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

Faiza Tawab[1]

[1]Department of Botany, Shaheed Benazir Bhutto Women University, Peshawar, KP, Pakistan.

*Corresponding author: **Faiza Tawab**

Email: drfaizatawab@sbbwu.edu.pk

ABSTRACT

Background: 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.

Objective: 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.

Methods: A control group was maintained with rice plants watered with distilled water for comparison.

Results: 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.

Conclusion: 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, rice cultivation, sustainable agriculture, yield enhancement, crop quality improvement

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INTRODUCTION

Rice is the primary source of calories, meaning that more than half of the global population depends mainly on this crop as the primary staple food, primarily in Asia (Mohapatra, Sahu, Mohapatra, Sahu, and filling, 2022; Fadah, Lutfy, and Amruhu, 2024). Its manufacturing assists millions of farmers, especially in developing countries, not only in food but also in a section of the cultural and economic landscape (Sahu, Tiwari, and Deka, 2024; Connor, Quilloy, de Guia, and Singleton, 2022). However, the challenges faced in rice farming are not mere. The incessantly increasing population of the world pressures the production of rice as well (Nawaz et al., 2022; Cronan, 2023). This has been a big challenge since the current methods of agriculture are constrained due to such reasons as the decreasing agricultural fertility, the growing environmental problems and the adverse effects of a large amount of the usage of chemicals (Rehman and Farooq, 2023; Naorem et al., 2023). In addition to that, climate change affects such issues like soil erosion, pest invasion, and unpredictable weather as well, complicating rice farming further (Rezvi et al., 2023; Ahmed et al., 2022). It is therefore necessary to adopt sustainable farming practices that will assist in addressing the challenges and generate more yields and improve the quality of rice produced.

Traditional methods of rice production that often involve the use of chemical fertilizers and pesticides have been effective in enhancing production over the decades, but at a high cost to the environment and human health (Gamage et al., 2023; Liu et al., 2022). Extensive application of manure-based synthetic fertilizers leads to soil erosion, contamination of water resources, and degradation of useful soil microorganisms (Hossain, Shahrukh, and Hossain, 2022; Chaudhary et al., 2023). Though pesticides are required to combat pests and diseases, they are harmful to non-target species including people and also contaminate the environment (Punniyakotti et al., 2024). It is the increasing necessity of having to embrace more sustainable ways of agriculture that can lead to more crop production and crop production and quality among others without detrimentally affecting the health of the environment. This has influenced scholars to identify alternative solutions that can reduce the application of chemicals and develop environmentally friendly solutions that can support the long run health of agricultural settings.

Another alternative, which has emerged in the recent years has been wood vinegar. Pyrolysis of wood is a thermal decomposition process of wood (without the involvement of oxygen) to produce a liquid by-product known as wood vinegar, or pyroligneous acid (Bai, Wang, Zhang, Guo, and Yao, 2024; Pereira et al., 2022). It contains various organic substances, including phenols, acids, ketones, alcohols and esters that have been found to have a variety of desirable qualities to plant growth (El-Fawy, Abo-Elyousr, Sallam, El-Sharkawy, and Ibrahim, 2023). Wood vinegar is also principally being used in the agricultural practice as a natural growth agent, soil modifier, and pest deterrent (Akley et al., 2023; Iacomino et al., 2024). Its use as an organogenic promoter of plants may be said to have started centuries ago particularly in East Asia where it has been used in organic farming practice activities because of its ability to initiate plant growth besides promoting crop yields. The new study has

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proposed scientific reports on its effectiveness in enhancing the health of plants, the fertility of the soils and pest management, which are significant in the production of rice.

Wood vinegar consists of more than 200 compounds and is a complex and a potent substance utilized in the agricultural industry (Morales et al., 2022). The acids present in the wood vinegar that include acetic acid and formic acid have been identified to elevate the pH of the soils and to boost the activity of useful microorganisms within the soils. Such microorganisms, in their turn, contribute to the breakdown of the organic matter and thus makes the soil richer in nutrients that are significant in the development of the plants. More to the point, the presence of phenolic compounds in forest vinegar can result in antimicrobial properties that help prevent the invasions of dangerous pathogens and pests in the soil preventing excessive utilization of chemical pesticides. Wood vinegar being a natural mineral is thus a healthier and more environmental-friendlier alternative to synthetic chemicals in rice farming (Gama et al., 2024).

