Valorization of Cassava Stem and Peel Waste into Pyrolysis-Derived Liquid Smoke as a Rapid Bio-Termiticide

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ABSTRACT

Cassava (*Manihot esculenta*), generates agricultural waste, such as stems and peels, which can be used as biomass. This study examines the effectiveness of liquid smoke produced from cassava stem and peel waste as a natural anti-termite agent. The liquid smoke was produced via pyrolysis at 350-450 °C for 120 min, followed by chemical characterization using Gas Chromatography–Mass Spectrometry (GC-MS). The results revealed that the liquid smoke contained various bioactive compounds, particularly phenolic derivatives and organic acids, which are known for their antimicrobial and insecticidal properties. Cassava stem liquid smoke contained 18.92% phenolic content, while cassava peel liquid smoke contained 12.89%. Efficacy tests against termites were conducted using brush and spray application methods. Both techniques resulted in 100% termite mortality with an average death time of less than 1 min after exposure. This rapid response indicates that cassava-derived liquid smoke has strong potential as an environmentally friendly bio-pesticide for termite control.

Keywords-cassava waste; liquid smoke; pyrolysis; phenolic compounds; termite control

I. INTRODUCTION

Cassava (*Manihot esculenta*) grown in subtropical regions, is a major source of carbohydrates for hundreds of millions of people worldwide [1-3]. Due to its adaptability to marginal soils and varying climatic conditions, cassava contributes significantly to food security and is used as a raw material in the production of starch, animal feed, and bioethanol [4, 5]. The growth of the cassava industry has generated large amounts of agricultural waste, such as stems and peels, which must be properly managed [6]. These residues contain significant amounts of lignocellulosic components, such as cellulose, hemicellulose, and lignin, which can be used to produce valuable bio-based products [7]. Pyrolysis is a thermochemical process that can turn lignocellulosic biomass into useful products, such as biochar, bio-oil, and liquid smoke. Liquid smoke, also known as pyroligneous acid, is produced by condensing vapors generated during the thermal decomposition of biomass [8, 9]. It is a complex mixture of organic acids, phenolic compounds, alcohols, and carbonyl derivatives that can be utilized in food preservation, as an antimicrobial agent, for wood protection, and for agricultural pest control [10–12]. Various bioactive compounds, particularly phenolics and other secondary metabolites, exhibited promising insecticidal properties for pest management applications [13-15]. The need for environmentally friendly pest control methods has become increasingly important [16-18] due to environmental pollution, toxicity to non-target organisms, and long-term ecological risks of conventional synthetic pesticides. Termites are among the most destructive pests affecting wooden materials, crops, and other cellulose-based resources, causing economic losses in buildings, forestry products, and agricultural systems [15, 16]. Dealing with termites still relies on chemical pesticides, raising concerns about environmental safety and sustainability, so bioactive liquid smoke is a promising approach for developing sustainable termite control solutions. Authors in [10-12] focused on general chemical characterization or antimicrobial applications. This study aims to examine the chemical composition and anti-termite activity of liquid smoke derived from cassava stems and peels using Gas Chromatography–Mass Spectrometry (GC–MS) analysis, and evaluate the effect of different application methods.

II. MATERIALS AND METHOD

A. Raw Materials and Preparation

Cassava stems and peels were collected and used as raw materials for producing liquid smoke. First, the materials were cleaned to remove soil and impurities, followed by cutting into smaller pieces to ensure uniformity. The samples were dried under controlled conditions at 60°C for 24 h until they reached a constant weight, which reduced their moisture content. Basic characterization of the raw materials was conducted to ensure reproducibility and support the interpretation of the results, determining the moisture content, as well as considering the general composition based on the characteristics of lignocellulosic biomass (cellulose, hemicellulose, and lignin fractions), which influence pyrolysis behavior and product composition.

B. Pyrolysis Process and Liquid Smoke Production

Liquid smoke production was carried out using a stainless steel, laboratory-scale, batch-type pyrolysis reactor designed to withstand high temperatures and prevent corrosion. For each experimental run, approximately 500 g of dried biomass was loaded into the reactor. Pyrolysis was conducted at a final temperature of 400°C with a heating rate of 10°C/min under limited oxygen conditions. The generated vapors were directed through a condensation system to produce liquid smoke. The liquid smoke yield was recorded as a percentage of the initial biomass weight. The obtained crude liquid smoke was dark brown and exhibited a homogeneous liquid phase; however, slight phase separation was observed after prolonged storage.

