Scientific Nexus
Vol 2(1) 2026:2737
https://doi.org/10.35472/scinexus.2737
RESEARCH ARTICLE
OPEN ACCESS

Effect of coconut shell liquid smoke as a biopesticide on the growth and productivity of maize (*Zea mays* L.)

Dian Syahputra Saragi[1], Arysca Wisnu Satria[1*], Hendry Wijayanti[2]

[1]Department of Chemical Engineering, Institut Teknologi Sumatera, South Lampung 35365, Indonesia
[2]Department of Biological Science, Institut Teknologi Sumatera, South Lampung 35365, Indonesia
[*]Corresponding author: Jl Terusan Ryacudu, Way Hui, Jati Agung, South Lampung 35365, Indonesia. Email: arysca.wisnu@tk.itera.ac.id

ABSTRACT

Pest infestation is a persistent constraint on maize productivity, driving interest in environmentally friendly biopesticides as alternatives to synthetic pesticides. This study evaluated the effect of coconut shell-derived liquid smoke, applied as a foliar biopesticide, on the growth and productivity of maize (*Zea mays* L.). A field experiment was conducted from January to May 2025 at the Lampung Provincial Agriculture Office's Agropark garden using a Randomized Complete Block Design with four dilution levels: undiluted (1:0), 1:2, 1:4, and 1:10. Plant height, stem diameter, grain number per cob, cob weight, and total ear weight were measured and analyzed using ANOVA followed by Tukey's Honestly Significant Difference test. Liquid smoke dosage significantly affected all measured parameters ($P < 0.05$). The 1:2 dilution produced the greatest plant height (187.94 ± 6.53 cm), stem diameter (17.04 ± 2.41 mm), grain number per cob (389.80 ± 17.89), cob weight (23.08 ± 0.79 g), and total ear weight (146.62 ± 7.43 g), while the highest dilution produced the lowest total ear weight (101.02 ± 7.03 g; $P < 0.001$). These findings indicate that coconut shell-derived liquid smoke applied at a 1:2 dilution has strong potential as an environmentally friendly biopesticide for maize cultivation.

Keywords: biopesticide, liquid smoke, maize, plant growth, productivity

PLAIN LANGUAGE SUMMARY

Farmers often use chemical pesticides to protect crops from pests, but these chemicals can harm the environment and human health. This study tested whether coconut shell smoke, a liquid byproduct of burning coconut shells, could work as an eco-friendly pest-control spray for maize (corn). Researchers sprayed maize with the smoke liquid at different strengths, from full strength to heavily diluted with water. A 1:2 dilution with water gave the best results, producing taller, healthier plants and more corn per plant than other treatments. This suggests coconut shell smoke could be a safe, affordable alternative to chemical pesticides for maize farmers.

Introduction

In the agricultural industry, pest infestations represent a critical challenge that directly compromises both crop yields and quality. Consequently, pesticides have become an essential tool for farmers seeking to safeguard their investments and sustain productivity. However, the systemic overapplication of synthetic pesticides due to the prioritization of short-term economic efficacy often precipitates a disregard for ecological sustainability and a significant threat to public health [1]. Specifically, persistent pesticide residues in the soil frequently result in the unintended mortality of non-target organisms, the contamination of hydrological systems, and the broader degradation of local ecosystems [2]. Further, these residues undergo biomagnification, as they accumulate within plant tissue, posing acute and chronic toxicity risks to both wildlife and human consumers [3]. Despite these risks, the reliance on chemical interventions for pest eradication remains a prevailing necessity, creating a complex dilemma within modern agricultural management.

To mitigate these adverse effects, an environmentally friendly alternative to synthetic chemical pesticides has emerged in the form of biopesticides. Biopesticides, derived from living organisms such as plants, animals, or microorganisms, are effective in inhibiting the growth and development of, or killing, pathogenic pests [4]. Their production generally requires only simple equipment, making them a more sustainable and accessible solution for farmers [5]. Moreover, biopesticides are characterized by rapid biodegradability, leaving minimal toxic residues on crops and in ecosystems [5]. However, despite these advantages, information regarding their efficacy, formulation, and large-scale application remains limited.