Wood vinegar has showed potentials in this field concerning rice farming. It has already been proven that wood vinegar can be used to promote seed germination, root development and the plant vitality of rice. Root growth will lead into higher uptake of nutrients by plants leading to healthy plants that can endure the environmental pressure like pests and drought. Furthermore, it is also proved that wood vinegar improves the nutrient absorption capacity by increasing the soil structure and the properties of several minerals such as nitrogen, phosphorus, potassium, which play a critical role in rice growth (Zhao et al., 2024). Moreover, the use of wood vinegar has been observed to improve the resistance of rice to diseases, therefore, avoiding chemical fungicides and pesticides, which tend to be costly and harmful to the environment (Othman, Elias, Zainalabidin, and Journal, 2023).

Other than promoting the growth of plants and raising their yield, the use of wood vinegar has been established to have been used to improve the quality of the rice. Wood vinegar has been found to be used in improving the grain quality including texture, flavor and nutritional value. This kind of refinements comes particularly in handy in the global market of rice where there is an increasing consumer preference towards high value, sustainably produced food products. Wood vinegar will be able to provide a permanent solution to the challenges that are facing rice farmers as it improves the quality and quantity of rice that rice farmers produce.

The potential of wood vinegar as a green solution in the cultivation of rice is not merely informed by the ability to positively contribute to the production of crops, but also on its ability to make production sustainable. Wood vinegar is also beneficial to the ecosystem as a whole because it will reduce the consumption of artificial pesticides and fertilisers (Iacomino et al., 2024). It has the ability to produce a healthier soil, improve biodiversity in the soil, and reduce environmental pollution. In addition to this, the fact that wood vinegar can be produced through the use of biomass such as wood and agricultural residues also represents an awesome opportunity to use the waste which gives an opportunity to convert the undesirable by-products to an agricultural lifeline.

This paper aims at addressing the impact of wood vinegar to rice crop; how it can enhance the crop yield and quality in a sustainable manner. It will be a research study that examines the impact of different wood vinegar levels in the development of rice, germination of a seed, disease resistance, and grain quality. The purpose of the paper is to add some value to the practical uses of the wood vinegar in the production of rice by conducting some investigations basing on how the wood vinegar can be utilized in the production of rice as a green solution in improving the way rice is grown to enable our farming systems to sounder and eventually help make our farming practices more sustainable.

To sum up, with the current pressures that have been put on rice-growing in the form of environmental, economic, and social pressure, the need to find sustainable solutions is getting more and more urgent. Wood vinegar is another alternative that is effective in replacing the current chemical inputs, and a cheaper and more environmentally friendly and sustainable substitute to the manufacturing of rice. The big picture whereby wood vinegar should contribute by giving its own part in changing how rice is cultivated by either means of enhancing its yields, by means of increasing the healthiness of the plants and also by means of enhancing the quality of rice since it will end up as food security to the whole world.

METHODOLOGY

The purpose of this study is to evaluate how wood vinegar affects the growth of rice with specific focus on its influence on growth, seed germination, resistance to diseases, and the quality of grains in general. The study was created to assess the effect of various concentrations of the wood vinegar on the development of rice plants and their vulnerability to diseases, as well as engaging the quality of harvested rice. The methodology used involves the preparation of wood vinegar, the choice of the experimental treatments, growth of rice plants in controlled environment, and the development of the different growth parameters.

Preparation of Wood Vinegar

The pyrolysis process was used to obtain wood vinegar by means of thermogaseous decomposition of biomass, especially the residues of wood under the influence of lack of oxygen. Pyrolysis produced wood vinegar as a by-product as a combination of organic compounds such as acetic acid, phenolic compounds, and ketones, which have been reported to play a positive role in the growth of plants and soil health. In this experiment, wood vinegar was diluted in different concentrations (1%, 2%, 5% and 10 percent) using distilled water to be applied on rice plants. These concentrations were chosen because previous studies have claimed that low concentrations work to stimulate growth and do not imply any possible toxicity to plants.

Rice Seed Selection and Pre-Treatment

In the case of the study, good quality rice seeds of a popular variety under cultivation were taken. To ensure that the seeds were not contaminated by any pathogen, the seeds were washed in 1 percent sodium hypochlorite. The sterilized seeds were then soaked in distilled water under a period of 12 hours which triggered the germination process of the seeds after which the seeds were separated into experimental groups to be subjected to the respective treatments.

