Al-Hayat: Journal of Biology and Applied Biology
Volume 7, No 1 (2024): 57-70
DOI. 10.21580/ah.v7i1.20704

A Review of Termite Contributions to Sustainable Green Building

Dina Tiara Kusumawardhani[1]*, Aah Ahmad Almulqu[1]

[1]Forest Management Study Program, Forestry Department, Politeknik Pertanian Negeri Kupang, East Nusa Tenggara

Abstract

Despite their beneficial nature, termites often cause significant losses by damaging materials composed primarily of cellulose. Therefore, a more in-depth study of termites is essential for realizing sustainable green building. Although 3,106 termite species have been documented worldwide, little is known about those in Indonesia. Hence, the present review utilized the *Google Scholar* search platform to gather information on termite species. From the 34 sources reviewed, the species were identified in 16 provinces across 4 islands in Indonesia. Among these sites, the researchers found 106 termite species on Sumatra, Kalimantan, Sulawesi, and Java islands. The most prevalent species across all regions were *Macrotermes sp.*, *Microtermes sp.*, and *Coptotermes sp*.

Keywords: *Macrotermitinae*, subterranean termites, termite diversity, termite infestation

Introduction

Termites are found worldwide and play a crucial role as wood decomposers, nutrient recyclers, and global carbon cyclers. At least 3,016 species of living and fossilized termites have been recorded and identified (Krishna et al., 2013). As a significant group of eusocial insects, termites are among the most prevalent structural insect pests. They are eusocial arthropod decomposers that enhance soil fertility and crop yield and are utilized by humans for their benefits globally. As vital ecosystem components, termites constitute up to 10% of animal biomass (Ahmad et al., 2021).

Despite their beneficial aspects, termites frequently cause substantial losses by damaging cellulose materials, such as books, stored timbers, wooden structures, buildings, grain products, crops, standing trees, and forests (Ravan et al., 2015). Termites are estimated to inflict an economic loss exceeding 40 billion USD annually worldwide (Subekti et al., 2015). However, of 3,016 termite species, only 183 species cause significant damage to buildings and other wooden materials (Hassan & Morrell, 2021). While these studies have significantly advanced the understanding of termites, information about their distribution within individual regions remains scant.

This review was conducted to provide more detailed information on the species distribution across different regions of Indonesia. The results contribute to a broader knowledge base that can be disseminated widely and utilized in other related research. In this review, the researchers compiled information on the termite species in Indonesia published between 2014 and 2024, employing online platforms and databases.

Methodology

The information on species and the distribution of termites in Indonesia from 2014 to 2024 was searched using *Google Scholar*. The

[1*] *Corresponding Author: Dina Tiara Kusumawardhani, email: kusumawardhani.dt@gmail.com, Forest Management Study Program, Politeknik Pertanian Negeri Kupang. Prof. Dr. Herman Johanes St., Lasiana, Klp. Lima, Kupang, East Nusa Tenggara, Indonesia, 85011*

keywords included "*analisis rayap*", "*studi rayap*", and "*kajian rayap*". Two selection criteria were used to select relevant publications: (1) studies on termite species conducted in Indonesia and (2) years of publication from 2014 to 2024. Accordingly, all publications were obtained using *Google Scholar* (Fig. 1).

Results and Discussion

Diversity of termite species

In this research, only 34 studies met the selection criteria. All were peer-reviewed national publications (see Table 1). In Sumatra Island, 45 termite species were identified in Banda Aceh, North Sumatra, West Sumatra, Riau, Jambi, Lampung, and South Sumatra. In Java Island, 10 species were recorded in Jakarta, West Java, the Special Region of Yogyakarta, and Central Java. In Kalimantan Island, 19 species were found in West Kalimantan, Central Kalimantan, and South Kalimantan. A total of 24 species of termites were also identified in North Sulawesi, Central Sulawesi, and South Sulawesi (see Table 1).

Termites, often referred to as white ants, comprise six families. However, only the *Termitidae* family falls into the more highly evolved termites category, featuring four sub-families, including *Macrotermitinae* (Lee & Wood, 1971). These more derived termites have undergone significant evolutionary changes compared to their more primitive counterparts. The more socially complex species of termites exhibit advanced social structures, such as constructing mounds with an intricate network of tunnels at the core of the nest to enhance defenses and protect the termite queen.

The selection of nesting places is a factor that supports the rate at which termite populations increase. Termites from the *Macrotermitinae* subfamily prefer soil as a nesting place because it offers higher nutrient content and suitable temperature and humidity stability. The growth of termite colonies from the *Macrotermitinae* subfamily can be described as rapid and extensive. In the tropics, the termite *Macrotermes bellicosus* can lay up to 40,000 eggs daily (Bouillon, 1969). In the sub-tropics, the winter season disrupts egg-laying activities. In addition to rapid colony growth, termites of the *Macrotermitinae* subfamily also exhibit a long colony lifespan. Nests occupied by reproductive castes in some *Macrotermes* species can be inhabited and maintained for up to 80 years. Termite species of *Macrotermes* construct mound-shaped nests in the ground, which can be found isolated in open areas or near trees. The termite life cycle includes three periods of colony growth: an early (juvenile) period when only workers and soldiers are produced, followed by an adult period when alates are typically produced, and finally, an old (mature) period when the production of alates decreases and eventually ceases (Lee & Wood, 1971).

