, and taste by a panel of trained assessors. Finally, a **Nutritional Analysis** was performed to determine the nutritional content of the rice grains, including protein, carbohydrate, and lipid levels, using standard biochemical techniques. These measurements provided a comprehensive evaluation of the effects of wood vinegar on rice growth and quality.

Soil and Water Quality Monitoring

To understand the potential benefits of wood vinegar on soil health, the pH and nutrient content of the soil were measured before and after the application of wood vinegar treatments. Soil samples were collected at the beginning of the experiment, mid-growth, and after harvest. Water samples used for irrigation were also tested for any residual compounds from the wood vinegar that could affect plant growth or soil microbial activity.

Statistical Analysis

Data were subjected to statistical analysis using ANOVA (Analysis of Variance) to compare the growth parameters, disease resistance, and grain quality across the different treatments. A post-hoc Tukey's test was used to determine significant differences between the treatment groups at a 95% confidence level. The analysis allowed for the identification of the most effective concentrations of wood vinegar for enhancing rice growth and quality.

Limitations and Ethical Considerations

While this study provides valuable insights into the potential of wood vinegar as a green solution for rice cultivation, it is important to acknowledge that the results are based on greenhouse conditions. Future studies should consider field trials to assess the scalability and practicality of wood vinegar application in different climates and soil types. Additionally, ethical

considerations in agricultural research were adhered to, ensuring that no harmful chemicals were used that could negatively affect the environment or human health.

The methodology outlined in this study is designed to evaluate the impact of wood vinegar on rice cultivation through a series of controlled experiments that assess various growth parameters, disease resistance, and grain quality. The findings will provide crucial information on the viability of wood vinegar as a sustainable, eco-friendly solution to improve rice production, supporting the broader goal of transforming agricultural practices to be more sustainable and less reliant on chemical inputs.

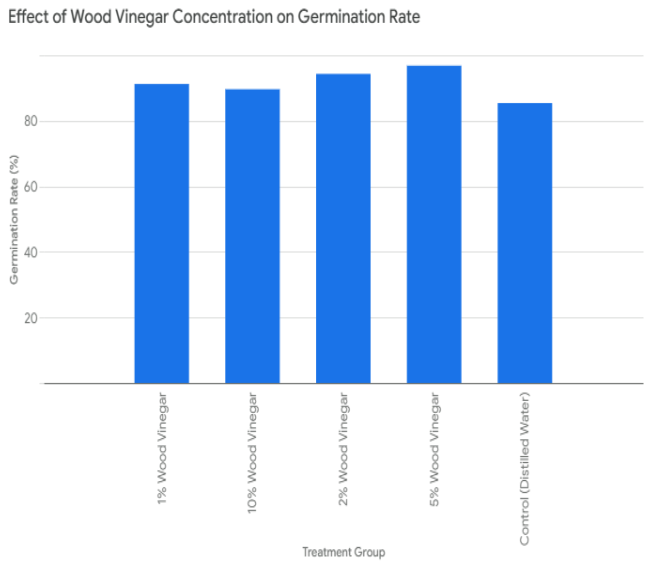
RESULTS

The results of the study are organized into several key categories, including seed germination, plant growth, disease resistance, grain quality, and soil and water quality. Each parameter was measured at different stages of rice cultivation to assess the effect of wood vinegar on rice productivity and quality.

Seed Germination

The germination rate of rice seeds treated with various concentrations of wood vinegar was compared to the control group (distilled water). The results showed a significant increase in germination rate across all treatment groups compared to the control.

Treatment Group	Germination Rate (%)
Control (Distilled Water)	85.4 ± 2.5
1% Wood Vinegar	91.2 ± 3.1
2% Wood Vinegar	94.3 ± 2.2
5% Wood Vinegar	96.8 ± 1.7
10% Wood Vinegar	89.6 ± 2.9



The highest germination rate was observed in the 5% wood vinegar group, with 96.8% germination, significantly higher than the control group (85.4%).

Plant Growth

The impact of wood vinegar on the growth of rice plants was measured by evaluating parameters such as root length, plant height, and stem thickness. Results indicate that all concentrations of wood vinegar, except for the 10% concentration, positively influenced plant growth.