To date, several studies have investigated the use of liquid smoke as a biopesticide, including coconut shell-derived liquid smoke applied as an insecticide on soybean, which reduced pest infestation and produced yields not significantly different from those obtained using biological or chemical insecticide treatments [6]. These promising findings suggest that coconut shell liquid smoke has strong potential to be further developed and applied to other crops, such as corn (*Zea mays*). A related study demonstrated that coconut shell liquid smoke, applied as a biopesticide against the rice brown planthopper (*Nilaparvata lugens*), showed insecticidal activity while limiting toxicity to the rice plants themselves [7].

Corn is one of the major food crops cultivated in Lampung Province, making it an important agricultural commodity in the region [8]. However, cultivation faces severe pressure from a complex of destructive pests, such as *Spodoptera frugiperda* (fall armyworm), *Ostrinia furnacalis* (Asian corn borer), and *Helicoverpa armigera*, which can significantly reduce yield and crop quality [9,10,11]. These challenges highlight the need for effective and environmentally friendly pest management strategies to minimize yield losses while maintaining crop sustainability.

Although coconut shell-derived liquid smoke has demonstrated considerable antimicrobial and insecticidal potential, previous studies have largely been limited to post-harvest preservation and efficacy against individual pest species. Consequently, little is known about the capacity of different liquid smoke concentrations to simultaneously manage diverse pest complexes under field conditions while minimizing phytotoxic stress. Moreover, the optimal concentration that balances effective pest suppression with the maintenance of healthy vegetative growth and crop productivity in regional maize varieties has yet to be clearly established.

To address this gap, this study aimed to evaluate the effectiveness of coconut shell-derived liquid smoke by identifying optimal application rates at varying dosages and to assess its influence, specifically, on both the vegetative development and reproductive yield of maize (*Zea mays* L.) across four distinct trials. By systematically mapping the dose–response curve, this study provides novel insights into the precise concentration required to maximize agricultural productivity and pest resilience while minimizing crop physiological stress.

Methods

The research was conducted from January to May 2025 at the Lampung Provincial Agriculture Office's Agropark garden. The primary treatment variable consisted of liquid smoke sourced as a byproduct from a briquette factory in Natar, South Lampung. The maize variety 'BISI 2 Super Hybrid' was employed as the test crop. This variety was selected for its regional relevance and suitability for the environmental conditions of the study site.

Seed preparation and field establishment

Seed priming was initiated by soaking BISI 2 Super Hybrid maize seeds in a solution of 10 mL Pupuk Organik Cair Istimewa (POCI) Masaro and 10 mL of water for 48 hours. The experimental area, measuring 10 × 10 m, was cultivated using mechanical tillage. Prior to plowing, Masaro compost was applied as a basal amendment, followed by an application of POCI Masaro (12.5 mL/1.5 L water). A secondary application of the liquid organic fertilizer was performed post-tillage, after which the soil was fallowed for 3–7 days. Planting was executed using the Jajar Legowo double-row spacing pattern (75 × 50 × 30 cm) at a seeding depth of 5–10 cm.

The experiment followed a Randomized Complete Block Design (RCBD) with four treatments (D1–D4) and five replications per treatment, arranged in 2 blocks. Each experimental unit (plot) consisted of 10 plants, of which 5 were designated as sample plants for data collection.