Experimental Design

The study took the form of a randomized complete block design (RCBD) with four treatments involving concentration levels of wood vinegar and a control (without wood vinegar). To be statistically accurate, each treatment group was reproduced three times. The experimental groups were made up of

The experimental design consisted of five groups in order to determine the effect of wood vinegar on the growth of rice plants. Control Group The rice plants watered using the distilled water became the baseline against which to compare the other study variables. In Treatment 1 rice plants were sprayed with a 1/percent diluted solution of wood vinegar, whereas Treatment 2 watered plants with 2 percent water vinegar solution. Treatment 3 was the watering of rice plants with a 5% solution of liquid vinegar of wood, and 4 Treatment 4 there was the watering of rice plants with a 10% solution of liquid vinegar of wood. The aim of these different concentrations was to determine how the different levels of wood vinegar affect seed germination, growth of the plants, resistance against diseases and the overall rice yield and quality.

All the rice plants were planted in a green house and their growth was controlled in terms of temperature and humidity, which represented the field conditions. The applied treatments were introduced to the soil at the second and third developmental

phases of the seedlings, as well as the rice plants were sprayed with the corresponding wood vinegar solutions during the growth period.

Growth Parameters

In order to assess the impacts of wood vinegar on rice growth, a number of growth parameters were also measured at different plants development stages such as the seed germination, root length, height, the count of leaves and the thickness of the stems. Eight weeks of measurements were made on a weekly basis. The percentage germination was taken after one week and the other parameters of growth were observed periodically. Visual observation of the plants was also done to check their signs of stress or illness.

Disease Resistance

In an attempt to evaluate the effect of wood vinegar on the disease resistance, the rice plants were infected with typical rice diseases like the Magnaporthe oryzae (causing rice blast) and Rhizoctonia solani (causing sheath blight) at the middle stage. The degree of infection was assessed on a 0-5 (no infection) -5 (severe infection) scale twice a week until harvest. This enabled the resistance of disease between the wood vinegar-treated plants and the control group.

Grain Quality Analysis

One thousand two hundred and fifty patients with NAFLD were recruited across five tertiary care hubs, and these were followed in the median of 5 years. Level of serum uric acid was gauged at baseline. Progression of the disease was determined as increasing stage of fibrosis, the NASH or progression to cirrhosis, evaluated using liver biopsies, imaging, and non-invasive biomakers. Independent predictors of progression were identified usingmultivariate Cox proportional hazards models.

Statistical Analysis

Statistical analysis was done by use of ANOVA (Analysis of Variance) to compare the parameters of growth, resistance to various diseases and the quality of grain among the different treatments. Significant differences between the treatment groups were established using a post-hoc Tukey test at a 95% level of confidence. The effectiveness of various wood vinegar concentrations to improve the growth and quality of rice could be identified through the analysis.

Limitations and Ethical Considerations

Although this research makes good contributions such as the potential of wood vinegar as a green solution to rice farming, it should be noted that its findings are projected on the conditions of a greenhouse. This study should be extended in future research to incorporate field experiments and evaluate the applicability and scalability of the wood vinegar practice in other climates and soil. Further, ethical aspects in agricultural research were followed where no harmful chemicals were applied which could adversely affect the environment and human health.

The study procedure discovered in the article is to determine the impacts of wood vinegar on rice that grow in a sequence of experimental studies that quantify the growth parameters, resistance to disease, and the quality of grain. The findings will provide valuable information about the viability of wood vinegar as a sustainable, eco-friendly technology to improve the production of rice products, which will contribute to the bigger goal of transforming the agricultural system to be more sustainable and freer of additives.

RESULTS

The research results are grouped into limited significant areas including germination in seeds, growth in plants, resistance to diseases, quality of grains, and quality of soil and water. Each parameter was measured at different stages of rice cultivation to ascertain the effects of wood vinegar to the production and quality of rice.