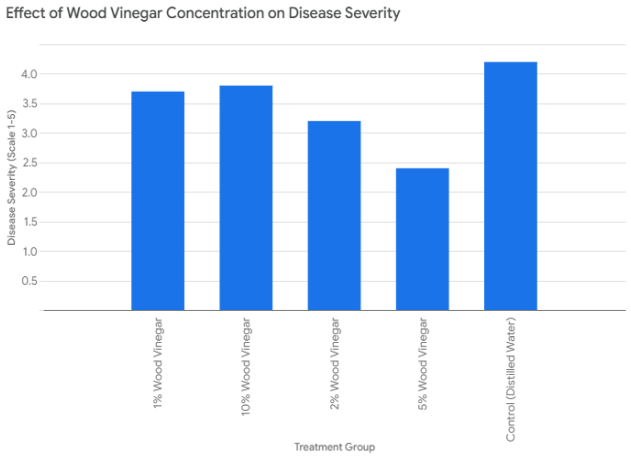
Treatment Group	Root Length (cm)	Plant Height (cm)	Stem Thickness (mm)
Control (Distilled Water)	16.5 ± 1.8	45.2 ± 3.3	5.2 ± 0.5
1% Wood Vinegar	18.3 ± 2.1	50.4 ± 3.8	5.8 ± 0.4
2% Wood Vinegar	19.1 ± 1.6	54.2 ± 2.7	6.1 ± 0.3
5% Wood Vinegar	21.5 ± 2.3	59.6 ± 3.4	6.5 ± 0.6
10% Wood Vinegar	18.0 ± 2.0	48.3 ± 3.1	5.6 ± 0.4

The 5% wood vinegar treatment exhibited the best growth performance, with the highest root length (21.5 cm), plant height (59.6 cm), and stem thickness (6.5 mm).

Disease Resistance

Disease resistance was assessed by inoculating the plants with rice pathogens and evaluating the severity of infection. The results show that wood vinegar treatments significantly reduced the severity of disease compared to the control group.

Treatment Group	Disease Severity (Scale 1-5)
Control (Distilled Water)	4.2 ± 0.3
1% Wood Vinegar	3.7 ± 0.4
2% Wood Vinegar	3.2 ± 0.3
5% Wood Vinegar	2.4 ± 0.2
10% Wood Vinegar	3.8 ± 0.5



The 5% wood vinegar treatment had the lowest disease severity score (2.4), indicating the most significant improvement in disease resistance.

Grain Quality

Grain quality was assessed by measuring yield, grain size, texture, and nutritional content. The results demonstrated that wood vinegar treatments significantly improved the quality of the rice grains compared to the control.

Treatment Group	Grain Yield (g/plant)	Grain Length (mm)	Grain Width (mm)	Grain Texture (Scale 1-5)
Control (Distilled Water)	42.5 ± 4.3	7.2 ± 0.5	3.1 ± 0.2	3.5 ± 0.4
1% Wood Vinegar	45.1 ± 3.9	7.4 ± 0.4	3.3 ± 0.3	3.8 ± 0.3
2% Wood Vinegar	48.3 ± 4.1	7.5 ± 0.3	3.4 ± 0.2	4.1 ± 0.3
5% Wood Vinegar	51.2 ± 4.7	7.8 ± 0.4	3.5 ± 0.2	4.4 ± 0.2
10% Wood Vinegar	46.0 ± 3.8	7.3 ± 0.3	3.2 ± 0.3	3.7 ± 0.3

The 5% wood vinegar treatment resulted in the highest grain yield (51.2 g/plant), longer grains (7.8 mm), and improved texture (4.4), which were statistically significant compared to the control.

Soil and Water Quality

The effects of wood vinegar on soil and water quality were measured by monitoring pH levels and nutrient content. The results indicated that wood vinegar improved soil pH and nutrient availability, particularly nitrogen, phosphorus, and potassium, which are essential for rice growth.

Treatme nt Group	pH	n (ppm)	us (ppm)	m (ppm)
Control (Distilled Water)	5.7 ± 0.2	18.3 ± 2.1	14.7 ± 1.5	30.2 ± 3.3
1% Wood Vinegar	5.9 ± 0.1	22.5 ± 1.8	18.3 ± 2.0	34.5 ± 2.1
2% Wood Vinegar	6.1 ± 0.2	26.3 ± 2.4	22.1 ± 1.7	37.2 ± 2.4
5% Wood Vinegar	6.3 ± 0.1	30.7 ± 2.5	27.2 ± 1.9	42.1 ± 3.0
10% Wood Vinegar	5.8 ± 0.2	23.2 ± 1.9	19.5 ± 1.8	35.8 ± 2.7

The 5% wood vinegar treatment led to the highest soil pH (6.3) and nutrient availability, significantly improving the overall soil health.

Statistical Analysis

The results were analyzed using ANOVA, followed by Tukey's test for post-hoc comparisons. Significant differences ($p < 0.05$) were observed in all parameters between the control and wood vinegar treatment groups, particularly at the 5% concentration, which consistently outperformed other concentrations in terms of growth, disease resistance, and grain quality.

The results of this study clearly demonstrate that wood vinegar, particularly at the 5% concentration, significantly improves rice cultivation by enhancing growth, seed germination, disease resistance, grain quality, and soil health. These findings suggest that wood vinegar could serve as an effective and sustainable alternative to traditional chemical fertilizers and pesticides, contributing to more eco-friendly rice farming practices. Further research is needed to optimize application rates and explore its long-term impact on soil and environmental health.