Crop management and biopesticide application

Nitrogenous fertilizers were applied according to crop requirements to ensure optimal nutrient availability. Gap filling (replanting) was conducted

Table 1. Measurements for the application of coconut shell-derived liquid smoke

Liquid smoke dosage	pH liquid smoke	Plant height (cm) (mean ± SE)	Stem siameter (mm) (mean ± SE)	Grains per cob (number) (mean ± SE)	Cob weight (g) (mean ± SE)	Total ear weight (g) (mean ± SE)
1:0 (D1)	3.29	169.14 ± 7.22 [b]	13.18 ± 0.74 [b]	336.40 ± 4.07[ab]	22.16 ± 2.03[a]	144.30 ± 5.85[a]
1:2 (D2)	4.01	187.94 ± 6.53 [a]	17.04 ± 2.41 [a]	389.80 ± 17.89[a]	23.08 ± 0.79[a]	146.62 ± 7.43[a]
1:4 (D3)	4.48	181.52 ± 8.36 [ab]	15.14 ± 0.22 [ab]	351.00 ± 26.71[ab]	20.20 ± 2.73[a]	130.98 ± 8.41[a]
1:10 (D4)	5.11	175.68 ± 11 [ab]	14.14 ± 2.41 [ab]	297.60 ± 13.42[b]	10.36 ± 0.73[b]	101.02 ± 7.03[b]
F-value		3.61*	4.46*	3.88*	58.41**	10.82**
P-value		0.036	0.018	0.029	<0.001	<0.001

*Note: Values are mean ± standard error (SE); n = 5 replicates per treatment, arranged in a Randomized Complete Block Design with five blocks. Means within a column followed by the same lowercase letter are not significantly different according to Tukey's Honestly Significant Difference (HSD) test (P < 0.05). *P < 0.05; **P < 0.001.*

1–2 weeks after planting (WAP) to maintain plant population density. Pest monitoring was performed regularly, with interventions triggered upon the first signs of infestation.

The liquid smoke biopesticide was applied via foliar spray at four dilution levels, hereafter denoted D1–D4: undiluted liquid smoke (D1, 1:0), a 1:2 dilution of liquid smoke to water (D2), a 1:4 dilution (D3), and a 1:10 dilution (D4). Each dilution was applied at a spray volume of 1 L per plot, with applications repeated every 7 days from 2 WAP until all the silks turn completely brown and dry out., for a total of 11 applications per treatment.

Harvesting was conducted at approximately 90 days after planting (DAP), consistent with the physiological maturity of the BISI 2 variety.

Data collection and statistical analysis

To comprehensively evaluate the effects of treatment levels on maize development, both vegetative growth and reproductive productivity were assessed. Vegetative vigor was evaluated by measuring plant height (cm) and stem diameter (mm). Reproductive success and structural yield were quantified by assessing grain number per cob, cob weight (g), and total ear weight (g) at harvest.

The experimental data were subjected to Analysis of Variance (ANOVA) using a Randomized Complete Block Design (RCBD). Where significant F-values were observed ($P < 0.05$), means were separated using Tukey's Honestly Significant Difference (HSD) test at the 5% level of probability.

Results

The results of all measurements for the application of coconut shell-derived liquid smoke are summarized in Table 1. The pH of the liquid smoke solutions increased with increasing dilution (Table 1). Undiluted liquid smoke (D1; 1:0) exhibited the lowest pH value (3.29). Dilution at a ratio of 1:2 (D2) increased the pH to 4.01, while further dilution to 1:4 (D3) resulted in a pH value of 4.48. The highest dilution level (D4; 1:10) produced the highest pH value (5.11).

Liquid smoke dosage significantly influenced plant height ($F(3,16) = 3.61$, $P = 0.036$) (Fig 1A, Table 1). Plants treated with D2 exhibited the greatest mean plant height (187.94 ± 6.53 cm), which was significantly higher than D1 (169.14 ± 7.22 cm). Treatments D3 (181.52 ± 8.36 cm) and D4 (175.68 ± 11.00 cm) were statistically intermediate between D1 and D2, with D3 showing greater variability among replicates.

