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Bamboo-derived wood vinegar improves the growth and yield of corn under varying application levels

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ABSTRACT

Corn is a vital staple crop in the Philippines, but its production heavily depends on chemical fertilizers that can cause soil degradation and nutrient loss. This study aimed to assess the response of corn to varying levels of bamboo-derived wood vinegar on growth performance. The treatments included T0 (control) with 0 mL, T1 with 10 mL, T2 with 20 mL, and T3 with 30 mL of wood vinegar (WV) per liter of water, while T4 received a commercial fertilizer application. Growth parameters such as plant height, cob diameter, and days to silking were measured. Results showed significant differences in plant height ($P=0.040$) at the fourth week, cob diameter ($P=0.021$), and days to silking ($P=0.019$), indicating that wood vinegar enhanced specific growth attributes. However, no significant effects were observed on the number of leaves, days to tassel, ear length, 1000-kernel weight, and biomass percentage. These findings suggest that bamboo-derived wood vinegar can serve as a supplementary growth enhancer, offering a potential eco-friendly alternative to synthetic fertilizers, and it can positively impact specific corn growth parameters. Further studies are recommended to explore other sources of wood vinegar and application methods to maximize its agricultural benefits.

Contribution/Originality: This study is among the first field-based evaluations in the Philippines assessing bamboo-derived wood vinegar on corn. Using the RCBD design, multiple WV concentrations were compared with complete NPK fertilizer, which was applied through repeated soil drenching until silking. Comprehensive measurements provide locally relevant evidence of WV as a potential eco-friendly supplement to synthetic fertilizers.

1. INTRODUCTION

Corn (*Zea mays* L.) is one of the most important staple crops in the Philippines, ranking second to rice in utilizing agricultural resources. Beyond human consumption, it is used in animal feed and various industrial applications, playing a critical role in developing the livestock and manufacturing sectors. However, the overuse of chemical fertilizers to improve crop yield has resulted in significant soil environmental problems, including soil compaction and nutrient depletion (Koch, McBratney, & Lal, 2012). Additionally, the excessive use of chemical fertilizers has led to environmental pollution and health concerns, including the exhaustion of soil organics, poor water retention, and the deterioration of soil structure. Furthermore, long-term application of these fertilizers has caused a decrease in soil fertility and an increase in water and soil losses.

Excessive chemical fertilization pollutes the environment. It leaves harmful residues in crops, compromising the safety and quality of food products. As a result, there is an urgent need to develop sustainable alternatives that can improve crop production without harming the environment. One alternative is wood vinegar, an organic by-product obtained through the distillation, condensation, and separation of plant-derived gases. It has gained widespread attention in recent years for its potential applications in agriculture (Chen, Wu, Si, & Lin, 2016). Wood vinegar contains various organic compounds, including acids, alcohols, phenols, and esters, that have multiple benefits for crop growth and soil health (Sindhu, Zakaria, & Fashya, 2015).

Wood vinegar is highly suitable for use in organic agriculture. As a natural organic compound, it is an effective alternative to many toxic chemicals commonly used in farming. Wood vinegar is known to promote growth and increase the yield of field crops (Yongyuth, Chandumpai, & Faroongsarng, 2018). Furthermore, it functions as a plant growth regulator analog, and when applied at appropriate concentrations, it can benefit crop development (Flematti, Ghisalberti, Dixon, & Trengove, 2004; Nelson, Flematti, Ghisalberti, Dixon, & Smith, 2012).

