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Possibility of liquid smoke from plant waste as an anti-termite agent to protect traditional houses in Indonesia: a systematic review

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ABSTRACT: Indonesia is a country with a rich diversity of traditional houses that represent various ethnic groups and cultures. However, these traditional houses are increasingly being abandoned due to deterioration and termite infestations. One potential method to preserve these cultural assets is by utilizing liquid smoke. This study aims to provide a valuable reference for protecting traditional houses in Indonesia from termite infestations. Liquid smoke is eco-friendly because it utilizes waste from plant species readily available in Indonesia. This systematic review follows the reporting guidelines for Synthesis Without Meta-Analysis (SWiM). The study identifies three termite families commonly found in residential areas of Indonesia: Kalotermitidae, Rhinotermitidae, and Termitidae. Most frequently reported species are *Macrotermes gilvus* and *Coptotermes curvignathus*. The liquid smoke can be produced from 13 plant species from eight families distributed across Indonesia, effectively controlling termite populations. These plant families include Apocynaceae, Arecaceae, Dipterocarpaceae, Fabaceae, Lamiaceae, Lauraceae, Meliaceae, and Poaceae. Utilizing waste from these plants to produce liquid smoke offers an environmentally friendly alternative for termite control. The application of liquid smoke can play a crucial role in protecting traditional houses in Indonesia from termite infestations, thereby ensuring that these cultural symbols of ethnic identity and heritage are preserved.

Keywords: Cultural heritage preservation; Termite control; Wood vinegar; Traditional houses; Indonesia.

1. INTRODUCTION

A house is a building that not only functions as a place to live; it also displays unique characteristics reflecting the culture of an ethnic group. In Indonesia, traditional houses represent cultural diversity, and each region has a distinct architecture. Over 34 traditional houses in Indonesia symbolize each region and ethnicity, showcasing the country's rich cultural heritage [1]. With changing weather conditions and technological advancements, traditional houses are increasingly unkempt, and their numbers are decreasing, leading to the loss of cultural heritage. Furthermore, traditional houses in Indonesia face extinction as people prefer concrete over wood, which is a more sustainable and cost-efficient material [2]. For instance, the traditional house in Bawomataluo Village, Nias Island, Indonesia, is starting to change shape from its original architecture. The

village has many traditional houses, but maintaining these cultural properties has become difficult due to changes in agriculture and infrastructure. Villagers modifying houses have caused damage to the original structures [3]. Likewise, the Joglo Pencu house is undergoing architectural changes, which is starting to decrease because people are moving to modern houses [4]. The villagers have started using more affordable building materials, which has led to changes in the original architectural structure and design [3]. Furthermore, traditional houses now incorporate modern materials instead of natural ones like wood, indicating a shift in building material preferences [5].

The traditional houses in Indonesia face several challenges, such as the risk of extinction, mentality and behavior issues, and management challenges in preserving them [6]. It is essential to make efforts to preserve cultural heritage, such as traditional houses, to prevent them from becoming increasingly rare. Most of the materials used in traditional houses are wood, non-engineered structures of wood better than concrete houses [7]. Other natural materials besides wood include bamboo, stone, clay, straw, and reeds [5]. However, natural materials will be damaged by climate. Climate factors like rainfall, temperature, and humidity significantly negatively impact termite damage to structural wood in houses [8].

Termites are major pests in urban settings, particularly due to their preference for wood, soil, and climate characteristics [9,10]. The building damage by termites is not only limited to components made of wood, but to all components made of materials containing cellulose and lignocellulose [11]. Termites were discovered at the age of the building of more than 26 years, with the discovery of four species of termites, such as *Macrotermes gilvus* (Hagen), *Bulbittermes constrictiformis* (Holmgren), *Schedorhinortermes mediobcorus* (Holmgren), and *Coptotermes gestroi* (Wasmann) [12].

To control the termite population, we can use botanical insecticides or termicides. One of the alternatives is Liquid smoke, an effective and environmentally friendly alternative widely tested to protect wood from termite attacks. It is sustainable, does not pollute the environment, and does not harm humans. Some examples of wood waste that have tried to protect the wood from termites are coconut shells [13], Bintangur wood [14], Bamboo Wulung [15], and many studies have reported the effectiveness of these products. This paper conducts to present a systematic review of the alternative method to protect traditional houses in Indonesia from termite infestations by utilizing liquid smoke as a product from plant waste. This study is expected to provide a valuable reference for the community and relevant stakeholders in protecting traditional houses, a cultural heritage in Indonesia, from household pests like termites. The approach is designed to be eco-friendly, as it utilizes waste from plant species readily available in Indonesia.