Figure 1
Chart of the selection process following the selection criteria

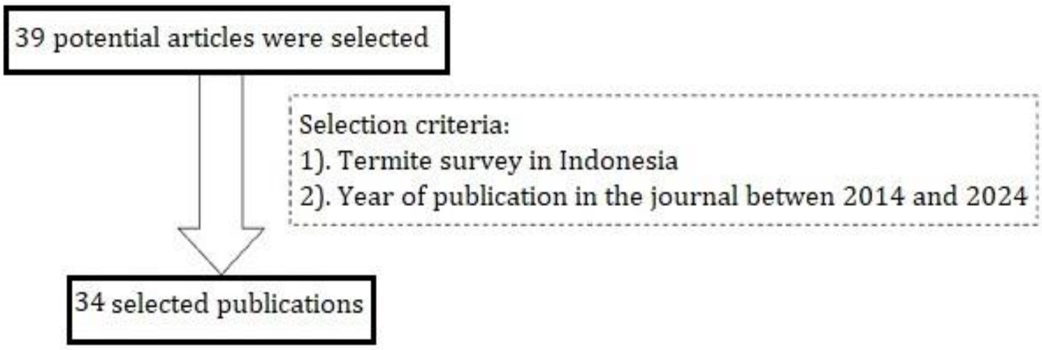

Table 1
Diversity of termite species and their sources

No	Location		Species	Sources
	Province	Region		
1	Banda Aceh	Leuser Mount National Park	• *Nasutitermes roboratus* • *Nasutitermes matangensis* • *Hospitalitermes bicolor* • *Nasutitermes neoparvus* • *Nasutitermes havilandi* • *Nasutitermes proatripennis* • *Hospitalitermes hospitalis* • *Bulbitermes neopusillus* • *Longipeditermes leucops* • *Aciculitermes sp* • *Longipeditermes longipes*	Ervany et al. (2019)
2	North Sumatra	Medan City	• *Coptotermes curvignathus*	Anugrah (2022)
3	West Sumatra	Dharmasraya Regency	• *Coptotermes curvignathus* • *Schedorhinotermes longirostris* • *Schedorhinotermes javanicus* • *Heterotermes indicola* • *Globitermes globosus* • *Dicuspiditermes nemorosus* • *Pericapritermes mohri* • *Macrotermes gilvus* • *Microtermes sp* • *Bulbitermes neopusillus* • *Hospitalitermes hospitalis* • *Nasutitermes havilandi* • *Nasutitermes longinasus*	Heriza (2023); Heriza et al. (2022)
4	Riau	Kampar Regency	• *Bulbitermes sp* • *Nasutitermes sp* • *Capritermes sp* • *Macrotermes sp* • *Schedorhinotermes sp* • *Coptotermes sp*	Ayu et al. (2023)
5	Jambi	Sarolangun Regency	• *Macrotermes gilvus* • *Coptotermes sp*	Bagaskara et al. (2017)
6	Jambi	Jambi City	• *Pericapritermes mohri* • *Termes rostratus* • *Microtermes sp* • *Odontotermes oblongatus* • *Hospitalitermes hospitalis* • *Longipeditermes longipes* • *Nasutitermes longinasus* • *Bulbitermes constrictoides* • *Prohamitermes sp*	Johari et al. (2022)
7	Lampung	Lampung City	• *Macrotermes gilvus*	Pratama et al. (2023)
8	South Sumatra	Palembang City	• *Coptotermes sp*	Nurmalina (2019)