A similar trend was observed for stem diameter ($F(3,16) = 4.46$, $P = 0.018$) (Fig 1B, Table 1). Plants treated with D2 produced the largest mean stem diameter (17.04 ± 2.41 mm), significantly exceeding D1 (13.18 ± 0.74 mm). Stem diameter in D3 (15.14 ± 0.22 mm) and D4 (14.14 ± 2.41 mm) did not differ significantly from either D1 or D2.

Liquid smoke dosage also significantly affected the number of grains per cob ($F(3,16) = 3.88$, $P = 0.029$), cob weight ($F(3,16) = 58.41$, $P < 0.001$), and total ear weight ($F(3,16) = 10.82$, $P < 0.001$) (Fig 2, Table 1). Treatment D2 produced the highest mean grain number per cob (389.80 ± 17.89),

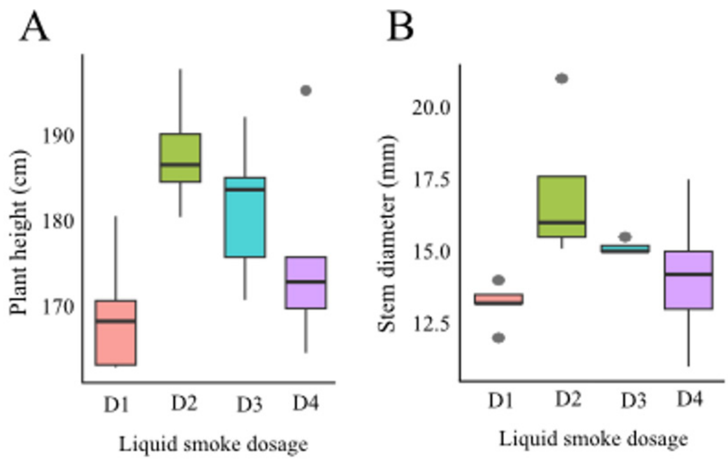

Figure 1. Effect of coconut shell-derived liquid smoke dosage on maize vegetative growth. (A) Plant height (cm) and (B) stem diameter (mm) under four dilution treatments: undiluted (D1, 1:0), 1:2 (D2), 1:4 (D3), and 1:10 (D4). Data are presented as mean ± SE (n = 5 per treatment). Bars/points labeled with different lowercase letters differ significantly according to Tukey's HSD test ($P < 0.05$).

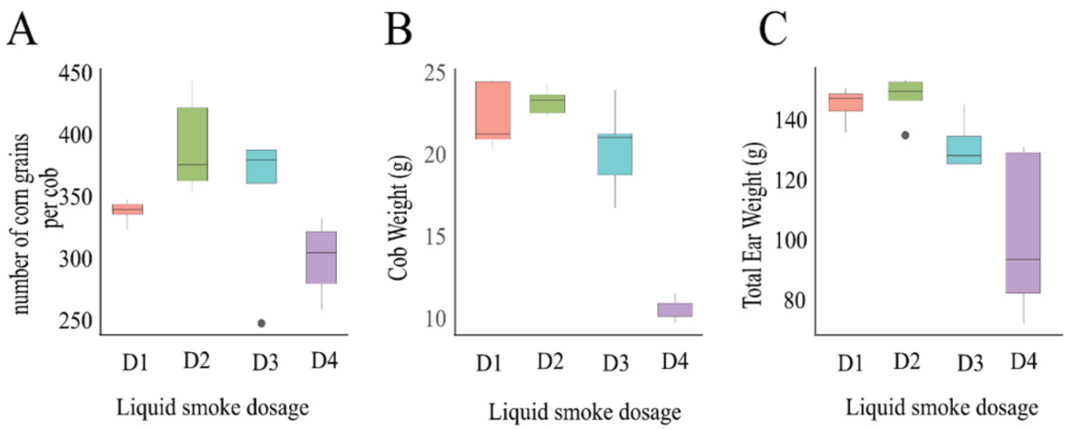

Figure 2. Effect of coconut shell-derived liquid smoke dosage on maize yield components. (A) Number of grains per cob, (B) cob weight (g), and (C) total ear weight (g) under four dilution treatments: undiluted (D1, 1:0), 1:2 (D2), 1:4 (D3), and 1:10 (D4). Data are presented as mean ± SE (n = 5 per treatment). Bars/points labeled with different lowercase letters differ significantly according to Tukey's HSD test ($P < 0.05$).