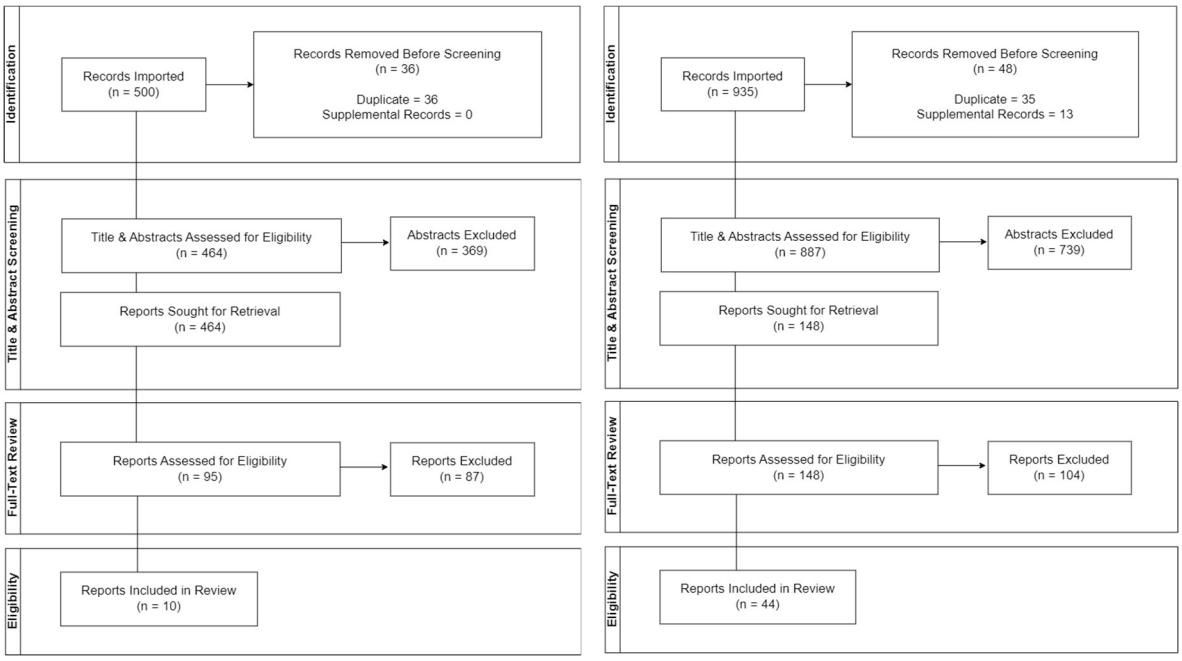
2. MATERIALS AND METHODS

2.1. Study eligibility

This study has two main parts. The first part focuses on termites found in residential or urban areas in Indonesia. This part aims to gather information on the termite species found in these areas that can damage wooden building materials. The criteria for this part are original articles published in scientific journals (excluding gray literature and books) that include information about the termite species in residential or urban areas in Indonesia and articles published between 2000 and 2024. The second part concerns plants found in Indonesia that can be used to make liquid smoke to control termite populations that damage wood. The criteria for the second part are articles published in scientific journals (excluding gray literature and books) that discuss using plant waste to create liquid smoke, testing it on termites identified by the species name, using different concentrations of liquid smoke to test termite mortality, and the articles published between 2000 and 2024.

2.2. Study design and search strategy

This study follows the reporting guidelines for Synthesis Without Meta-Analysis (SWiM) [16]. However, the review steps were adapted from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [17]. The PRISMA protocol is not registered to any databases because the topic of this study is not related to health of medical analysis. The article was obtained from two databases, Google Scholar and Semantic Scholar. Article searches within the databases were done using the Publish or Perish platform on Microsoft Windows (https://harzing.com/). The keywords used for the initial part of the review process were "termite AND (urban area OR residential area) AND Indonesia." For the second part of the review process, the keywords used were "((liquid smoke OR wood vinegar OR pyrolysis liquid) AND (Insect* OR biopesticide OR repel* OR termiticide))."



(A) (B)

Figure 1. The illustration of the screening process for reviewing the eligibility of literature. (A) The first part addresses the topic of termites in urban areas in Indonesia. (B) The second part explores using plants as a source for liquid smoke production to control termites that damage wood materials.

2.3. Screening Process and Data Extraction

All articles collected from online databases were screened using the online systematic literature review screener (https://catchii.org/), following the established criteria for each part. The screening involved reviewing the titles, abstracts, and full texts. Initially, 500 articles were obtained for the first part. After eliminating 36 duplicates, 464 articles remained. These 464 articles underwent title and abstract screening, resulting in 95 eligible articles. Subsequently, these 95 articles were screened based on their full texts, resulting in 10 articles that met all the criteria for the first part. For the second part, a total of 935 articles were collected. After removing 48 articles (35 duplicates and 13 supplemental records), 887 were eligible for screening. During the title and abstract screening, 148 articles were eligible. These 148 articles were screened by full text, resulting in 52 articles. Following data extraction, 44 articles were eligible and fulfilled all criteria for the second part (Figure 1). Species and family names of termites and their distribution are validated on https://isoptera.speciesfile.org/, while plants that produce liquid smoke are validated on https://worldfloraonline.org/.