C. Chemical Characterization

The chemical composition of the liquid smoke was analyzed using GC-MS. Samples were filtered prior to analysis to remove impurities. The GC-MS analysis used a capillary column (HP-5MS, 30 m × 0.25 mm × 0.25 µm) and helium as the carrier gas at a flow rate of 1.0 mL/min. The injection volume was 1 µL in split mode (1:10). The oven temperature was programmed to increase from 50 °C (with a 2-min hold) to 250 °C at a rate of 10 °C/min, followed by a 10-min final hold. The mass spectrometer operated in Electron Ionization (EI) mode at 70 eV with a scan range of m/z 40–500. Compounds were identified using the NIST library database.

D. Anti-Termite Bioassay and Experimental Design

The anti-termite activity of liquid smoke was evaluated under controlled laboratory conditions. Termites (*Coptotermes sp.*) were collected from local environments and prepared for testing. Each experimental unit consisted of ten worker termites, with three independent replicates (n = 3) for each treatment. The experiments were conducted at a temperature of 27 ± 2°C and a relative humidity of 70 ± 5%. The test containers were Petri dishes. Liquid smoke was applied using two methods: brush application and spray application. Control treatments included: a negative control (untreated termites), a solvent control (if applicable), and a positive control using a commercial pesticide. Mortality time was recorded for each replicate until 100% mortality was reached.

E. Data Analysis and Statistical Methods

Mortality time data were expressed as the mean ± Standard Deviation (SD) from three replicates. A one-way ANOVA followed by a Tukey's post hoc test was performed on the data, with a significance level of $p < 0.05$. Prior to analysis, the normality of the data and homogeneity of variance were evaluated using Shapiro–Wilk and Levene's tests, respectively.

F. Conceptual Framework

This study's conceptual framework is based on sustainably using cassava biomass waste, specifically stems and peels. These materials contain cellulose, hemicellulose, and lignin, which can be thermochemically converted into valuable products, such as liquid smoke, through pyrolysis. The thermal degradation of these components during pyrolysis produces various organic compounds, including phenols, organic acids, and carbonyl compounds, which exhibit antimicrobial and insecticidal properties. In this study, cassava stem and peel waste is processed using a controlled pyrolysis system to produce liquid smoke. The liquid smoke was chemically characterized using GC–MS to identify bioactive compounds, particularly phenolic derivatives that may contribute to insecticidal activity. After chemical characterization, the liquid smoke's effectiveness as a natural anti-termite agent was tested. Termites were exposed to the liquid smoke via two application methods: brush and spray. Their mortality response was observed, including the time required for death to occur after exposure. This study integrates the usage of cassava biomass waste, the production of liquid smoke, the identification of chemical compounds, and the testing of biological efficacy. Through this framework, the study aims to demonstrate that cassava agricultural residues can be converted into an environmentally friendly bio-pesticide, contributing to sustainable waste management and the development of a circular bioeconomy.

G. Research Flowchart

The research was conducted in sequential stages. First, cassava stems and peels were collected and prepared as primary biomass materials. The materials were cleaned, cut into smaller pieces, and dried in the sun to reduce their moisture content before processing. Then, the dried biomass was subjected to pyrolysis in a laboratory-scale reactor at controlled temperatures of 350 °C, 400 °C, and 450 °C for approximately 120 min. This process thermally decomposed the lignocellulosic components and produced smoke vapor. The resulting vapor was condensed using a cooling system with circulating water and collected as liquid smoke in glass containers. Liquid smoke samples derived from cassava stems and peels were analyzed using GC–MS to determine their chemical composition and identify bioactive compounds, particularly phenolic compounds and organic acids. Then, anti-termite efficacy tests were conducted by exposing termites collected from infested wooden structures to the liquid smoke via brush and spray application methods. Mortality responses were recorded. Finally, the data obtained from the GC-MS analysis and the bioassay tests were analyzed descriptively to evaluate the potential of cassava-derived liquid smoke as an environmentally friendly bio-pesticide. Figure 1 presents the overall research procedure, with the stages of biomass preparation, pyrolysis, chemical characterization, and anti-termite evaluation.