significantly greater than D4 (297.60 ± 13.42), the lowest-performing treatment; D1 and D3 were statistically intermediate.

For cob weight, treatment D2 produced the numerically highest value (23.08 ± 0.79 g), followed by D1 (22.16 ± 2.03 g), D3 (20.20 ± 2.73 g), and D4 (10.36 ± 0.73 g). Given the highly significant F-value for this variable, a Tukey's HSD grouping are shown for cob weight in Table 1.

Total ear weight followed a comparable pattern: D1, D2, and D3 did not differ significantly from one another (144.30 ± 5.85, 146.62 ± 7.43, and 130.98 ± 8.41 g, respectively), while D4 (101.02 ± 7.03 g) was significantly lower than all other treatments.

Discussion

The findings of this study show that the D2 treatment (1:2 dilution) provided the most favorable conditions for both vegetative development and yield formation, consistent with the interpretation that liquid smoke acts as a biostimulant and biopesticide at moderate concentrations. Bioactive compounds such as phenols and organic acids in liquid smoke are known to disrupt insect feeding activity and development, allowing maize to conserve energy and reallocate resources toward growth and yield formation rather than solely toward biotic stress defense [12]. Phenolic compounds, present at concentrations of up to 90.75% in some coconut shell liquid smokes, inhibit fungal growth, destroy pathogen cell membranes, and function as insecticides or antifeedants [13,14,15,16]. The moderate concentration used in D2 may therefore have provided indirect benefits to maize development by reducing pest-related stress while avoiding the phytotoxic effects associated with higher concentrations.

These growth responses are broadly consistent with findings from other pyrolysis-derived liquid smoke (wood vinegar) studies on maize. For instance, foliar application of bamboo-derived wood vinegar to corn produced significant increases in plant height and cob diameter compared with an untreated control, although the effect was concentration-dependent and not all growth parameters responded significantly [17]. This supports the pattern observed in the present study, in which growth benefits were concentrated at an intermediate dilution (D2) rather than increasing linearly with liquid smoke concentration.

In contrast, the undiluted treatment (D1) consistently produced the lowest or near-lowest values across most growth and yield parameters. This is best explained by the low pH of undiluted liquid smoke (pH 3.29), which may impose physiological stress on the plant and interfere with nutrient uptake. Under strongly acidic soil conditions, phosphorus tends to bind with aluminum to form aluminum phosphate compounds that are largely unavailable for root absorption, restricting the phosphorus supply needed to support plant development [18,19]. This mechanism offers a plausible explanation for why D1, despite containing the highest concentration of potentially bioactive phenolic and organic acid compounds, did not translate into the best growth or yield outcomes: any pest-suppression benefit at this concentration was likely offset by acidity-related nutrient stress. This highlights the need for careful dosage selection that balances pest control effectiveness against the risk of soil acidification and reduced nutrient availability.

Grain development also appeared to be sensitive to the pH of the applied solution, with the highest grain number per cob observed at the D2 treatment (pH 4.01) and the lowest at the most dilute, highest-pH treatment (D4, pH 5.11). A favorable metabolic environment during the reproductive stage, characterized by adequate moisture availability, sustained photosynthetic activity, and reduced physiological stress, can minimize kernel abortion and promote greater kernel set, thereby increasing the number of grains per cob [20]. The comparatively poor performance of D4 suggests that once liquid smoke is diluted beyond the point of providing meaningful bioactive protection, maize may lose the pest-suppression benefit without gaining any compensating advantage, resulting in the lowest yield components among the four treatments.