3. RESULTS AND DISCUSSION

3.1. Traditional houses in Indonesia

Indonesia's archipelago comprises five large islands and thousands of smaller ones, totaling more than 18,000 islands. This chain of islands covers an area approximately the size of Europe. About two-thirds (67%) of Indonesia's territory is water, while the remaining third consists of islands with a combined area of around 1.89 million square kilometers [18]. The island chain is divided into administrative regions in the form of provinces. According to the Undang-Undang Republik Indonesia Number 29 of 2022, Indonesia established its newest province, the Province of Southwest Papua, with its capital in Sorong in 2022. With this establishment, Indonesia now officially has 38 provinces.

Indonesia is home to a large and diverse array of ethnicities and cultures. Provincial divisions often align with the dominant ethnicity and culture of the region. There are more than 600 ethnicities in Indonesia, each with cultural heritages represented by traditional houses. Traditional houses and Indonesian architecture, influenced by various cultures and landscapes, offer a wide variety of styles, materials, and techniques, reflecting the importance of these buildings in people's lives and social status [19]. The diversity is evident in the architectural forms, ranging from the complex and unique Rumah Gadang, a traditional house from West Sumatra Province as a symbol of Minangkabau ethnic, to the simple architecture Honai house, a traditional house from Papua. Each province showcases a unique architectural style and design, with traditional houses holding distinct appearances and cultural meanings.

Indonesia is home to a rich cultural diversity, reflected in the various forms of traditional house architecture found throughout the country. These traditional houses are not just places to live but also serve as symbols of the unique identities of different ethnic groups. The number of traditional houses can vary based on the number of provinces in Indonesia. For example, on Papua Island, the Honai house represents the region. In two provinces, Maluku and North Maluku, the Baileo traditional house can be found. The Javanese ethnic group spread across Central Java, Yogyakarta, and East Java, and it is also represented by a single traditional house known as the Joglo house (Table 1).

Table 1. The diversity of traditional houses representatives of each province and region in Indonesia.

Province	Capital City	Traditional House
Sumatra Island		
Aceh	Banda Aceh	Rumoh Aceh
North Sumatra	Medan	Rumah Bolon
South Sumatra	Palembang	Rumah Limas
West Sumatra	Padang	Rumah Gadang
Bengkulu	Bengkulu	Rumah Bubungan Lima
Riau	Pekanbaru	Rumah Selaso Jatuh Kembar
Riau Islands	Tanjung Pinang	Rumah Atap Limas Potong
Jambi	Jambi	Rumah Kajang Lako
Lampung	Bandar Lampung	Rumah Lamban Pesagi
Bangka Belitung Islands	Pangkal Pinang	Rumah Rakit Limas
Kalimantan Island		
West Kalimantan	Pontianak	Rumah Radakng
East Kalimantan	Samarinda	Rumah Lamin
South Kalimantan	Banjarbaru	Rumah Bubungan Tinggi

Central Kalimantan	Palangkaraya	Rumah Betang
North Kalimantan	Tanjung Selor	Rumah Baloy
Java Island		
Banten	Serang	Rumah Sulah Nyanda
Jakarta Special Capital Region	Jakarta	Rumah Kebaya
West Java	Bandung	Rumah Julung Ngapak
Central Java	Semarang	Rumah Joglo
Yogyakarta Special Region	Yogyakarta	Rumah Joglo
East Java	Surabaya	Rumah Joglo
Lesser Sunda Islands and Bali Island		
Bali	Denpasar	Rumah Bale Manten
East Nusa Tenggara	Kupang	Rumah Musalaki
West Nusa Tenggara	Mataram	Rumah Bale Sasak
Sulawesi Island		
Gorontalo	Gorontalo	Rumah adat Dulohupa
West Sulawesi	Mamuju	Rumah Boyang
Central Sulawesi	Palu	Rumah Tambi
North Sulawesi	Manado	Rumah Walewangko
Southeast Sulawesi	Kendari	Rumah Banua Tada
South Sulawesi	Makassar	Rumah Tongkonan
Maluku Islands		
North Maluku	Sofifi	Rumah adat Baileo
Maluku	Ambon	Rumah adat Baileo
Papua Island		
West Papua	Manokwari	Rumah Honai
Papua	Jayapura	Rumah Honai
Central Papua	Nabire	Rumah Honai
Papua Pegunungan	Wamena	Rumah Honai
Papua Selatan	Merauke	Rumah Honai
Papua Barat Daya	Sorong	Rumah Honai

Traditional houses in Indonesia are built using natural materials such as wood, bamboo, stone, clay, straw, and reeds [5]. For example, the traditional house of the Osing tribe in Banyuwangi, East Java, uses Bendo wood as the primary foundation and building walls. The house's walls are also made of woven Bamboo tied with ropes from Aren tree fibers [20]. Another instance is the Besemah House, a variant of traditional houses in South Sumatra, which is constructed using three types of wood: Mersawa wood (*Anisoptera* sp.), Surian wood (*Toona sureni* Merr.), and Rasamala wood (*Altingia excelsa* Noronha) [21]. Meanwhile, Rumah Gadang in West Sumatra utilizes *Senna Siamea* wood [22].

