PRODUCTION AND CHARACTERIZATION OF LIQUID SMOKE FROM MAHANG (*MACARANGA PRUINOSA*) WOOD USING A TRADITIONAL PYROLYSIS METHOD

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Liquid smoke is a condensate formed from the incomplete burning of lignocellulosic materials, which generates chemical compounds such as acetic acid, phenols, carbonyls, and their derivatives. This study aims to utilize mahang wood (*Macaranga pruinosa*) as an alternative raw material for generating liquid smoke and to examine the properties of the resulting compounds. A traditional pyrolysis technique was utilized for the production process, with pyrolysis times of 30, 45, and 60 minutes. A simple condensation system was used to collect the combustion vapors. The findings suggest that mahang wood can generate liquid smoke with a fairly good yield, noted for its dark brown color and unique scent. Preliminary analysis revealed that the primary components were organic acids, phenols, furans, and their derivatives, as identified through GC–MS (Gas Chromatography–Mass Spectrometry) analysis. The research shows that increasing pyrolysis duration decreases the total phenolic content in the liquid smoke, with the highest value of 18.65 mg GAE/g identified at 30 minutes through UV–Vis spectrophotometric analysis. Based on FTIR spectra, prolonged pyrolysis of mahang wood decreases oxygenated and aliphatic groups, while increasing aromatic structures, reflecting enhanced aromatization and structural stability in the resulting pyrolysis products. Consequently, mahang wood possesses considerable potential as an affordable and eco-friendly raw material for producing liquid smoke, while also increasing the added value of local forest resources that are not fully utilized.

Keywords: liquid smoke, mahang wood, pyrolysis, acids, phenols

INTRODUCTION

Wood is a plentiful natural resource in Indonesia, especially timber sourced from forests, which can be found in both natural forests and industrial plantations. Wood consists fundamentally of three primary components: cellulose, hemicelluloses, and lignin. These three components can be thermochemically converted into a variety of high-value derivative products, one method being pyrolysis. Pyrolysis is the process of heating organic materials at high temperatures (usually <600 °C) in the absence of oxygen or under limited oxygen conditions.[1,2] This process breaks down the complex structure of wood into simpler products like charcoal (biochar), pyrolysis gas, and liquid smoke.[3,4,5]

Liquid smoke is formed from the condensation of pyrolysis vapors that indicate a variety of chemical compounds resulting from the thermal breakdown of lignocellulosic materials,[6,7] such as phenols, organic acids, aldehydes, ketones, and other aromatic substances.[8,9] These compounds play an important role in determining the functional properties of liquid smoke, such as antimicrobial and antioxidant activities, as well as the formation of smoky flavor and aroma, are significantly influenced by these compounds. Due to its natural ability to inhibit the growth of various

organisms, liquid smoke is extensively utilized as an antifungal,[10] termiticide,[11,12] insect repellent,[13] antitermite,[14] and antibacterial agent.[15] However, the quality and chemical composition of liquid smoke are significantly affected by pyrolysis parameters, including temperature, type of feedstock, heating rate, and most critically, the duration of pyrolysis. A pyrolysis duration that is too short may result in suboptimal decomposition of lignocellulosic components, resulting in a reduced quantity and concentration of volatile compounds that become part of liquid smoke. On the other hand, excessively long pyrolysis durations may cause further thermal degradation of active compounds, such as phenols. This would result in a lower total phenolic content in the liquid smoke produced.

In traditional pyrolysis processes, the control of temperature and time is less precise compared to modern methods (like controlled pyrolysis with automated reactors). This makes it essential to choose a suitable pyrolysis duration to achieve liquid smoke of optimal quality. To explore the impact of differing process durations on the composition of liquid smoke produced from biomass, this research utilized a traditional pyrolysis configuration typical of community use, with pyrolysis times of 30, 45, and 60 minutes. One of the biomasses that can be utilized is mahang wood (*Macaranga pruinosa*), which is commonly found in Indonesia's secondary forests and degraded areas. Although mahang wood is a lightweight, and belongs to fast-growing species with abundant availability, yet its utilization remains limited, typically restricted to firewood or pulp production. The lignin, cellulose, and hemicellulose content of mahang wood makes it a promising raw material for liquid smoke production through the pyrolysis process.