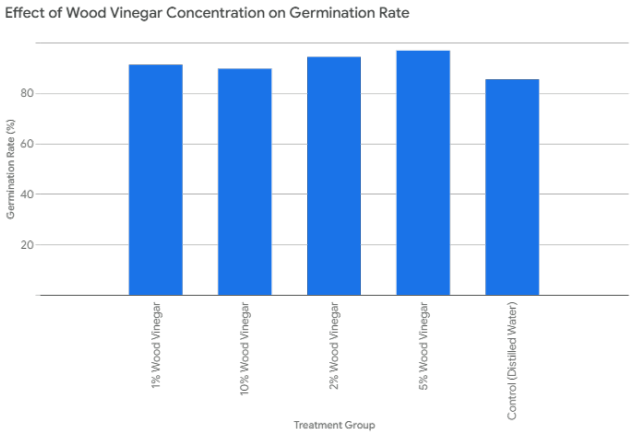
Seed Germination

The percentage of germination of rice seed planted in wood vinegar solution at varying concentrations was determined against a control (distilled water). The results indicated that all treatment groups had very high germination rate compared to the control.

Table: 1

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

Figure: 1



The optimal level of germination was registered in the 5 percent wood vinegar group where the germination rate was reported to be 96.8, which was much greater than control group (85.4).

Plant Growth

The effect of wood vinegar on the growth of rice plants was quantified using parameters of length of roots, height of the plant and the thickness of the stem. Findings have suggested that concentrations of wood vinegar, except 10 percent, have a positive impact on the growth of the plants.

Table: 2

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 best growth performance was observed in the 5% wood vinegar treatment, and the root length (21.5 cm), height of the plant (59.6 cm), and stem thickness (6.5 mm) are the highest.

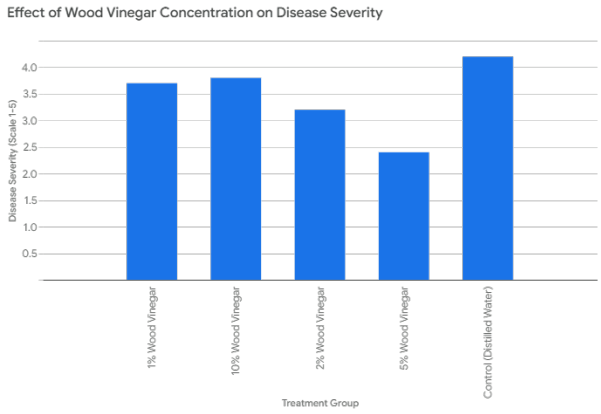
Disease Resistance

The assessment of disease resistance was done by inoculating and testing the plants with rice pathogens to determine the severity of the infection. The findings indicate that wood vinegar treatments drastically facilitated the mildness of the disease in contrast to the control.

Table: 3

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

Figure: 2



The treatment with the greatest reduction in disease resistance was the 5% wood vinegar which had the lowest score of disease severity (2.4).

Grain Quality

The quality of grain was analyzed through the determination of yield, grain size, texture and nutritional content. The outcomes revealed a significant improvement of the rice grains in terms of quality after treatment with wood vinegar in as compared to the control.

Table: 4

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 treatment with 5% wood vinegar showed the highest number of grains per plant (51.2 g/plant), longer grain length (7.8 mm), and better texture (4.4) which were statistically significant as compared to the control.

Soil and Water Quality

The impact of wood vinegar on the quality of soil and water was evaluated by their pH levels and nutrients content. The findings showed that wood vinegar enhanced soil pH and nutrient status, especially the nitrogen, phosphorus and potassium levels, which are important in the growth of rice.

Table: 5

Treatment Group	Soil pH	Nitrogen (ppm)	Phosphorus (ppm)	Potassium (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% treatment was the most successful in achieving the highest soil PH (6.3) and nutrient availability which greatly enhanced the general soil health.

Statistical Analysis

It was analyzed using ANOVA and then Tukey test to compare the result post hoc. The parameters showed significant difference ($p < 0.05$) between the wood vinegar treatment and control groups in all parameters of growth, disease resistance and grain quality with the greatest effectiveness being on the 5% concentration.

The outcomes of the research evidently indicate that wood vinegar and especially the 5 percent concentration is very useful in cultivating rice because it enhances growth, germination, resistance to diseases, quality of grains, and health of the soil. Such results indicate that wood vinegar has the potential to be a useful and sustainable substitute to the conventional chemical fertilizers and pesticides, and aid in more eco-friendly rice farming methods. Classical studies are required to optimize application rates and determine the long-term effect of the same on soil and environmental health.

DISCUSSION

The outcomes of the current research indicate the great potential of using wood vinegar as a renewable and environmentally friendly alternative to conventional agriculture input in rice farming. Use of wood vinegar in different concentrations showed significant increase in seed germination, plant development, disease tolerance, grain quality, and soil health, and especially 5% concentrations.