Houses made of natural materials like wood and bamboo have different durability compared to houses made of concrete. As a result, maintaining traditional houses becomes more challenging. If they are not properly maintained, people will move to modern houses that are easier to maintain, leading to the extinction of traditional houses. According to [23], nearly 19.37% of traditional houses of Minangkabau Ethnic in West Sumatra are uninhabited due to damage and urbanization, affecting their sustainability. Traditional houses are meaningful cultural representations but are no longer authentic. Modern society prefers simple and more easily obtainable building materials that do not require special skills for installation or manufacturing [5].

Maintaining traditional houses is increasingly challenging due to existing structural damage. Weather and climate factors contribute to the deterioration of traditional houses' wooden structures. The combination of weather conditions, humidity, and the types of wood used make the materials in traditional houses susceptible to termite damage. Termites, known for damaging wood and other cellulose materials, are a significant concern for people [11,24]. According to [25], termites can infiltrate buildings through wall holes, crawl through foundation cracks, and climb through the roof. Damage caused by termite attacks severely threatens traditional houses, deteriorating wooden components and causing structural weaknesses. Consequently, traditional houses may be abandoned, with people opting for modern houses constructed from more durable concrete materials.

3.2. Termites in the Residential or Urban Areas in Indonesia

Termites are social insects that play a crucial role in ecosystem functioning by promoting essential ecological processes [26], decomposing organic matter, creating biostructures, and influencing the distribution of resources like water and nutrients, affecting soil diversity [27]. Various environments, such as forests, agricultural fields, plantations, and residential or urban areas, serve as habitats for termites. Most termites are distributed in tropical areas, such as Indonesia, because Indonesia is warm, humid tropical climate, organic-rich soil, and diverse range of woody plants provide an ideal termite habitat [28].

Termites are significant pests in urban settings, mainly due to their preference for wood, soil, and climate characteristics, despite their ecological importance leading to structural damage to buildings [9,10]. The building damage by termites is not only limited to components made of wood but to all components made of materials containing cellulose [11] because the main diet of termites is cellulose and lignocellulose [28].

The reduction of forest areas and the increasing number of residential areas has reduced the habitat of termites. Termites are finally distributed in residential and urban areas, thus becoming pests. This study found three families of termites in several residential and urban areas in Indonesia. The termite families known are Kalotermitidae, Rhinotermitidae, and Termitidae. Various residential and urban areas across Indonesia have reported termite infestations, including in the following regions: Minahasa Raya in North Sulawesi Province, South Jakarta in the Capital Region of Jakarta, the University of Bengkulu Campus in Bengkulu Province, Semarang City in Central Java Province, Pekanbaru in Riau Province, West Lampung in Lampung Province, Padang City in West Sumatra Province, and Purwokerto in Central Java Province (Table 2).

The most common species found in almost all regions are from the Termitidae family, which consists of nine species, followed by the Rhinotermitidae family, with seven species, and Kalotermitidae, with three species. Termitidae is most commonly found in urban areas because this family has an extensive distribution, with the largest number of species (85% of known termite species come from the Termitidae family). This family is also found at 3000 meters above sea level [48]. The most commonly found species, *Macrotermes gilvus* (Hagen, 1858), is present in seven regions, followed by *Microtermes insperatus* Kemner, 1934 and *Coptotermes curvignathus* Holmgren, 1913, which are spread across four regions. *Coptotermes gestroi* (Wasmann, 1896) and *Odontotermes javanicus* Holmgren, 1912 are found in two regions, while the rest are each spread across one region in Indonesia (Table 2).

The most common species found in urban areas in Indonesia in this study was *M. gilvus*. *M. gilvus* is a subterranean termite that can play dual roles as decomposers of natural wood and pests in plantations and urban areas. The damages caused by these termites in urban areas reach 35%, and the wood industry can reach 40% [49]. Saviri et al. [32] also reported that *M. gilvus* was found in almost 71% compared to other termites in urban areas. *M. gilvus* abundance is also the highest, with a value of 150,000 individuals/m^3 around the Bengkulu University campus, with an attacking intensity reaching 25.26% [50].

Table 2. The termite species found in residential or urban areas in Indonesia.