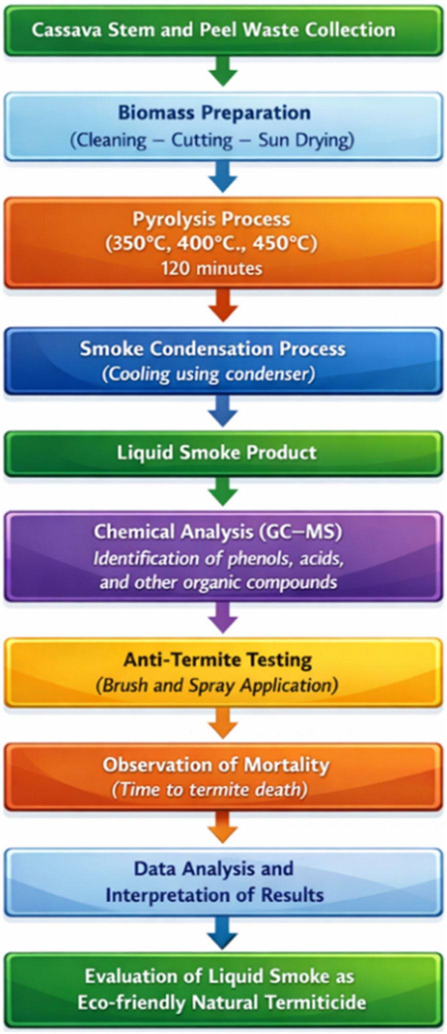

Fig. 1. Research flowchart of liquid smoke production from cassava waste.

III. RESULTS AND DISCUSSION

A. *Chemical Composition of Liquid Smoke Derived from Cassava Stem Waste*

The chemical composition of liquid smoke produced from cassava stem waste was analyzed using GC–MS, revealing the presence of 95 chemical compounds formed from the thermal degradation of lignocellulosic biomass during pyrolysis. These compounds primarily originated from the decomposition of the main structural components of cassava stem biomass: cellulose, hemicellulose, and lignin. The identified compounds entailed several groups of bioactive substances, including organic acids, phenolic compounds, carbonyl compounds, and furan derivatives. Phenolic compounds were found in high proportions and are important due to their known antimicrobial and insecticidal properties. GC-MS results showed the presence of phenol (2.56%), 3-methylphenol (1.35%), 2-methoxyphenol (4.03%), creosol (1.89%), and 2,3-dimethoxyphenol (4.54%). These compounds are mainly derived from lignin degradation during pyrolysis and are associated with antimicrobial, antifungal, and insecticidal effects. Table I summarizes the chemical compounds detected in cassava stem liquid smoke, indicating its strong potential for biological applications, particularly as a natural pesticide or wood preservative.

TABLE I. MAIN CHEMICAL COMPOUNDS IDENTIFIED IN CASSAVA STEM LIQUID SMOKE BY GC–MS ANALYSIS

No	**Compound name**	**Chemical group**	**Relative area (%)**	**Biological relevance**
1	Phenol	Phenolic compound	2.56	Antimicrobial, insecticidal activity
2	3-Methylphenol (m-Cresol)	Phenolic compound	1.35	Antimicrobial properties
3	2-Methoxyphenol (Guaiacol)	Phenolic compound	4.03	Antioxidant, antimicrobial
4	Creosol (2-Methoxy-4-methylphenol)	Phenolic compound	1.89	Antimicrobial, preservative
5	2,3-Dimethoxyphenol	Phenolic compound	4.54	Bioactive phenolic compound
6	Propanoic acid	Organic acid	–	Contributes to acidity and antimicrobial activity
7	Butanoic acid	Organic acid	–	Enhances insecticidal properties
8	Furfural	Furan derivative	–	Biomass pyrolysis product
9	5-Methylfurfural	Furan derivative	–	Derived from carbohydrate degradation
10	Various minor compounds	Mixed compounds	–	Contribute to overall bioactivity

Furthermore, GC–MS analysis identified organic acids, such as propanoic and butanoic acids, which contribute to the acidic nature of liquid smoke. These organic acids play an important role in enhancing the antimicrobial and insecticidal activity of liquid smoke by disrupting the cellular metabolism and physiological functions of target organisms. Therefore, the combination of phenolic compounds and organic acids in cassava stem liquid smoke contributes to the bioactive characteristics.