The utilization of mahang wood as a raw material for generating liquid smoke could not only enhance the added value of local forest resources, but also support sustainable forest management efforts. Additionally, this innovation offers communities residing in proximity to forests an alternative economically valuable product and reduces reliance on conventional feedstocks such as coconut shells or sawdust. Therefore, an investigation into the relationship between pyrolysis duration and the composition of liquid smoke from mahang wood can provide valuable insights into the optimal conditions for producing high-quality liquid smoke. In this context, the present study was conducted to investigate the effect of varying pyrolysis durations (30, 45, and 60 minutes) on the composition of liquid smoke generated from mahang wood in a traditional pyrolysis setup. The results are expected to provide scientific insights and serve as a foundation for the development of small-scale pyrolysis technologies based on local biomass resources.

EXPERIMENTAL

Pretreatment of mahang wood

Mahang wood (*Macaranga pruinosa*) was subjected to a pretreatment to achieve a consistent particle size and moisture content to be used as the raw material for liquid smoke production. According to the technique described by Cheng and Zhao,[16] the raw material was cut into chips of 10–30 mm dimensions and subsequently milled to create particles around 2 mm in size, specifically those that went through a 10-mesh (2.0 mm) sieve and were kept on a 14-mesh (1.4 mm) sieve. Then, the material was dried to achieve an air-dry moisture content of 12–18%, in compliance with SNI 7973:2013. The drying process was done naturally under sunlight or in a drying oven set to 60–80 °C until the desired moisture content was reached. The dried samples were stored in airtight containers to prevent moisture absorption from the air before their use in the pyrolysis process.

Pyrolysis process of mahang wood

The traditional pyrolysis process followed the method described by Amrullah and Octaviananda.[17] An iron plate of 30 cm in diameter, 67 cm in height, and 1 mm in thickness was used to build the conventional pyrolysis reactor. The diameter of the conduit that directed the pyrolysis fumes to the condenser was 2.5 cm. The condenser was composed of a 0.5 mm-thick, cylindrical iron plate chamber. To improve heat transfer and vapor condensation, a spiral (coiled) pipe was added inside the condenser. The pipe used for the spiral coil had a diameter of 2.5 cm.

After reducing the wood particles size to around 2 mm and drying them to a moisture content of 12–18%, a total of 1 kg of pretreated mahang wood (*Macaranga pruinosa*) was put into the pyrolysis reactor, which was then securely closed. After that, the condensation apparatus was assembled, and cold water was circulated through the condenser to maintain the condensation temperature. Until the material in the reactor underwent pyrolysis and produced smoke, heating was achieved using a combustion furnace. The smoke produced was directed into a condensation tube with a spiral pipe and cooled with tap water, resulting in the smoke condensing into liquid smoke, which then flowed into a collection container. The pyrolysis process was conducted with heating durations of 30, 45, and 60 minutes (measured from the first drop of condensed liquid smoke) to determine the effect of pyrolysis time on the yield of liquid smoke produced.

Characterization of liquid smoke from mahang wood

The identification of volatile compounds in the liquid smoke was carried out using GC–MS (Gas Chromatography–Mass Spectrometry) to determine the types and composition of chemical compounds generated during pyrolysis. Using a UV–Vis spectrophotometer, which determines the concentration of phenolic compounds from absorbance intensity at certain wavelengths, total phenolic content was analyzed. Meanwhile, quantitative data on the organic acids in the liquid smoke was obtained by determining the total acid content using HPLC (High Performance Liquid Chromatography). The functional groups of the liquid smoke were studied using Fourier transform infrared (FTIR) spectroscopy in the wave number range of 400 – 4000 cm^{-1}. These four analyses were used to evaluate the chemical quality of the liquid smoke produced for different pyrolysis durations.

RESULTS AND DISCUSSION

Yield of liquid smoke from mahang wood

The liquid smoke yield indicates the percentage of liquid smoke obtained from the raw material post-pyrolysis, in relation to the initial weight of the material that underwent pyrolysis. The yield of liquid smoke is significantly affected by various factors, including the process parameters (such as pyrolysis temperature and duration), characteristics of the raw material (like tree species, moisture content, and particle size), the effectiveness of the condensation system, post-pyrolysis purification methods, and the pyrolysis technique employed. Figure 1 shows the yield of liquid smoke generated from mahang wood (*M. pruinosa*) with a traditional pyrolysis system.