Family	Species	Location	Reference
Kalotermitidae	*Cryptotermes brevis* (Walker, 1853)	Minahasa Raya Region, North Sulawesi Province	[10]
	Cryptotermes dudleyi Banks, 1918	Minahasa Raya Region, North Sulawesi Province	[10]
	Cryptotermes sp.	Kota Semarang, Central Java Province	[29]
	Cryptotermes cyanocephalus Light, 1921	Universitas Negeri Semarang Campus, Central Java Province	[30]
Rhinotermitidae	*Coptotermes curvignathus* Holmgren, 1913	South Jakarta, Capital Region of Jakarta	[9]
		University of Bengkulu Campus, Bengkulu Province	[31]
		Kota Semarang, Central Java Province	[29]
		Kota Pekanbaru, Riau Province	[11]
		Kota Semarang, Central Java Province	[32]
		Universitas Negeri Semarang Campus, Central Java Province	[30]
	Coptotermes gestroi (Wasmann, 1896)	Minahasa Raya Region, North Sulawesi Province	[10]
		West Lampung, Lampung Province	[12]
	Coptotermes sp.	Kota Padang, West Sumatra Province	[28]
	Prorhinotermes flavus (Bugnion & Popoff, 1910)	Minahasa Raya Region, North Sulawesi Province	[10]
	Schedorhinortermes sp.	Kota Padang, West Sumatra Province	[28]
	Schedorhinotermes medioobscurus (Holmgren, 1914)	West Lampung, Lampung Province	[12]
	Schedorhinotermes translucens (Haviland, 1898)	Minahasa Raya Region, North Sulawesi Province	[10]
Termitidae	*Bulbitermes constrictiformis* (Holmgren, 1914)	West Lampung, Lampung Province	[12]
	Hospitalitermes hospitalis (Haviland, 1898)	Kota Padang, West Sumatra Province	[28]
	Longipeditermes mandibulatus (Thapa, 1981)	Kota Padang, West Sumatra Province	[28]
	Macrotermes gilvus (Hagen, 1858)	Universitas Bengkulu Campus, Bengkulu Province	[31]
		Purwokerto, Central Java Province	[33]
		Kota Semarang, Central Java Province	[29]
		South Jakarta, Capital Region of Jakarta	[6]
		West Lampung, Lampung Province	[10]
		Kota Padang, West Sumatra Province	[28]
		Kota Semarang, Central Java Province	[32]
		Universitas Negeri Semarang Campus, Central Java Province	[30]
	Microtermes insperatus Kemner, 1934	Purwokerto, Central Java Province	[33]
		South Jakarta, Capital Region of Jakarta	[9]
		University of Bengkulu Campus, Bengkulu Province	[31]
		Kota Semarang, Central Java Province	[29]

Family	Species	Location	Reference
	Nasutitermes javanicus (Holmgren, 1913)	Minahasa Raya Region, North Sulawesi Province	[10]
	Nasutitermes matangensis (Haviland, 1898)	Kota Padang, West Sumatra Province	[28]
	Odontotermes javanicus Holmgren, 1912	Purwokerto, Central Java Province	[33]
		Kota Semarang, Central Java Province	[29]
		Universitas Negeri Semarang Campus, Central Java Province	[30]
	Odontotermes sp.	Kota Padang, West Sumatra Province	[28]

Table 3. The waste of plant species that readily available in Indonesia that can use to produce liquid smoke for termite population control.

Family	Plant Species	Vern name	Source	Termites Species	Reference
Apocynaceae	*Cerbera odollam* Gaertn.	Bintaro	Seed	*Coptotermes curvignathus* Holmgren, 1913	[34]
Arecaceae	*Cocos nucifera* L.	Coconut palm	Coconut Shells	*Cryptotermes* sp.	[35]
				Odontotermes sp.	[36]
	Elaeis guineensis Jacq.	Oil palm	Trunk	*Coptotermes curvignathus* Holmgren, 1913	[37]
			Trunk	*Coptotermes formosanus* Shiraki, 1909	[38]
			fruit bunches	*Coptotermes formosanus* Shiraki, 1909	[39]
			fruit bunches	*Coptotermes* sp.	[40]
	Nypa fruticans Wurmb	Nipah	Palm shells	*Coptotermes curvignathus* Holmgren, 1913	[41]
Dipterocarpaceae	*Shorea laevis* Ridl.	Bengkirai	Wood	*Coptotermes formosanus* Shiraki, 1909	[39]
Fabaceae	*Paraserianthes falcataria* (L.) I.C.Nielsen	Sengon	Wood	*Macrotermes gilvus* (Hagen, 1858)	[42]
Lamiace	*Vitex pubescens* Vahl	Laban	Wood Meals	*Reticulitermes speratus* (Kolbe, 1885)	[43]
				Coptotermes formosanus Shiraki, 1909	[43]
				Coptotermes curvignathus Holmgren, 1913	[44]
				Coptotermes curvignathus Holmgren, 1913	[44]
Lauraceae	*Camphora parthenoxylon* (Jacq.) Nees	Selasian wood	Stem Wood	*Coptotermes curvignathus* Holmgren, 1913	[45]
Meliaceae	*Toona sinensis* (Juss.) M.Roem.	Surian	Sawdust	*Coptotermes curvignathus* Holmgren, 1913	[46]
Poaceae	*Bambusa balcooa* Roxb.	Bamboo	Culms	*Coptotermes curvignathus* Holmgren, 1913	[47]
	Dendrocalamus latiflorus Munro	Bamboo	Culms	*Coptotermes curvignathus* Holmgren, 1913	[47]
	Gigantochloa robusta Kurz	Awi mayan	Culms	*Coptotermes curvignathus* Holmgren, 1913	[47]
	Gigantochloa atroviolacea Widjaja	Bamboo Wulung	Culms	*Reticulitermes speratus* (Kolbe, 1885)	[15]
				Coptotermes formosanus Shiraki, 1909	[15]