B. Chemical Composition of Liquid Smoke Derived from Cassava Peel Waste

A GC–MS analysis of liquid smoke derived from cassava peel waste revealed 75 chemical compounds formed by the pyrolytic degradation of lignocellulosic materials, such as cellulose, hemicellulose, and lignin. Several phenolic compounds were identified, including phenol (2.44%), 2-methoxyphenol (3.15%), creosol (1.58%), and 2,3-dimethoxyphenol (4.02%). These compounds are derived from lignin decomposition and are well-known for their antimicrobial and insecticidal properties. Table II summarizes the main compounds identified in cassava peel liquid smoke, highlighting the presence of phenolic compounds, furan derivatives, and organic acids, emphasizing the potential for biological applications. In addition to phenolic compounds, the GC–MS analysis detected furan derivatives, such as 2-furanmethanol (4.63%), which form from the thermal degradation of cellulose and hemicellulose. These derivatives may contribute to the antimicrobial and bioactive properties of liquid smoke. Organic acids were also identified in cassava peel liquid smoke, contributing to its acidity and overall bioactivity. These compounds indicate that, like cassava stem waste, cassava peel waste has strong potential as a raw material for producing bioactive liquid smoke, with phenolic compounds playing a key role in pest control applications. The GC–MS analysis revealed the complex chemical compositions of both samples, identifying 95 compounds in cassava stem liquid smoke and 75 in cassava peel liquid smoke. Chromatograms of both samples are presented in Figure 2, which shows the distribution and intensity of the detected compounds.

TABLE II. MAIN CHEMICAL COMPOUNDS IDENTIFIED IN CASSAVA PEEL LIQUID SMOKE BY GC–MS ANALYSIS

No	**Compound name**	**Chemical group**	**Relative area (%)**	**Biological relevance**
1	Phenol	Phenolic compound	2.44	Antimicrobial and insecticidal activity
2	2-Methoxyphenol (Guaiacol)	Phenolic compound	3.15	Antioxidant and antimicrobial properties
3	Creosol (2-Methoxy-4-methylphenol)	Phenolic compound	1.58	Antimicrobial and preservative effect
4	2,3-Dimethoxyphenol	Phenolic compound	4.02	Bioactive phenolic compound
5	2-Furanmethanol (Furfuryl alcohol)	Furan derivative	4.63	Product of cellulose degradation; contributes to bioactivity
6	Furfural	Furan derivative	–	Derived from hemicellulose degradation
7	Acetic acid	Organic acid	–	Contributes to acidity and antimicrobial activity
8	Propanoic acid	Organic acid	–	Enhances antimicrobial properties
9	Butanoic acid	Organic acid	–	Contributes to insecticidal activity
10	Other minor compounds	Mixed compounds	–	Contribute to overall chemical complexity

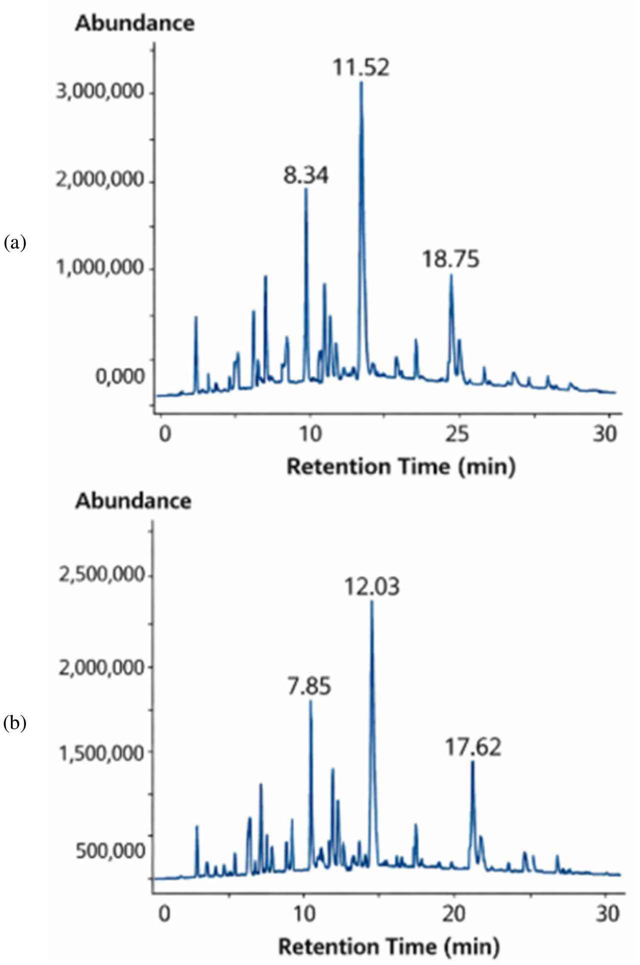

Fig. 2. GC–MS chromatograms of liquid smoke derived from: (a) cassava stem and (b) cassava peel.