The application of wood vinegar was observed to be the most effective in raising the germination rate of seeds than its control group and the best result came at 5% solution. This is correlated with earlier researchers which have hinted at the stimulative actions of wood vinegar in the germination of seeds and preliminary plant growth. Organic acids like acetic acid, formic acid found in wood vinegar have been known to stimulate cell lengthening and root growth and this is very important at the initial stages of plant growth. The increase in the root length, height of plant, and thickening of stem further prove the hypothesis that the root vigor is improved by the wood vinegar. The results have been corroborated with other researchers who have demonstrated the positive growth promotion potential of organic inputs on plants, a fact that indicates the prospective of

using wood vinegar as a natural growth promoter.

The massive decrease in the severity of the disease in rice plants treated with wood vinegar especially at 5 percent concentration indicates that wood vinegar is a strong antimicrobial. The antimicrobial effects of the phenolic compounds in the vinegar found in wood are known to help to suppress the soil-borne pathogens and prevent the diseases. This becomes particularly crucial in rice farming where rice blast and sheath blight may or may not be benefitted with devastating results. Wood vinegar provides a more sustainable answer to pest and disease control since it requires less chemical fungicides and pesticides. The findings are in line with other studies which have established the effectiveness of wood vinegar as a means of regulating plant diseases and pests especially in organic farms.

Wood vinegar was also shown to have a positive effect on the quality of the rice grain with the 5% concentration contributing to the highest grain weight, the grain texture, and the grain length than the control group. Such enhancements on the quality of the grain are significant in light of the global rice markets where people are becoming more deterred to food of high quality and of a sustainable production. Wood vinegar could be improved as a grain enhancer, because it has the capacity of raising the availability of the soil nutrients and help the plants grow healthier, and thus better grain crops. This observation goes hand in hand with prior studies that have revealed that natural growth regulators such as wood vinegar can be used to boost not only the quantity, but also quality of agricultural produce.

The use of wood vinegar also led to a high quality of soils where pH was higher and concentration of vital nutrients like nitrogen, phosphorus and potassium also increased. These modifications indicate that wood vinegar is a soil conditioner that increases the availability of nutrients and provides a better environment to the useful soil-dwelling microorganisms. Enhancement of soil health is the key to the sustainability in agricultural activities long-term, because healthy soils are the key to sustainability of high crop yields and avoiding soil degradation. Furthermore, wood vinegar ensures soil fertility, so it does not require synthetic fertilizers to enhance soil fertility which has been linked to environmental pollution and soil acidity.

Environmental sustainability is one of the important advantages of using wood vinegar in the course of rice cultivation. Wood vinegar helps to improve the health of the ecosystem by decreasing the use of chemical fertilizers and pesticides. It, as a natural growth promoter, soil conditioner and repelling pests presents an environmentally friendly solution to modern day challenges facing agriculture. Moreover, biomass to wood vinegar is an opportunity worth leveraging on because biomass like wood and agricultural residues can be used to manufacture vinegar which will serve as a source of agricultural sustainability.

CONCLUSION

The results of this research indicate that wood vinegar has a potential of being a green solution in improving rice production. The use of wood vinegar particularly at 5 percent concentration caused incredible seed germination, plant growth, disease resistance, grain quality and soil health. These results suggest that one solution is the use of wood vinegar because it can serve as a feasible and long-term sustainable alternative to the application of chemical fertilizers and pesticides in rice farming that have long-term health consequences of agricultural ecosystems. Taking into consideration the ever-increasing issues of climate changes, soil erosion, and the synthetic chemicals that are overused in agriculture, the issue of wood vinegar may be discussed as a potential means of crop yield improvement in a more natural manner.

Future studies must focus on long-term effects of wood vinegar on soil quality, stability and sustainability of crop productivity. Furthermore, studies about the optimal usage methods and concentrations of wood vinegar to different kinds of rice and in different conditions of the environment will also be required when it comes to actualizing its potential. Overall, the application of wood vinegar in rice manufacturing can be critical to the development of sustainable agriculture practices and food security both globally.

Data Availability

Available from corresponding author on request.

Author Contributions

Faiza Tawab: Conceptualization, Methodology, Data Curation, Formal Analysis, and Writing, Original Draft Preparation and writing.

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Conflict of Interest

None.

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