Several studies have shown the different utilization of wood vinegar for crops, soils, and animals, such as enhancing crop yields and nutrient uptake by plants, followed by its application in agricultural soils (Jeffery, Verheijen, Van Der Velde, & Bastos, 2011) as an odor remover, animal feed additive, and agricultural uses such as an insect repellent, and soil or foliar fertilizer (Mohan, Pittman Jr, & Steele, 2006). In rice (*Oryza sativa*), wood vinegar-primed seeds resulted in more remarkable shoot growth and plant population at maturity, while GA3-primed seeds had more rapid germination. Yield-related agronomic performance characteristics, such as tiller plant−1 and yield in ton ha−1, were significantly higher for primed seed, and weed biomass was reduced considerably (Simma et al., 2017). In cucumber (*Cucumis sativus*), there was an increase of 20.9% and 5.02%, respectively ($P < 0.05$), when added with wood vinegar at the 10,000-fold dilution, as revealed by Lei, Zhang, Chen, and Wang (2022). In tomato (*Solanum lycopersicum* L.), the application of wood vinegar (WV) and FB, alone or in combination, showed slight increases in total plant dry weight, fruit number, fruit fresh weight, and fruit dry weight, but significantly enhanced the total soluble solutes of tomato fruit ($P<0.01$) (Mungkunkamchao, Kesmala, Pimratch, Toomsan, & Jothityangkoon, 2013). Moreover, wood vinegar (bamboo-sourced) as a potential insecticide was tested against fruit flies and exhibited equivalent insecticidal properties to commercial insecticides in eliminating D. melanogaster, with 2.37 mortalities min^{-1} for pure bamboo vinegar and 4.40 mortalities min^{-1} for commercial insecticide. The time difference in terminating fruit flies was only 2 minutes (Alias et al., 2020).

In swine (*Sus scrofa*), wood vinegar has been shown to provide beneficial effects. Pigs fed 0.1%, 0.2%, and 0.3% wood vinegar diets exhibited significantly higher average daily weight gain (ADWG) and average daily feed intake (ADFI) than those without wood vinegar supplementation (Choi, Shinde, Kwon, Song, & Chae, 2009). Another study revealed that bamboo vinegar diets resulted in a significantly higher average daily weight gain (ADWG) and gain: feed (G:F) ratio in pigs compared to a control group from 0 to 3 weeks and 0 to 6 weeks (Yan, Kim, & Huh, 2012). Furthermore, a significantly higher ($p=0.048$) bi-weekly cumulative body weight (BCWG) gain at week 4 was noted in pigs given 5% bamboo-sourced wood vinegar (Macasait, Roylo, & Espina, 2021). In broilers (*Gallus gallus domesticus*), a recent study revealed that the varying concentrations of bamboo-sourced wood vinegar resulted in a significant difference in the WFI of the broilers at days 9-15 ($p = 0.013$) and 16-22 ($p = 0.005$). Despite insignificant results of this study regarding cumulative weight gain, 4% wood vinegar addition produced numerically higher cumulative weight gain among treatments (Vistal, Macasait Jr, & Espina, 2021).

Applying wood vinegar and its different sources to other crops in the Philippine setting is still exploratory. Few studies are available on systematic research on growth and response, such as development, yield, quality, and resistance of different crops given wood vinegar (especially bamboo-sourced). Further, the Philippine Department of Agriculture Region 8 promotes using wood vinegar as a soil amendment for crops and livestock feed supplement by establishing wood vinegar plants (Department of Agriculture Region 8, 2013). The effects of wood vinegar produced by bamboo plants have not yet been investigated in many crops, such as corn. Therefore, this study aimed to assess the response of corn to varying levels of bamboo-sourced wood vinegar.

2. MATERIALS AND METHODS

A total area of 240 m^2 was plowed, harrowed, pulverized, and divided into four (4) main plots with dimensions of 15 m x 4 m. Each plot was further subdivided into five (5) subplots measuring 3 m x 4 m. A total of 1280 (HYBRID 101 BT GT) seeds were acquired from the AgriVet store and used for this study. The bamboo-sourced wood vinegar (WV) was obtained from the Department of Agriculture Region 8-Abuyog Experiment Station production area, Balinsasayaw, Abuyog, Leyte, Philippines. The experiment was conducted from June to October 2021 at the Department of Agricultural Sciences nursery area, Visayas State University - Alangalang campus, Alangalang, Leyte, Philippines.