Hasan et al. [12] also reported that the *M. gilvus* species is the most commonly found in housing in West Lampung. Not only found in urban areas, but this termite species is also a significant pest in the cocoa cultivation industry [51] and castor plantation (*Jatropha curcas* L.) in Indonesia [52].

M. gilvus is also the most adaptable species to various conditions. Its colonies can grow well at high temperatures and relatively low humidity. Besides that, its colonies can also grow well at low temperatures, high humidity, and less sunlight, and this species also does not discriminate on wood quality [33]. *M. gilvus* builds its nests on the ground and does not utilize wood as a substrate for nesting. Wood is a food and nutrition source for its colony [9]. *M. gilvus* nests are easily identified by their mound-like shape, which is made of soil that sticks up from the ground. The outer part of the nest is hard because it is built from stiff clay [12]. *M. gilvus* prefers to nest in silty clay rather than in the loamy sand of soil. A strong correlation exists between termite infestation and soil criteria [9].

In addition to *M. gilvus*, *C curvignathus* is a species found in many urban locations in Indonesia. Specifically, it can be found in South Jakarta, Bengkulu, Kota Semarang, and Kota Pekanbaru. Edwards and Mill [53] reported that in Australia, termites from the genus Coptotermes are one of the genera with the largest number of pests, around 28 species. *C curvignathus* has a high ability to destroy wood and has been reported to attack many apartment buildings in South Jakarta [54]. In addition to being a pest in urban areas, *C curvignathus* is also a pest on plantations in Indonesia, such as cocoa plantations in Sumatra [51] and palm oil plantations [55]. Termites in urban areas that attack houses come from the high-level subterranean termites group [33]. The presence of subterranean termites is challenging to detect directly. Generally, subterranean termite colonies will create wandering tunnels or holes under the soil's surface so that they appear on the ground occasionally [56]. In this case, termites from the genus Microtermes usually act as pioneers in opening paths or making tunnels in damaging wooden objects, followed by termites from the genus Macrotermes [57]. Termites that damage wood do not have a preference for certain types of wood because they can damage any wood [33].

3.3. The Liquid Smokes from Plant Waste to Control the Household Pest Termites

Termite population management in residential areas can be implemented through pre and post-construction methods. The pre-construction method involves treating the foundation and wood materials before building the house to deter termites from infesting the wood. This method is practical and cost-effective as it prevents termite damage. On the other hand, the post-construction method involves controlling termite infestations in existing buildings by applying anti-termite materials to the building floor, spraying wood with anti-termite liquids, and using termite baiting techniques (Savitri, 2016). So far, the post-construction method has used termicides. Some active ingredients of termicides to control the termite population are Chlorpyrifos [58], Fipronil [59], Novaluron [60], Permethrin [61], and other termicides active ingredients.

One alternative method for controlling the termite population is to use liquid smoke. Liquid smoke, also known as wood vinegar and pyrolysis liquid, is produced from the condensation process of smoke from burning wood or other organic materials containing cellulose or lignocellulose under high-temperature conditions. The process of pyrolysis of sawdust or wood chips, followed by the removal of carcinogenic polyaromatic hydrocarbons, produces a liquid with a distinctive aroma [62-64]. Liquid smoke ranges from light yellow to yellowish-brown in color, and the darkness of the vinegar increases with the increase in temperature and smoky odor [43,45]. Liquid smoke is not only used as an insect repellent [65,66] but is also widely used as an antimicrobe against food-borne pathogens [64] and food preservative [63].

Liquid smoke is one of the alternative methods for controlling the termite population, which acts as a pest in settlements. The present study investigates the utilization of organic waste of various plant species for

the production of liquid smoke as an eco-friendly method for termite population control. The data reveals thirteen plant species from eight distinct families produce liquid smoke in Indonesia. The families of these plants are Apocynaceae, Arecaceae, Dipterocarpacea, Fabaceae, Lamiaceae, Lauraceae, Meliaceae, and Apoaceae. The family with the highest number of species is Apoaceae, which consists of four species, followed by Arecaceae with three species, and other families consisting of one species each (Table 3).