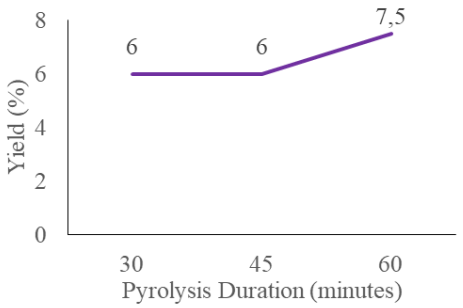

Figure 1: Yield of liquid smoke from mahang wood

According to Figure 1, the effect of traditional pyrolysis duration on the yield of liquid smoke from mahang wood indicates that at a pyrolysis time of 30 minutes, the yield was 6%. This remained relatively stable at 45 minutes and then increased to 7.5% at 60 minutes. This pattern suggests that longer pyrolysis duration offers more chance for the thermal decomposition of lignocellulose, a greater opportunity for more effective release of volatile compounds that condense into liquid smoke. This indicates that the longer the pyrolysis time, the higher the potential for forming the liquid fraction that can be utilized, as long as excessive breakdown of large hydrocarbon molecules into smaller molecules – thereby turning into permanent gases – does not occur.

These findings align with earlier research that highlights the significance of pyrolysis duration. According to previous studies,[18] the yield of liquid smoke from sawdust increased with longer pyrolysis durations, achieving 58% at a duration of 90 minutes. This finding aligns with the pattern observed in Figure 1, in which the yield increases with extended pyrolysis time. Furthermore, despite showing a similar result, the greatest yield achieved in this study (7.5% at 60 minutes) is considerably lower than that observed in the literature. The effectiveness of the condensation mechanism in the traditional pyrolysis setup, which may have led to incomplete recovery of condensable vapors. In addition, the relatively small biomass particle size (2 mm) would have promoted rapid devolatilization and secondary cracking reactions, thereby reducing the liquid yield. The relatively low yield found in this study suggests that operational factors particularly condensation efficiency and reactor conditions play a critical role, even though it can be stated that pyrolysis time has a major influence on liquid smoke generation. In the context of this investigation, a 60 minute pyrolysis period still yielded the maximum output when compared to shorter durations; however, additional tuning is required to increase yield and guarantee improved economic viability for possible industrial

applications. Therefore, it can be concluded that the duration of traditional pyrolysis has a considerable impact on the yield of liquid smoke and that within the framework of this study, a pyrolysis duration of 60 minutes yielded the best results in comparison to shorter durations.

GC–MS analysis of liquid smoke from mahang wood

The purpose of the GC–MS analysis was to identify the chemical compounds produced in liquid smoke from mahang wood subjected to traditional pyrolysis process at different pyrolysis durations. Table 1 shows the results of the liquid smoke GC–MS analysis.

The GC–MS analysis of liquid smoke derived from mahang wood showed that phenolic compounds (phenol, guaiacol, creosol, syringol) were predominant during pyrolysis durations of 30 to 45 minutes, with guaiacol reaching its maximum concentration of 8.87% at the 45-minute mark. Meanwhile, at a longer pyrolysis time (60 minutes), the phenolic compounds tended to decrease, being replaced by the dominance of ester compounds, such as ethyl oleate (44.79%) and the appearance of degraded carbohydrates (D-Allose 6.36%). This pattern illustrates a chemical transformation: at first, lignin breaks down into volatile phenols, while additional pyrolysis yields heavier compounds from the breakdown of carbohydrates.

The research conducted by Muliyanti *et al*.[19] indicates that the compounds obtained from liquid smoke through pyrolysis, including phenol and its derivatives such as phenol, 2-methyl-phenol, and 3-methyl-phenol, are the primary constituents of liquid smoke. These compounds demonstrate potent antimicrobial effects and function as natural pesticides. These compounds are effective against termites, disrupting their metabolism and tissue structure through oxidation reactions. In particular, 2-methyl-phenol demonstrates stability at high pyrolysis temperatures, while 3-methyl-phenol has a synergistic effect that increases toxicity.