Phenolic compounds derived from lignin decomposition exhibited strong antimicrobial and insecticidal properties. These compounds can disrupt cellular membranes and interfere with enzymatic activity in insects, leading to physiological stress and mortality. Organic acids also enhance bioactivity by lowering pH, creating unfavorable conditions for target organisms, and increasing toxicity and preservative effects. In this study, the relative abundance of the identified compounds is expressed as a percentage of the peak area from the GC–MS analysis, indicating their semi-quantitative distribution. The results show that phenolic compounds (35%-50%) and organic acids (20%-35%) constitute a significant proportion of the detected compounds in cassava stem and peel liquid smoke. The higher proportion of these compounds in cassava stem samples likely contributes to their relatively stronger bioactivity, as observed in anti-termite tests.

C. Phenolic Content and Bioactive Potential of Cassava-Derived Liquid Smoke

Phenolic compounds are considered one of the most important groups of bioactive substances found in liquid smoke. According to the GC–MS results, the total phenolic content in liquid smoke derived from cassava stems was

18.92%, while the content in liquid smoke derived from cassava peels was 12.89%. The higher phenolic content in cassava stem liquid smoke suggests that cassava stems have a higher lignin content than cassava peels. Table III summarizes the phenolic content and associated bioactive roles in cassava-derived liquid smoke.

TABLE III. PHENOLIC CONTENT AND BIOACTIVE FUNCTIONS OF CASSAVA-DERIVED LIQUID SMOKE

Raw material source	Total phenolic content (%)	Major phenolic compounds detected	Reported bioactive functions
Cassava stems	18.92	Phenol, Guaiacol, Creosol, Methoxyphenols	Insecticidal activity, antimicrobial effects, disruption of insect enzymatic systems
Cassava peels	12.89	Phenol, Guaiacol derivatives	Antimicrobial activity, feeding inhibition in insects
Phenolic compounds (general function)	Phenol and phenolic derivatives	Damage to insect cellular membranes, interference with nervous system, inhibition of feeding behavior	

Phenolic compounds play a significant role in pest control. They interfere with insect physiological systems, disrupt enzymatic activity, and damage cellular membranes, leading to physiological stress and mortality. The presence of phenol and its derivatives, such as guaiacol, creosol, and methoxyphenols, significantly contributes to the toxicity of liquid smoke against insects and microorganisms. These compounds act as natural toxins that affect insect nervous systems and inhibit feeding activity.

D. Anti-Termite Efficacy of Liquid Smoke from Cassava Stem Waste

The anti-termite efficacy test demonstrated that liquid smoke derived from cassava stem waste is highly effective in killing termites, achieving 100% mortality in all treatments. Two application methods were used: brush and spray. Both methods resulted in rapid termite death shortly after exposure. Mortality occurred within 30–44 s with the brush application and within 21–48 s with the spray application. These rapid responses indicate that the bioactive compounds in liquid smoke quickly affect termite physiology through direct contact, allowing phenolic compounds and organic acids to penetrate and disrupt biological systems. Table IV summarizes the effectiveness of both application methods, showing complete mortality within a short exposure time. The observed mortality time of approximately 20–50 s is notably faster than that reported for most bioinsecticides, suggesting that multiple mechanisms may be involved. One possible explanation is the high acidity (low pH) of liquid smoke, which may create a harsh chemical environment that causes rapid physiological stress. Additionally, the liquid form may physically coat the termite body, potentially blocking spiracles and causing suffocation. This physical effect may act independently of or synergistically with chemical toxicity. The high concentration of bioactive compounds, particularly phenolic derivatives and organic acids identified in the GC–MS analysis, likely intensifies the overall toxic effect. Therefore, the rapid termite mortality observed in this study is possibly the result of a combined physicochemical effect involving chemical toxicity and physical interference with respiration. The mortality time values are presented as the mean ± SD; the relatively low SD indicates consistent results across replicate experiments.