Liquid smoke from various species and methods will produce different organic compounds and characteristics. Liquid smoke generally contains acetic acid, phenol, and other volatile organic compounds [39,45]. The quality and characteristics of liquid smoke can differ, depending on the type of wood used and the method of pyrolysis applied [39,43]. Furthermore, the size of the material and the quantities of cellulose, hemicellulose, lignin, volatile extractives, fixed carbon, and ash in the samples also determine the chemical composition of wood vinegar [67,68].

The process of making liquid smoke uses the pyrolysis method at high temperatures. The best temperature for making liquid smoke is in the range of 300-500ºC. According to [69], Pyrolysis temperature affects the active compound content of the liquid smoke produced. Pyrolysis temperatures below 300ºC and above 500ºC produce low active content of liquid smoke because low temperatures cause pyrolysis to be incomplete, while secondary decomposition is likely to occur at high temperatures. Rosalina et al. [34] reported that liquid smoke from *Cerbera odollam* Gaertn fruit made with a pyrolysis temperature of between 300-500ºC will produce organic compounds from the phenol group, acetic acid, and other volatile organic compounds and can cause death of up to 100% termites. Liquid smoke from Coconut shells made at a temperature of 300-400ºC could also be utilized as a termiticide [36]. Liquid smoke made from oil palm trunk waste at a temperature of 400ºC [37] and empty oil palm bunch waste at 350-450ºC will produce Phenol and acetic acid [40]. The most exciting results were the content of the phenolic component of wood vinegar obtained from *Shorea laevis*, such as 4-methyl Phenol, 2-methoxy-4-methyl Phenol, and 2,6-dimethoxy Phenol, which were made at a temperature of 450°C [39]. Liquid smoke production at this temperature range can be used effectively as a termiticide [34,36,37,40].

Several other studies have also reported that liquid smoke can not only be effective as a termiticide made at a temperature range of 300-500ºC. However, those made below 300ºC can also be effective as termiticides. For example, wood from Suren (*Toona sinensis*) is very popular as a primary material for furniture and construction in West Sumatra because of its durability, beauty, and color. However, waste from this wood is not utilized to be used as a primary material for liquid smoke. This liquid smoke is made at a temperature of 250-300ºC, produces up to 57.34% acetic acid, and shows strong termicidal activity [46]. Liquid smoke from Sengon wood also contains more heptanoic acid (37.50%), which is made with a combustion temperature of 250ºC [42]. The dominant components in the vinegar vary depending on the type of biomass and pyrolysis temperature [39]. So, the active compounds in liquid smoke are influenced by temperature during the production process and the source of species of plants used. According to Komarayati and Wibowo [70], the pH scale of wood vinegar also affects the quality of liquid smoke. Additionally, the pH scale was influenced by the moisture content of the liquid smoke [71]. Many characteristics can be considered to produce good quality liquid smoke and act as good termicides.

The waste plants made into liquid smoke in this study are all distributed in Indonesia and tested on several species of termites. The termite species tested consisted of seven species, namely *Coptotermes curvignathus*, *Cryptotermes* sp., *Odontotermes* sp., *Coptotermes formosanus*, *Coptotermes* sp., *Macrotermes gilvus*, and *Reticulitermes speratus* (Table 3). However, the termite species distributed in Indonesia and also

found in urban areas are only six species (Table 2). One more termite species is not distributed in Indonesia but is used as a test insect using liquid smoke from plants distributed in Indonesia. The species is *C. formosanus*, which is only found in several countries such as China, Japan, Philippines, Pakistan, Sri Lanka, Kenya, South Africa, and America (www.isoptera.speciesfile.org). *C. formosanus* is a serious pest in residential and urban area [72,73].

All liquid smoke produced from waste wood of 13 species of plants is effective as an alternative termicide in controlling the population of termites found in urban areas in Indonesia. At low concentrations, liquid smoke can be a repellent. As reported by Oramahi & Yoshimura [48], at the lowest concentration of 10%, liquid smoke from *Vitex pubescens* had a significant repellent effect on termites *R. speratus* and *C. formosanus*. Likewise, the effectiveness of *Paraserianthes falcataria* can also act as an alternative termicide on *M. gilvus* [42]. *M. gilvus* is termite species that is often found in urban areas [9,12,28-33]. In addition, termites often found in Indonesia's urban areas, namely *C. curvignathus*, can also be controlled with liquid smoke from *Cerbera odollam* [34], *Elaeis guineensis* [37], *Nypa fruticans* [41], *Vitex pubescens* [44], *Camphora parthenoxylon* [45], *Toona sinensis* [46], *Bambusa balcooa*, *Dendrocalamus latiflorus*, and *Gigantochloa robusta* [47].

3.4. The Termicidal Activity of Liquid Smoke Against Pest Termite

The efficacy of liquid smoke in termite population control may not stem from individual components but rather from the synergistic effects of its various constituents. The combined action of these compounds likely leads to enhanced biological activity, including termiticidal effects. The chemical composition of liquid smoke depends on the plant waste source and the temperature used during its production. Generally, liquid smoke contains dominant chemical components, with the most prominent being phenol [43,47] and acetic acid [34,38,39,45,46]. Higher concentrations of organic acids correlate with increased termiticidal activity, suggesting that the total acid content plays a critical role in liquid smoke's effectiveness against termites [45].