A similar study by Komarayati *et al*.[20] found that an analysis using GC–MS of liquid smoke from different wood types showed variations in chemical components for each species. Liquid smoke derived from the five wood types examined was predominantly characterized by the presence of acetic acid (also known as ethylic/acetic acid), phenol (specifically, 2,6-dimethoxyphenol), and carbamic acid. In addition to phenolic compounds and their derivatives, cellulose degradation in mahang wood encompasses depolymerization reactions that fragment long-chain molecules into smaller sugar units, predominantly producing levoglucosan, water, acetic acid, and acetone.[21] Table 1 illustrates that various acidic compounds and their derivatives were generated during each pyrolysis duration. In addition to phenolic and organic acid compounds, carbonyl compounds, such as furfural and 2-cyclopenten-1-one are toxic to insects and microbes. These substances successfully contribute to wood protection by creating an unfavorable environment for harmful organisms.[22]

Total acid analysis

Total acid, which represents the amount of organic acid compounds (mostly acetic acid) present, is one of the important factors for assessing the quality of liquid smoke. These compounds are formed as a result of hemicellulose and cellulose components breaking down during the pyrolysis process.[23]

At a pyrolysis duration of 30 minutes (1.47%), the total acid content was the lowest because the degradation of wood components, especially hemicelluloses and cellulose, was not yet at its best due to the relatively short pyrolysis process. Organic acids, such acetic acid and formic acid, are mostly formed from these two components.[24,25] At 45 minutes of pyrolysis (1.64%), the total acid content increased due to the longer pyrolysis duration, which allowed more complete depolymerization reactions. The longer the pyrolysis process, the greater is the formation of carbonyl compounds and organic acids resulting from the thermal breakdown of lignocellulosic compounds. Meanwhile, the pyrolysis duration of 60 minutes (1.79%) produced a higher total acid content, compared to the other two treatments. This is because the prolonged pyrolysis time raises the temperature within the reactor, accelerating the formation of organic acids. The increase in total acid indicates that the traditional pyrolysis process is suitable for producing liquid smoke with a relatively high organic acid content, even in the absence of exact temperature control.

Hemicelluloses, which begins to break down at 250–340 °C, produces acetic acid as the main product,[26] while cellulose (300–380 °C) and lignin (300–500 °C) contribute to the formation of other acidic compounds, such as formic acid and weakly acidic phenols.[27]

Table 1
Chemical compounds of liquid smoke from mahang wood (*M. pruinosa*)

No	Chemical compound	Chemical formula	Area (%)		
			30 minutes	45 minutes	60 minutes
	Phenol and its derivatives				
1	Phenol	C_6H_6O	2.56	5.86	-
2	Phenol, 2-methyl-	C_7H_8O	0.48	1.45	-
3	Phenol, 3-methyl- (p-Cresol)	C_7H_8O	0.97	2.16	-
4	Phenol, 2-methoxy- (Guaiacol)	$C_7H_8O_2$	2.86	8.87	6.83
5	Creosol (2-Methoxy-5-methylphenol)	$C_8H_{10}O_2$	1.69	4.47	-
6	Phenol, 2,6-dimethoxy- (Syringol)	$C_8H_{10}O_3$	2.37	4.26	1.61
7	4-Ethyl-2,6-dimethoxyphenol	$C_{10}H_{14}O_3$	2.7	4.57	2.71
8	Phenol, 4-ethyl-2-methoxy-	$C_9H_{12}O_2$	-	1.77	-
9	3,5-Dimethoxy-4-hydroxytoluene	$C_9H_{12}O_3$		1.29	2.33
10	2,4-Di-tert-butylphenol (12,54%)	$C_{14}H_{22}O$		12.54	4.61
11	Creosol	$C_8H_{10}O_2$			4.22
	Organic acids and their derivatives				
12	Vanillin	$C_8H_8O_3$	1.26	1.99	-
13	Benzaldehyde, 4-hydroxy-3,5-dimethoxy-	$C_9H_{10}O_4$	0.87	2.31	-
14	Hexanoic acid ester	$C_6H_{12}O_2$	1.47	-	-
15	Butanoic acid	$C_4H_8O_2$	-	2.06	-
16	Butanoic acid, 2-methylbutyl ester	$C_9H_{18}O_2$	-	1.67	-
17	9-Octadecenoic acid (Z)-, methyl ester	$C_{19}H_{36}O_2$	-	0.58	-
18	Hexadecanoic acid, ethyl ester	$C_{18}H_{36}O_2$	-	-	3.9
19	Linoleic acid ethyl ester	$C_{20}H_{36}O_2$	-	-	1.8
20	Ethyl Oleate	$C_{20}H_{38}O_2$	-	-	44.79
21	Octadecanoic acid, ethyl ester	$C_{20}H_{40}O_2$	-	-	2.9
22	Eicosanoic acid, ethyl ester	$C_{22}H_{44}O_2$	-	-	0.3
	Furans and their derivatives				
23	Furfural	$C_5H_4O_2$	2.87	-	-
24	4-Methyl-5H-furan-2-one	$C_5H_6O_2$	0.34	-	-
25	2-Cyclopenten-1-one	C_5H_6O	-	6.67	0.56
26	2-Cyclopenten-1-one, 3-methyl-	C_6H_8O	-	2.34	-
27	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	$C_6H_8O_2$	-	1.39	-
28	10-Methylundecan-4-olide	$C_{12}H_{22}O_2$	-	1.8	-
29	Butyrolactone	$C_4H_6O_2$	-	-	3.39
	Other compounds				
30	Apocynin	$C_9H_{10}O_3$	0.77	-	-
31	Acetosyringone	$C_9H_{10}O_4$	0.58	-	-
32	Ethanone, 1-(4-hydroxy-3,5-dimethoxyphenyl)	$C_{10}H_{12}O_4$	-	1.22	-
33	D-Allose	$C_6H_{12}O_6$	-	-	6.36
34	Methacrylamide	C_4H_7NO	-	-	0.63
35	Isopropylamine, N-acetyl-	$C_5H_{11}NO$	-	-	2.25