TABLE IV. ANTI-TERMITE ACTIVITY OF LIQUID SMOKE DERIVED FROM CASSAVA STEM WASTE

Application method	Mortality time range (s)	Mortality time (s) (mean ± SD)	Observed mortality (%)	Mode of exposure
Brush application	30 – 44	25 ± 2.1	100	Direct contact through brushing on termite body surface
Spray application	21 – 48	30 ± 2.5	100	Contact exposure through sprayed droplets
Control (without liquid smoke) *	No mortality observed	-	0	No treatment

*Control treatment used for comparison

E. Anti-Termite Efficacy of Liquid Smoke from Cassava Peel Waste

Similar to cassava stem liquid smoke, liquid smoke derived from cassava peel waste demonstrated strong anti-termite activity. Efficacy tests showed that termites exposed to cassava peel liquid smoke experienced 100% mortality in less than 1 min. Table V presents the results of termite mortality following treatment with cassava peel liquid smoke, confirming its strong insecticidal potential. Termite mortality occurred within 24–57 s with the brush application treatment and within 34–59 s with the spray application treatment, indicating that cassava peel liquid smoke possesses significant insecticidal activity, albeit slower than cassava stem liquid smoke. This difference may be attributed to the lower phenolic content in cassava peel liquid smoke because phenolic compounds play a significant role in bioactivity. Therefore, the higher phenolic concentration in cassava stem liquid smoke likely contributes to its faster insecticidal effect. The mortality data are presented as the mean ± SD. Statistical analysis revealed significant differences among the treatments ($p < 0.05$), especially between the cassava stem and peel liquid smoke treatments and between the application methods. The observed bioactivity is possibly associated with insecticidal properties that affect termite physiological systems, including the nervous system. Phenolic compounds contribute to the observed toxicity.

TABLE V. ANTI-TERMITE ACTIVITY OF LIQUID SMOKE DERIVED FROM CASSAVA PEEL WASTE

Application method	Mortality time range (seconds)	Mortality time (s) (mean ± SD)	Observed mortality (%)	Mode of exposure
Brush application	24 – 57	20 ± 1.8	100	Direct contact through brushing on termite body surface
Spray application	34 – 59	50 ± 3.2	100	Contact exposure through sprayed droplets
Control (without liquid smoke) *	No mortality observed	-	0	No treatment

*Control treatment used as a comparison

F. Comparison of Application Methods (Brush vs Spray)

The results of the anti-termite efficacy test showed that the brush application method resulted in faster termite mortality than the spray method. This is likely due to a higher concentration of liquid smoke contacting the termites' bodies directly. In contrast, the spray method disperses the liquid into smaller droplets, reducing direct contact and slightly lowering exposure concentration. Despite this difference, both methods were highly effective, achieving 100% termite mortality in less than 1 min. This indicates that cassava-derived liquid smoke possesses strong insecticidal activity and can be applied effectively using different techniques. Table VI presents the comparative effectiveness of these application methods. The difference in mortality time between the two methods underscores the significance of application technique in determining the efficacy of bio-based pesticides. The brush method provides more direct and concentrated contact between the liquid smoke and the termite cuticle, facilitating the faster penetration of bioactive compounds, such as phenols and organic acids. In contrast, the spray method distributes the liquid smoke more evenly over a wider area. This may be advantageous for practical field applications, despite the slightly longer mortality time. Therefore, depending on the intended application conditions, both methods offer practical benefits.

TABLE VI. COMPARISON OF APPLICATION METHODS OF CASSAVA-DERIVED LIQUID SMOKE AGAINST TERMITES

Liquid smoke source	**Application method**	**Mortality time range (s)**	**Observed mortality (%)**	**Relative effectiveness**
Cassava stem	Brush	30 – 44	100	Faster mortality
	Spray	21 – 48	100	Slightly slower than brush
Cassava peel	Brush	24 – 57	100	Faster mortality
	Spray	34 – 59	100	Slightly slower than brush