The experiment followed a Randomized Complete Block Design (RCBD) with five treatments and four replications, randomly distributing 64 seeds per subplot. The treatments were:

T0: 0% Wood Vinegar (1000 mL plain water).

T1: 10 mL Wood Vinegar + 990 mL plain water.

T2: 20 mL Wood Vinegar + 980 mL plain water.

T3: 30 mL Wood Vinegar + 970 mL plain water.

T4: Complete fertilizer (90-60-60 NPK) at the recommended rate.

The seeds were directly sown within the furrows at a distance of 50 cm between hills and 75 cm between rows, with two (2) seeds per hill. The seeds were covered with a thin layer of soil to protect them from pests and other organisms. Before applying different treatments, thinning was performed per hill, leaving only one (1) plant per hill. Wood vinegar solutions were prepared using a 1:800 dilution (Mungkunkamchao et al., 2013) and adjusted for the specified treatment concentrations. Treatments were applied as soil drenches 10 days after emergence and weekly thereafter until silk emergence, with 200 mL of solution per hill per application. For T4, fertilizer was applied twice, at 14 and 60 days after emergence.

Weeding and cultivation were performed to keep the area free from weeds throughout the experiment. The first weeding was done two (2) weeks after planting, and occasionally, the weeds were removed every time they were seen in the respective treatment plots. Occasional watering of the corn plants was done depending upon the soil situation to provide adequate water required by the crop. Early morning and late afternoon were the scheduled times for watering the plants no infestation of any pests occurred during the study.

A total of 10 sample plants per plot were randomly selected and used for data collection for all parameters throughout the study. Harvesting was done based on the maturity index of the corn. The maturity index of the corn was determined by visual inspection, as indicated by the brownish color of the husk, and when the coloration of the point of attachment between the corn cob and kernels becomes black. Harvested ears were sun-dried for about 24 hours with an approximate 14% moisture content and then weighed. Data collection among parameters was as follows.

2.1. Data Gathered

2.1.1. Agronomic Characteristics

The number of days from emergence to tasseling was determined by counting the days until 85% of the plants produced tassels.

The number of days from emergence to silking was determined by counting the days from emergence until 85% of the plants produced silk.

Plant height was determined by measuring the height of the 10 sample plants weekly in each plot, from the ground level up to the tip of the tallest plant.

The number of leaves was determined by counting the leaves weekly.

2.1.2. Yield and Yield Components

Ear length was determined by measuring the ear from the base to the tip in each sample using a measuring tape.

Ear diameter measurement was determined by measuring the central portion of the ear using a Vernier caliper.

Weight of 1000 kernels. For each treatment, 1000 kernels of harvested corn were weighed in kilograms.

The moisture content of the biomass was determined by oven-drying the sample plants within 48 hours. Weighed the oven-dried sample and calculated the percent moisture content using the formula.

%Moisture Content =

Where:

MC – moisture content (%).

FW – fresh weight of biomass (g).

ODW – oven dry weight of biomass (g).

2.2. Statistical Analysis

The treatments were replicated four (4) times. The data collected were analyzed statistically through analysis of variance (ANOVA) to determine significant differences among treatments using the Statistical Tool for Agricultural Research (STAR). Post-hoc comparisons were performed using the Least Significant Difference (LSD) test at a 5% ($P<0.05$) significance level to determine treatment effects.

3. RESULTS AND DISCUSSIONS

3.1. Plant Height

Table 1 presents the height of corn plants showed significant differences among treatments at Week 4 ($p = 0.040$), with T4 (complete fertilizer) exhibiting the tallest plant height among all treatments. Although numerical differences were observed across other weeks, these differences were not statistically significant ($p > 0.05$). Generally, T4 exhibited a consistent trend of superior growth throughout the study period, followed by T1 (10 mL Wood Vinegar). Treatments with wood vinegar (T1, T2, and T3) demonstrated comparable growth patterns, but they did not surpass the results of T4.