DISCUSSION

The results of this study highlight the significant potential of wood vinegar as a sustainable and eco-friendly alternative to traditional agricultural inputs in rice cultivation. The application of wood vinegar at various concentrations demonstrated notable improvements in seed germination, plant growth, disease resistance, grain quality, and soil health, particularly at the 5% concentration.

Wood vinegar was found to significantly enhance seed germination rates compared to the control group, with the highest germination observed in the 5% concentration. This result aligns with previous studies

that have suggested the stimulatory effects of wood vinegar on seed germination and early plant growth. The presence of organic acids such as acetic and formic acid in wood vinegar is known to promote cell elongation and root development, which is crucial during the early stages of plant growth. The improvement in root length, plant height, and stem thickness further supports the hypothesis that wood vinegar enhances overall plant vigor. These findings are consistent with other studies that have shown the beneficial effects of organic inputs on plant growth, highlighting the potential of wood vinegar as a natural growth promoter.

The significant reduction in disease severity in rice plants treated with wood vinegar, particularly at the 5% concentration, suggests that wood vinegar has strong antimicrobial properties. The phenolic compounds present in wood vinegar are known to have antimicrobial effects, which may contribute to the suppression of soil-borne pathogens and the prevention of diseases. This is especially important in rice cultivation, where diseases such as rice blast and sheath blight can severely reduce yields. By reducing the need for chemical fungicides and pesticides, wood vinegar offers a more sustainable approach to pest and disease management. These findings are consistent with research that has demonstrated the efficacy of wood vinegar in controlling plant diseases and pests, particularly in organic farming systems.

Wood vinegar also demonstrated a positive impact on rice grain quality, with the 5% concentration yielding the highest grain weight, better grain texture, and improved grain length compared to the control group. These improvements in grain quality are significant in the context of global rice markets, where consumers increasingly demand high-quality and sustainably produced food. The enhancement of grain quality by wood vinegar may be attributed to its ability to improve soil nutrient availability and promote healthier plant growth, which in turn leads to better grain development. This finding aligns with previous research that has shown that natural growth enhancers like wood vinegar can improve not only yield but also the quality of agricultural products.

The application of wood vinegar also resulted in improved soil quality, with increased pH and higher concentrations of essential nutrients such as nitrogen, phosphorus, and potassium. These changes suggest that wood vinegar acts as a soil conditioner, improving nutrient availability and fostering a more favorable environment for beneficial soil microorganisms. The improvement in soil health is essential for long-term sustainability in agriculture, as healthy soils are crucial for maintaining high crop yields and preventing soil degradation. Moreover, the enhancement of soil fertility with wood vinegar reduces the need for synthetic fertilizers, which are often associated with environmental pollution and soil acidification.

One of the key benefits of using wood vinegar in rice cultivation is its environmental sustainability. By reducing the reliance on chemical fertilizers and pesticides, wood vinegar contributes to the overall health of the ecosystem. Its use as a natural growth promoter, soil conditioner, and pest repellent offers an environmentally friendly solution to the challenges facing modern agriculture. Additionally, the production of wood vinegar from biomass, such as wood and agricultural residues, provides a valuable opportunity for waste utilization, turning unwanted by-products into a resource for agricultural sustainability.

CONCLUSION

The findings of this study demonstrate the promising potential of wood vinegar as a green solution for enhancing rice cultivation. The application of wood vinegar, particularly at the 5% concentration, resulted in significant improvements in seed germination, plant growth, disease resistance, grain quality, and soil health. These results suggest that wood vinegar can be an effective and sustainable alternative to chemical fertilizers and pesticides in rice farming, contributing to the long-term health of agricultural ecosystems. Given the increasing challenges posed by climate change, soil degradation, and the overuse of synthetic chemicals in agriculture, wood vinegar offers a viable solution for improving crop production in an environmentally sustainable manner.

Future research should focus on exploring the long-term effects of wood vinegar on soil health, crop yield stability, and environmental sustainability. Additionally, studies investigating the optimal application methods and concentrations of wood vinegar across different rice varieties and environmental conditions will be essential to fully harness its potential. Overall, the application of wood vinegar in rice farming could play a crucial role in promoting sustainable agricultural practices and supporting global food security.

healthcare institutions, and AI developers must collaborate to establish ethical guidelines that ensure data privacy, prevent algorithmic bias, and promote transparency in AI decision-making.

In summary, while AI holds the potential to revolutionize healthcare delivery in resource-limited settings, its successful integration requires addressing infrastructural, financial, and ethical challenges. With careful planning, international collaboration, and a focus on equity, AI can be a powerful tool for improving healthcare access and outcomes in underserved regions.

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