These findings demonstrate the effectiveness of different application techniques and the broader potential of cassava-derived liquid smoke as a bio-based pest control agent. The rapid termite mortality observed in both methods indicates strong insecticidal properties, which can be used in various pest management strategies. Furthermore, using cassava stems and peels as raw materials is an innovative way to convert agricultural waste into valuable products, promoting sustainable pest control and biomass valorization. This approach supports environmentally friendly pest management strategies, reducing reliance on synthetic pesticides and aligning with sustainable agriculture and circular bioeconomy principles. The results further indicate that cassava stem liquid smoke exhibited a lower average mortality time than cassava peel. Statistical analysis using one-way ANOVA followed by Tukey's post hoc test confirmed that this difference was statistically significant ($p < 0.05$). This indicates that the observed variation is not due to random factors but rather reflects a consistent effect across replicates. The higher effectiveness of cassava stems is possibly associated with their relatively higher phenolic content, as identified in the GC–MS analysis. The anti-termite efficacy observed in this study is closely linked to the chemical composition identified through GC–MS analysis. Phenolic compounds, which were present in relatively high abundance, are known to disrupt cell membranes and interfere with metabolic processes in insects. Meanwhile, organic acids may enhance toxicity by lowering the environmental pH level and creating stressful conditions. These compounds' combined presence suggests a synergistic effect, wherein multiple bioactive constituents interact to produce a stronger insecticidal response, which leads to the rapid mortality observed in the bioassay.

G. Implications for Sustainable Pest Control and Biomass Waste Valorization

This study demonstrates that cassava agricultural residues, particularly stems and peels, can be effectively converted into valuable bioactive products using pyrolysis technology. This process produces liquid smoke containing bioactive compounds, such as phenolic derivatives, organic acids, and other oxygenated compounds, which exhibit strong insecticidal activity. From an environmental perspective, using cassava-derived liquid smoke as a natural termiticide has several advantages over conventional synthetic pesticides. Synthetic pesticides are often associated with environmental contamination, bioaccumulation, and adverse effects on non-target organisms. In contrast, bio-based products derived from biomass waste tend to be more environmentally friendly, biodegradable, and less harmful to surrounding ecosystems. Thus, developing natural pesticides from agricultural waste aligns with global efforts to promote sustainable, eco-friendly pest management strategies. In addition to its environmental benefits, converting cassava agricultural waste into liquid smoke contributes to biomass waste valorization. Cassava is one of the major agricultural commodities in many tropical countries, including Indonesia, and it generates large quantities of agricultural residues, such as stems and peels. These residues are often underused or discarded in the field. However, through pyrolysis technology, these residues can be transformed into valuable products with applications in agriculture, food preservation, and pest management. Furthermore, integrating cassava biomass waste usage into pest control strategies supports implementing a circular economy approach in agricultural systems. Converting waste materials into useful products reduces waste generation and creates additional economic value for farmers and agricultural industries. This approach enhances resource efficiency and promotes sustainable agricultural practices. Overall, this study's findings highlight cassava biomass waste's significant potential as a sustainable resource for producing bioactive liquid smoke with strong anti-termite properties. Developing such bio-based pest control products can contribute to environmentally friendly pest management and support the sustainable use of agricultural residues.

IV. CONCLUSIONS

This study demonstrates the strong potential of liquid smoke derived from cassava agricultural residues, particularly stems and peels, as a natural termiticide. Gas Chromatography–Mass Spectrometry (GC–MS) analysis revealed that cassava stem liquid smoke had a higher phenolic content (18.92%) than cassava peel liquid smoke (12.89%), suggesting a greater concentration of bioactive compounds linked to insecticidal activity. Anti-termite efficacy tests confirmed that both types of liquid smoke achieved 100% mortality in less than 1 min. The brush application method generally resulted in faster mortality than the spray method due to more direct contact. These results suggest that liquid smoke derived from cassava possesses significant bioactive properties, showing potential as an alternative to conventional chemical pesticides. It also supports sustainable pest control and the valorization of agricultural waste through the conversion of biomass into valuable products. Despite these promising results, several limitations should be acknowledged. First, the experiments were conducted at a laboratory scale under controlled conditions, which may not fully represent field environments. Second, the number of replicates remains relatively limited despite the inclusion of statistical analysis. Future research should focus on optimizing pyrolysis conditions, improving product formulation and stability, and exploring large-scale production and commercialization.

DECLARATION OF COMPETING INTERESTS

Not applicable to this work.

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DATA AVAILABILITY

Data acquisition procedure is described within the paper.

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