The control group (T0: 0% Wood Vinegar) consistently recorded the lowest values for plant height across all weeks, indicating the limited effect of plain water on promoting growth. Despite these variations, applying bamboo-sourced wood vinegar, especially at the 10 mL concentration (T1), demonstrated potential as an alternative to chemical fertilizer. However, its effects were less pronounced compared to the complete fertilizer treatment.

The findings are consistent with a previous investigation on bamboo vinegar derived from Phyllostachys bambusoides and Phyllostachys pubescens, which examined its effects on seed germination and radicle growth. Their study showed that high concentrations of bamboo vinegar inhibited seed germination, while appropriately diluted bamboo vinegar promoted germination and radicle growth in several seed species, including lettuce and watercress (Mu, Uehara, & Furuno, 2003). Similarly, in this study, treatments with bamboo-sourced wood vinegar (T1, T2, and T3) demonstrated growth benefits, particularly at the 10 mL concentration (T1). However, the results were less pronounced than the complete fertilizer treatment (T4). The consistency observed in plant growth across treatments with bamboo vinegar supports the notion that when applied at the correct dilution, bamboo vinegar could enhance plant development. Bamboo vinegar may be an effective, sustainable alternative to chemical fertilizers for improving plant height and overall growth.

Table 1. Effect of varying levels of bamboo-derived wood vinegar on corn height over 8 weeks.

Treatments	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
T0: 0% WV	45.29	74.65	109.32	153.50^{b}	184.44	228.38	246.30	245.59
T1: 10 mL WV	46.67	78.62	114.90	164.40^{ab}	191.47	224.25	236.20	237.75
T2: 20 mL WV	45.02	77.01	112.03	158.65^{b}	185.87	229.92	242.30	241.90
T3: 30 mL WV	45.77	75.98	109.73	158.90^{b}	187.07	231.97	242.93	243.27
T4: Complete fertilizer	46.89	80.51	121.73	180.31^{a}	257.43	244.95	249.03	247.72
P value	0.949	0.505	0.207	0.040*	0.282	0.293	0.499	0.731

Note: Means with the same letter are not significantly different at $p < 0.05$ according to the LSD test.
An asterisk (*) indicates significance at $p < 0.05$.

3.2. Number of Leaves

The data presented in Table 2 shows that the number of corn leaves was not significantly affected ($p > 0.05$) by varying levels of bamboo-sourced wood vinegar (WV) across all weeks of the study. Among the treatments, T4 (complete fertilizer) showed numerically higher values, particularly in Week 4, but these differences were not statistically significant. Similarly, T1 (10 mL Wood Vinegar) consistently demonstrated higher leaf counts compared to other Wood Vinegar treatments (T2 and T3) during the early weeks (Weeks 1–5), although no significant differences were observed.

Applying 10 mL of wood vinegar (T1) showed consistent growth trends, suggesting a positive impact on leaf development. This effect is likely attributed to organic acids and other beneficial compounds in wood vinegar, which are known to enhance plant growth. Wood vinegar contains 10%–20% organic compounds, including over 200 distinct chemical substances such as organic acids, ketones, aldehydes, alcohols, and phenols (Ma et al., 2013; Ma, Wei, Zhang, Shi, & Zhao, 2011; Qin, Ma, Zhao, Zhang, & Liu, 2010). These compounds can improve soil acidity, increase cation exchange capacity (CEC), and promote better nutrient uptake, particularly nitrogen and phosphorus (Jeffery et al., 2011; Vaccari et al., 2015). These properties may explain the increased leaf number, as efficient nutrient uptake, including leaf production, is critical for overall plant development.

The results of this study are supported by previous findings demonstrating that poplar-derived wood vinegar promoted root development in pepper seedlings, leading to increased biomass in shoots and roots (Luo et al., 2019). Similarly, a 400-fold dilution of wood vinegar significantly improved plant height and dry matter production in rapeseed (Zhu et al., 2021). These studies suggest that wood vinegar, whether derived from bamboo or other sources has the potential to improve plant growth through enhanced nutrient availability and improved soil conditions. These factors directly support leaf expansion and overall vegetative development.