The insecticidal properties of liquid smoke are attributed to the presence of acetic acid and phenolic compounds, which exhibit both toxic and repellent characteristics. Acetic acid is a significant component, originating from the acetyl groups in hemicellulose [74]. Phenol, another important compound, results from the thermal degradation of lignin [75]. Acetic acid has been found to possess termiticidal activity [36,76].

Currently, there are no reports detailing the mode of action or physiological mechanisms of liquid smoke against termites. We hypothesize that the acetic acid in liquid smoke may create an unfavorable acidic environment for termites, affecting their digestive processes and disrupting the gut microbiota that assist termites in digesting cellulose from wood. This disruption could ultimately impact termite survival rates.

3.5. The Possibilities of Liquid Smokes from Plant Waste to Control the Household Pest Termite in Traditional Houses in Indonesia

Indonesia has many traditional houses as cultural heritage and ethnic representations spread across every region and province. The public widely knows the representatives of traditional houses, as shown in Table 1, and there are still many variations of other traditional houses in Indonesia. For example, in South Sumatra Province, there are not only Limas houses but also there are other houses called Besemah houses [21]. Moreover, in South Sulawesi, there are not only Tongkonan houses from the Toraja ethnic but also Saoraja, Salassa, and Bola Sada houses from the Bone tribe [77].

Traditional houses in Indonesia have begun to be abandoned because they have weathered, so they are no longer suitable for habitation. The Rumah Gadang Houses in West Sumatra Province face significant

challenges due to damage, highlighting the need for government support and preservation policies [23]. Research has found that housing quality has decreased due to the long-term utilization of all aspects of the structure. Several factors, such as physical, mechanical, and biological variables, can lead to a decline in building quality. One approach to renewing a building is to replace elements that are broken or have been in use for an extended period [12]. If these traditional houses are abandoned and people move to modern houses, traditional houses as a cultural heritage will also disappear.

One of the causes of weathering in traditional houses in Indonesia is termite infestation because they eat cellulose and lignocellulose. Using continuously synthetic termicides or insecticides to control the termite population will cause resistance, so termites will be challenging to control their population in the future. For example, the termite Psammotermes hypostoma Desneux has been resistant to Pyrethrhoid [78]. Therefore, the use of liquid smoke is an alternative to control termites that infest traditional houses in Indonesia.

Several studies have found that wood waste from various plants in Indonesia can be used to make liquid smoke. This study shows that 13 plant species in Indonesia can produce liquid smoke, which can help preserve traditional houses and protect them from termites. Many other wood wastes from plants that have yet to be explored may also be used to make liquid smoke, which has much potential for further exploration. The waste from the 13 of plant species studied can be widely used to produce liquid smoke, possibly protecting traditional houses in Indonesia from termite infestation. The study also demonstrated that liquid smoke effectively controls the population of six termite species found in urban areas of Indonesia. These species are *C. curvignathus, Cryptotermes sp., Odontotermes sp., Coptotermes sp., M. gilvus,* and *R. speratus* (Table 3). Testing waste from other species of plants and other household pest termite's species is a new exploration opportunity for traditional house protection efforts in Indonesia.

Government support is also a factor in the success of traditional house preservation in Indonesia. According to Febriyano et al. [21] suggested that the government should help protect traditional houses by creating policies to preserve them, restore forests and land, grow the kinds of trees needed to build the houses, offer alternative species of wood, encourage tourism based on local culture, and help communities preserve their traditions. In addition, government support for using liquid smoke as part of the traditional house preservation effort is also significant because it is environmentally friendly and is made from waste that is not optimally utilized by the community.

4. CONCLUSION

Indonesia has a diverse culture reflected in traditional house architecture found throughout the country. These houses represent different ethnic groups. However, maintaining these houses is difficult due to structural damage caused by weather and climate. They are constructed using natural materials such as wood, which are prone to damage by termites. In Indonesia, termites are a significant concern, causing damage to buildings made of wood and other cellulose materials. This study found three families of termites in several residential and urban areas in Indonesia. The termite families known are Kalotermitidae, Rhinotermitidae, and Termitidae. The most common species of termites are *Macrotermes gilvus, Microtermes insperatus,* and *Coptotermes curvignathus*. Liquid smoke made from 13 plant species in Indonesai has been found effective in controlling the termite population. The families of these plants are Apocynaceae, Arecaceae, Dipterocarpacea, Fabaceae, Lamiaceae, Lauraceae, Meliaceae, and Apoaceae. This method could help protect traditional houses in Indonesia from termite infestation. Many other wood wastes from plants that have yet to be explored may also be used to make liquid smoke, which has much potential for further exploration.

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