Table 2
Acetic acid content in liquid smoke from mahang wood

No.	Pyrolysis time (min)	Concentration (%)
1	30	1.47
2	45	1.64
3	60	1.79

Thus, the longer the pyrolysis process, the greater the likelihood of forming these compounds. A high total acid concentration also affects the quality of liquid smoke, as organic acids lower the pH and provide antibacterial and antifungal properties. However, excessively high acid levels can make the liquid smoke too sharp or corrosive, necessitating redistillation to adjust its suitability, particularly for food applications.

Overall, the study's findings show that increasing the pyrolysis duration from 30 to 60 minutes is closely correlated with an increase in the liquid smoke's overall acid content, with the 60-minute treatment producing the highest total acid content.

Total phenol analysis

During the pyrolysis of mahang wood, major components, such as lignin, cellulose, and hemicelluloses, decompose into volatile compounds that subsequently condense into liquid smoke. Phenolic chemicals, which function as antioxidants and antimicrobials and contribute to the distinctive flavor and scent of liquid smoke, are one of its key components.[28,29] Based on the analysis results, the total phenol content of liquid smoke from mahang wood decreased with increasing pyrolysis duration, as shown in Table 3. Table 3 illustrates that the highest total phenol concentration of 18.65 mg GAE/g was obtained at a pyrolysis duration of 30 minutes, whereas the total phenol content decreased to 11.79 mg GAE/g at a longer pyrolysis duration of 60 minutes. Early in the pyrolysis process, the lignin in mahang wood breaks down to produce phenolic chemicals and their derivatives.

Long-term pyrolysis, however, may result in the high temperature further decompose phenolic chemicals into simpler volatile or non-phenolic molecules that do not condense into liquid smoke.[30,31]

Table 3
Total phenol content in liquid smoke from mahang wood

No.	Pyrolysis time (min)	Concentration (mg GEA/g)
1	30	18.65
2	45	13.34
3	60	11.79

Furthermore, oxygen can react with lignin at greater pyrolysis temperatures to create additional low-boiling-point chemicals.[32] For comparison, at a pyrolysis temperature of 300 °C, liquid smoke from the pyrolysis of Ubah Rukkok wood produced a phenol concentration of 19.73 mg GAE/g. At pyrolysis temperatures of 350 °C and 400 °C, the phenol content further dropped, with values of 14.78 and 13.10 mg GAE/g, respectively.[9]

These findings suggest that the duration of pyrolysis has a substantial impact on the overall phenol concentration of liquid smoke. Prolonged pyrolysis does not necessarily increase the amount of active compounds, instead it can lead to a decrease in phenol concentration due to thermal decomposition and secondary reactions. Therefore, in traditional pyrolysis operations, a 30-minute pyrolysis time can be thought of as the most ideal condition for producing liquid smoke with a high phenol concentration.