Table 2. Effect of varying levels of bamboo-derived wood vinegar on corn leaf number over 8 weeks.

Treatments	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
T_0: 0% WV	6.03	8.37	9.75	13.06	13.96	14.59	14.15	13.94
T_1: 10 mL WV	5.85	7.92	9.88	12.90	14.12	14.95	14.17	14.12
T_2: 20 mL WV	6.28	8.45	9.62	12.40	13.80	14.92	14.02	14.00
T_3: 30 mL WV	6.10	8.33	9.77	13.07	14.03	14.87	14.07	14.13
T_4: complete fertilizer	6.00	8.55	10.12	13.45	13.82	14.77	14.10	13.50
P value	0.482	0.513	0.573	0.242	0.983	0.878	0.987	0.355

Note: Means with the same letter are not significantly different at $p < 0.05$ according to the LSD test.
An asterisk (*) indicates significance at $p < 0.05$.

3.3. Number of Days to Tasseling and Silking

Figure 1 illustrates the number of days to tasseling, which showed no significant difference among treatments ($P > 0.05$). Figure 2 illustrates the number of days to silking, showing a significant reduction ($P = 0.019$), with T4 recording the earliest silking, closely comparable to T3.

Wood vinegar has been identified as a plant growth regulator analog, and when applied at appropriate dosages, it has been shown to influence plant growth positively (Flematti et al., 2004; Nelson et al., 2012). The accelerated growth observed in the present study may be linked to the earlier onset of silking, suggesting that wood vinegar may promote early reproductive development. Additionally, previous studies indicate that adding wood vinegar to soil can enhance the growth and yield of field crops (Yongyuth et al., 2018).

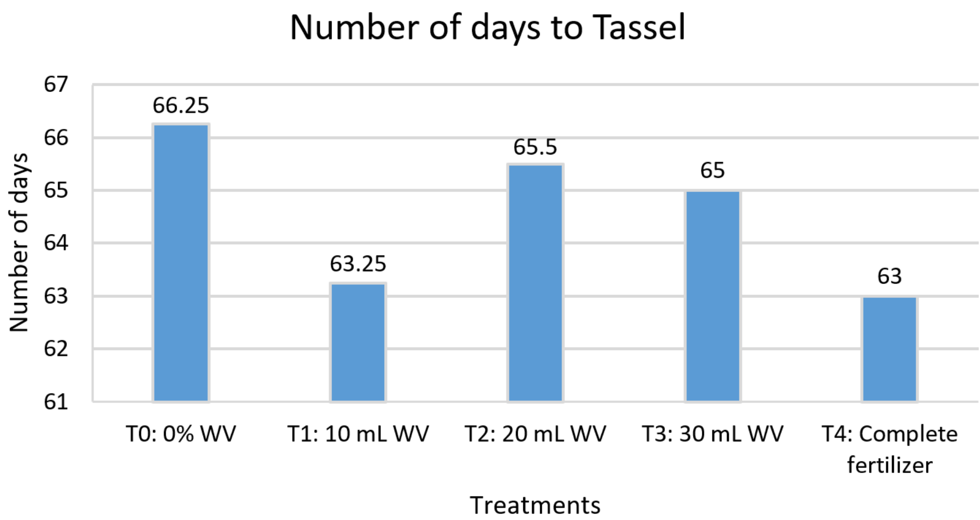

Figure 1. Number of days before corn's tassel emerged among varying levels of bamboo-derived wood vinegar.