Nevertheless, liquid smoke applications did not consistently produce proportional productivity gains across all treatments, and cob weight and total ear weight did not differ significantly among D1, D2, and D3. This indicates that factors other than biopesticide dosage, such as underlying soil fertility, microclimatic variation across blocks, and individual plant physiological responses, likely also contributed to the observed variability in maize productivity, and should be considered in future studies that aim to isolate the specific contribution of liquid smoke dosage from these confounding factors.

Conclusion

This study demonstrates that the application of coconut shell-derived liquid smoke significantly influenced both the growth and productivity of maize. Among the tested dilution levels, the 1:2 dilution (D2) consistently produced the greatest plant height, stem diameter, grain number per cob, and total ear weight, indicating that moderate dilution provides the most favorable balance between pest suppression and plant physiological performance. In contrast, the undiluted treatment (D1) was limited by excessive acidity, while the highest dilution (D4) likely provided insufficient bioactive compound concentration to suppress pest pressure effectively; both extremes resulted in reduced growth and yield performance relative to D2. These findings support the use of a 1:2 dilution as a practical starting point for coconut shell-derived liquid smoke application in maize cultivation, though further studies across diverse environmental conditions, soil types, and production systems are recommended to confirm the consistency of this response and to clarify the underlying physiological mechanisms responsible for the observed improvements.

Acknowledgment

We extend our sincere gratitude to the Lampung Provincial Agriculture Office for facilitating the conduct of this research at the Agropark garden under their management.

Declaration of interest

The authors have no conflicts of interest to declare.

Author contributions

DSS: Conceptualization; Methodology; Investigation; Resources; Data curation; Formal analysis; Writing–original draft. AWS: Supervision; Methodology; Validation; Writing–review & editing. HW: Formal analysis; Visualization; Writing – review & editing.

Received: March 21, 2026
Revised: June 16, 2026
Accepted: June 17, 2026
Published: June 29, 2026