FTIR analysis

Mahang wood that had been pyrolyzed for 30, 45, and 60 minutes showed notable changes in chemical composition as a function of pyrolysis duration, according to the Fourier Transform Infrared (FTIR) spectra in Figure 2. The resultant spectra showed distinctive lignocellulosic material absorption bands, indicating the presence of aromatic, hydroxyl, aliphatic, and carbonyl groups. As the pyrolysis duration increased, the intensity of the broad absorption band in the 3200–3600 cm^{-1} wavenumber region, which is linked to –OH hydroxyl stretching vibrations, rapidly reduced. A decrease in the polarity of the resulting pyrolysis material is the result of this occurrence, which is indicative of dehydration processes and the weakening of hydrogen bonds within the cellulose and hemicellulose matrix as a result of extended heat.[33,34]

The FTIR spectra of mahang wood liquid smoke show absorption bands in the 2000–2250 cm^{-1} wavenumber region, which are indicative of

the production of triple bonds, specifically C≡C groups, and possibly C≡N groups, as a result of the thermal breakdown of lignin and extractive chemicals during pyrolysis. These bands represent condensation processes and high-temperature thermal changes that result in the creation of conjugated carbon structures and unsaturated molecules. Despite the relatively modest absorption strength, the existence of these bands indicates a higher degree of aromatization, which is important for figuring out the chemical makeup and aroma characteristics of mahang wood liquid smoke, especially when pyrolysis is carried out for extended periods of time.

Furthermore, the creation of carbonyl (C=O) groups as a result of the thermal breakdown of lignocellulosic components is confirmed by the appearance of absorption bands about 1700 cm^{-1}, especially in samples exposed to 45 and 60 minutes of pyrolysis. In general, the synthesis of oxygenated molecules like organic acids, aldehydes, and ketones is linked to these carbonyl groups. In the meantime, all pyrolysis treatments consistently showed absorption bands in the 1400–1600 cm^{-1} range, which indicate the aromatic C=C stretching vibrations of lignin. These bands showed increased stability at the longest pyrolysis durations.

According to previous literature,[20] these results validate that lignin has higher heat stability than the cellulose and hemicellulose fractions. According to Zheng *et al*.,[34] extended pyrolysis generally results in a decrease in aliphatic and oxygen-containing functional groups and a rise in the dominance of aromatic structures. This chemical change suggests that longer pyrolysis times encourage the creation of materials with greater levels of structural stability and aromatization, which could improve the degree of carbonization and longevity of mahang wood pyrolysis products.

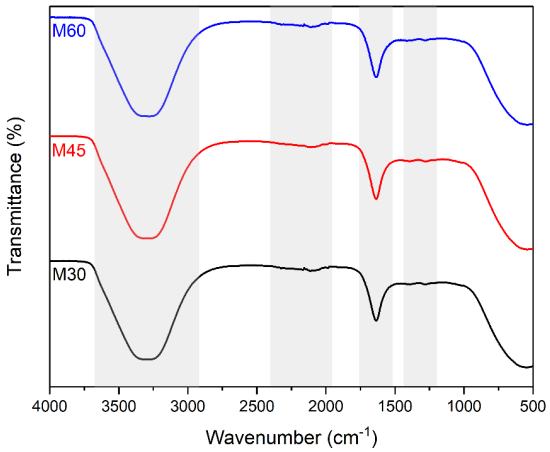

Figure 2: FTIR spectra of mahang wood liquid smoke obtained at different pyrolysis durations

CONCLUSION

Based on the results of this study, the mahang wood (*Macaranga pruinosa*) has a lot of potential as a raw material in the liquid smoke production process. Mahang wood can produce liquid smoke with a dark brown color, a distinctive flavor, and a relatively high yield through traditional pyrolysis methods that take 30 to 60 minutes. The formation of key chemical compounds, such as organic acids, phenols, and furans, has been confirmed. These compounds play important roles as biopesticides and antimicrobials, indicating that liquid smoke from mahang wood has potential applications in food, agriculture, and environmental industries. The total acid concentration in the liquid smoke increased from 1.47% for the 30 min pyrolysis to 1.79% for the 60 min pyrolysis, demonstrating that pyrolysis duration positively influences the formation of organic acids. Furthermore, the duration of pyrolysis has an impact on the production of phenolic compounds: shorter pyrolysis times (30 min) result in liquid smoke with the highest total phenol concentration when compared to longer pyrolysis times. Longer pyrolysis of mahang wood enhances aromatization and structural stability, while reducing oxygenated and aliphatic functional groups. The utilization of mahang wood adds value to this fast-growing species, which has been largely underutilized in the context of sustainable forest resource management.

Thus, the development of technology for producing liquid smoke from mahang wood serves as an innovative alternative for producing environmentally friendly products, while simultaneously creating economic opportunities for local communities near forest areas.

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