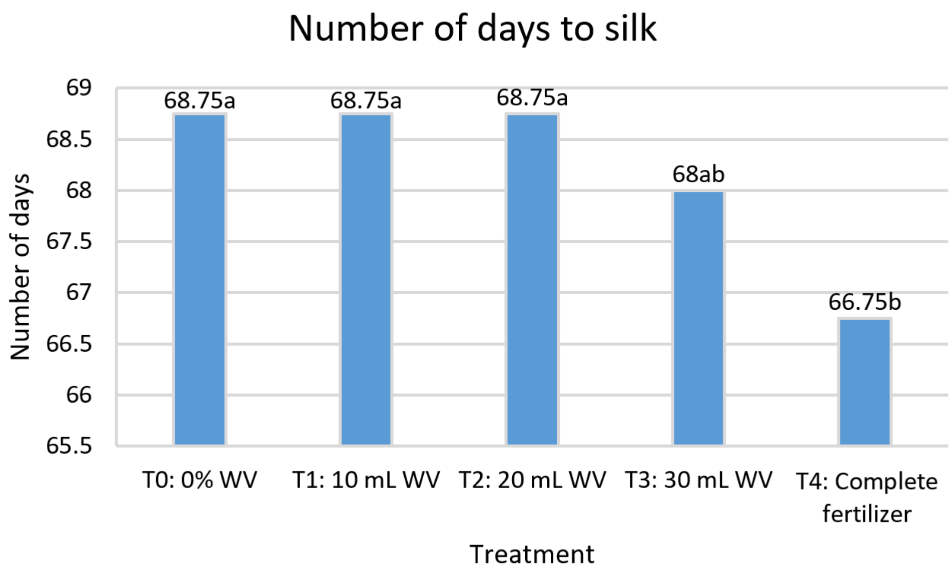

Figure 2. Number of days before corn's silk emerged among varying levels of bamboo-derived wood vinegar.

3.4. Diameter, Length of Cob, and Weight of Kernels

Table 3 presents a significant difference in the cob's diameter (P = 0.021) among treatments. T4 and T1 had similar cob diameters, while T4 exhibited the largest diameter. No significant difference was noted in the length of the cob or the weight of 1000 kernels (P > 0.05). However, T3 had the highest numerical weight of 1000 kernels, followed closely by T4.

These findings are consistent with those of a previous investigation, which observed a modest increase in the total dry weight of tomato fruit following the application of wood vinegar (Mungkunkamchao et al., 2013). Another supporting study reported that wood vinegar enhances crop yields and improves nutrient uptake when applied to agricultural soils (Wei, Ma, & Dong, 2010; Yongyuth et al., 2018). These studies support the idea that wood vinegar can improve growth and productivity across different crop species.

3.5. Moisture Content of Biomass

The data presented in Table 3 shows that although no significant differences in the moisture content of biomass were found, T1 exhibited the lowest numerical percentage of moisture content, indicating a higher dry weight than the other treatments.

The results of the present study are supported by previous findings demonstrating that poplar-derived wood vinegar promotes root development in pepper seedlings, leading to increased biomass in shoots and roots (Zhu et al., 2021). Another investigation also observed a slight increase in plant dry weight after applying wood vinegar and fermented bokashi (Mungkunkamchao et al., 2013). These studies support that wood vinegar can enhance biomass accumulation and contribute to more efficient plant nutrient use.

Table 3. Effect of varying levels of bamboo-derived wood vinegar on corn cob diameter, length, 1000-kernel weight, and biomass moisture content.

Treatments	Cob diameter (mm)	Cob length (cm)	1000-kernel weight (g)	Biomass moisture content (%)
T_0: 0% WV	38.61^b	22.19	281.49	69.08
T_1: 10 mL WV	46.51^a	21.45	286.51	63.39
T_2: 20 mL WV	45.01^a	21.16	270.29	73.74
T_3: 30 mL WV	45.27^a	20.43	306.38	69.62
T_4: complete fertilizer	47.62^a	21.78	299.91	69.84
P value	0.021*	0.207	0.391	0.231

Note: Means with the same letter are not significantly different at $p < 0.05$ according to the LSD test.
An asterisk (*) indicates significance at $p < 0.05$.

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