References

1. Tuhumury GNC, Leatemia JA, Hasinu RYRJV. Residu pestisida produk sayuran segar di Kota Ambon. Agrologia. 2012;1(2):99–105. https://doi.org/10.30598/a.v1i2.284
2. Jamin FS, Mustofa D, Restu K, Rusli M, Adhi S. Pesticide use in agriculture: health risks and environmentally friendly alternatives. J Kolaboratif Sains. 2024;7(11):4151–9. https://doi.org/10.56338/jks.v7i11.6342
3. Zhou W, Li M, Achal V. A comprehensive review on environmental and human health impacts of chemical pesticide usage. Emerg Contam. 2025;11:100410. https://doi.org/10.1016/j.emcon.2024.100410
4. Sumartini. Biopestisida untuk pengendalian hama dan penyakit tanaman aneka kacang dan umbi. Iptek Tanam Pangan. 2016;11(2):159–66.
5. Djunaedy A. Biopestisida sebagai pengendali organisme pengganggu tanaman (OPT) yang ramah lingkungan. Embryo. 2009;6(1):88–95.
6. Diptaningsari D, Meithasari D, Karyati H, Wardani N. Potential use of coconut shell liquid smoke as an insecticide on soybean and the impact on agronomic performance. IOP Conf Ser Earth Environ Sci. 2022;985(1):012058. https://doi.org/10.1088/1755-1315/985/1/012058
7. Ria ER, Faisal D, Turmuktini T. Activity of coconut-shell liquid smoke as a biopesticide on the rice brown planthopper (Nilaparvata lugens Stal.). In: Proceedings of the 5th International Symposium on Insects; 2023. p. 64–8.
8. BPS-Statistics Indonesia, Lampung Province. Harvested area, productivity, and production of maize by regency/city, Lampung Province [Internet]. Bandar Lampung: BPS-Statistics Indonesia; 2025 [cited 2026 June 29]. Available from: https://lampung.bps.go.id
9. Herlinda S, Suharjo R, Sinaga ME, Fawwazi F, Suwandi S. First report of occurrence of corn and rice strains of fall armyworm, Spodoptera frugiperda in South Sumatra, Indonesia and its damage in maize. J Saudi Soc Agric Sci. 2022;21(6):412–9. https://doi.org/10.1016/j.jssas.2021.11.003
10. Trisyono YA, Aryuwandari VEF, Sinulingga NGH, Andika IP. Damage assessment of the Asian corn borer, Ostrinia furnacalis (Lepidoptera: Crambidae), in corn production centers in Indonesia. Heliyon. 2025;11(4):e42795. https://doi.org/10.1016/j.heliyon.2025.e42795
11. Ginting S, Chozin M, Sudjatmiko S. Infestation of Helicoverpa armigera (Hübner) and Ostrinia furnacalis Guenée on three tropical altitude variations. J Trop Plant Pests Dis. 2023;23(1):31–7. https://doi.org/10.23960/jhptt.12331-37
12. Noel R, Benoit M, Wilder SL, Waller S, Schueller MJ, Ferrieri RA. Treatments with liquid smoke and certain chemical constituents prevalent in smoke reduce phloem vascular sectoriality in the sunflower with improvement to growth. Int J Mol Sci. 2022;23(20):12468. https://doi.org/10.3390/ijms232012468
13. Gani A, Husni H, Baihaqi A, Faisal M. Potential development of liquid smoke from oil palm solid waste as biofungicides. Int J Sci Eng. 2014;7(1):65–9. https://doi.org/10.12777/ijse.7.1.65-69
14. Oramahi HA, Diba F, Tavita GE, Wahyuni R. Penggunaan asap cair dari tandan kosong kelapa sawit dalam penekanan perkembangan jamur Schizophyllum commune. Tengkawang J Ilmu Kesehat. 2011;1(2):51–6. https://doi.org/10.23960/j.hptt.210146-153
15. Yatagai M. Utilization of charcoal and wood vinegar in Japan. Tokyo: Graduate School of Agricultural and Life Sciences, University of Tokyo; 2002.
16. Elad Y, David DR, Harel YM, Borenshtein M, Kalifa HB, Silber A, et al. Induction of systemic resistance in plants by biochar, a soil-applied carbon sequestering agent. Phytopathology. 2010;100(9):913–21. https://doi.org/10.1094/PHYTO-100-9-0913
17. Torres MRG, Macasait DR Jr, Arribado AO, Pedrosa SL. Bamboo-derived wood vinegar improves the growth and yield of corn under varying application levels. Int J Sustain Agric Res. 2025;12(3):172–80. https://doi.org/10.18488/ijsar.v12i3.4454

18. Akasah W, Fauzi, Damanik M. Serapan P dan pertumbuhan tanaman jagung (Zea mays L.) akibat pemberian kombinasi bahan organik dan SP-36 pada tanah Ultisol. J Agroekoteknologi. 2018;6(3): 640–7. https://doi.org/10.32734/ja.v6i3.2416
19. Bojórquez-Quintal E, Escalante-Magaña C, Echevarría-Machado I, Martínez-Estévez M, Gómez-Merino FC. Aluminum, a friend or foe of higher plants in acid soils. Front Plant Sci. 2017;8:1767. https://doi.org/10.3389/fpls.2017.01767
20. Pise N, Badgujar G, Saxena A. Effects of environmental and agronomic factors on crop yield at different phenological stages. In: Saraswat M, Tiwari R, Pavone M, Zaveri M, editors. Proceedings of the International Conference on Computational Intelligence, ICCI 2024. Algorithms for Intelligent Systems. Singapore: Springer; 2025. https://doi.org/10.1007/978-981-96-4539-8_13