No	Location		Species	Sources
	Province	Region		
9	South Sumatra	Ogan Ilir Regency	• *Macrotermes gilvus*	Arifin (2018)
10	Jakarta	South Jakarta	• *Microtermes insperatus* • *Macrotermes gilvus* • *Coptotermes curvignathus*	Arinana et al. (2016)
11	West Java	Bogor City	• *Macrotermes gilvus* • *Microtermes sp* • *Schedorhinotermes sp*	Arinana et al. (2023); Mubin et al. (2015)
12	West Java	Subang Regency	• *Coptotermes curvignathus*	Soesatrijo (2024)
13	Special Region of Yogyakarta	Kulon Progo Regency	• *Coptotemes curvignathus*	Lukmandaru et al. (2017)
14	Central Java	Semarang City	• *Macrotermes gilvus* • *Coptotermes curvignathus*	Savitri et al. (2016)
15	West Kalimantan	Pontianak City	• *Macrotermes sp*	Novitasari et al. (2014)
16	West Kalimantan	Mempawah Regency	• *Coptotermes curvignathus* • *Nasutitermes longinasoides*	Libertus & Diba (2020); Tampubolon et al. (2016)
17	West Kalimantan	Ketapang Regency	• *Macrotermes gilvus*	Simanjuntak et al. (2019)
18	West Kalimantan	Kubu Raya Regency	• *Coptotermes sp* • *Schedorhinotermes sp* • *Microtermes sp*	Habibi et al. (2017)
19	Central Kalimantan	Barito Timur Regency	• *Macrotermes gilvus*	Rafli et al. (2020)
20	South Kalimantan	Banjar Regency	• *Schedorhinotermes longirostris* • *Schedorhinotermes tarakensis* • *Macrotermes gilvus* • *Microtermes insperatus* • *Capritermes mohri* • *Procapritermes setiger* • *Termes propinquus* • *Hospitalitermes hospitalis* • *Nasutitermes longinasoides* • *Nasutitermes proatripennis* • *Parrhinotermes aequalis*	Trianto et al. (2020)
21	North Sulawesi	Manado City	• *Coptotermes sp*	Mandagi et al. (2023)
22	Central Sulawesi	Sigi Regency	• *Nasutitermes neoparvus* • *Nasutitermes havilandi* • *Nasutitermes matangensis* • *Bulbitermes constrictus* • *Bulbitermes contrictiformis* • *Odontotermes sp,* • *Coptotermes kalshoveni* • *Coptotermes sepangensis* • *Coptotermes javanicus*	Zulkaidhah et al. (2014)

No	Location		Species	Sources
	Province	Region		
			• *Microcerotermes serrula* • *Microcerotermes dubius* • *Schedorhinotermes javanicus* • *Schedorhinotermes medioobscurus* • *Hospitalitermes sp* • *Longipeditermes sp* • *Glyptotermes sp* • *Subulitermes sp*	
23	South Sulawesi	Bantaeng Regency	• *Coptotermes sp*	Arif & Nurdianty (2015)
24	South Sulawesi	Makassar Regency	• *Coptotermes curvignathus* • *Schedorhinotermes sp* • *Coptotermes gestroi* • *Microcerotermes serrula*	Arif, Putri, & Lestari et al. (2020); Zulkahfi et al. (2017)

Termites are primary physiological pests in trees, targeting the bark, phloem, cambium, or roots (Reinprecht, 2016). Termites from the *Macrotermitinae* subfamily bring food such as twigs, litter, and weathered wood back to the nest, where it is stored to be processed further (Arumugam et al., 2018). The large workers of this subfamily usually collect food from outside the nest, while the small ones work inside. In the small termite *Odontotermes magdalenae*, there is no visible activity in building nests or roaming burrows. Moreover, the division of workers between large and small is inconsistent, even within the *Macrotermitinae* subfamily. This division occurs in groups whose colonies forage in open land (Noirot, 1969). In addition to collecting food, termites from the *Macrotermitinae* subfamily also produce their food in the form of a fungus garden called a fungus comb, as is done by species from the genera *Microtermes*, *Macrotermes*, and *Odontotermes* (Anwar et al., 2020). Termites cultivate these fungus combs after they have ingested and digested plant or wood tissue, which is then excreted as primary excrement (mylospheres) consisting of partially digested plant tissue fragments and spores of the fungus *Termitomyces*. The micro mylospheres form *Termitomyces* on the fungus comb (Roberts et al., 2016). If a termite colony fails to establish a fungus comb, the colony will not be able to survive (Qian et al., 2011) because its food source becomes unavailable. The architecture of the fungus comb is similar to a mammal's brain, with hollow (alveolar) structures that connect the two parts of the fungus comb: the fresh part at the top and the old part at the bottom. The color of the fresh comb is dark orange, while the old one is slightly desaturated orange (Kusumawardhani et al., 2021).

Termites Infestation

Termites are part of the soil ecosystem and play a vital role as worldwide decomposers. They digest materials containing cellulose, such as litter, and every part of plants and trees. The effect of this decomposition can increase the organic carbon content, soil pH, and porosity, contributing to the cycling of dead organic matter. Of the approximately 2,500 species of termites globally, around 200, or nearly 10%, are found in Indonesia (Rismayadi & Arinana, 2007). Therefore, this country is one of the world's most crucial termite distribution areas (Nandika, 2015). Termites have even reached urban areas due to their ability to adapt to various environmental conditions. For example, in big cities such as Makassar, South Sulawesi Province, Indonesia, subterranean termites have been reported in urban housing, including species such as *Schedorhinotermes sp*., *Coptotermes gestroi*, and *Microcerotermes serrula* (Arif, Putri, & Muin, 2020). In the Jakarta area, Indonesia, Nandika et al. (2015) noted that the distribution of *Microtermes inspiratus* dominated West Jakarta and East Jakarta. Arinana et al. (2014) reported that in the Bumi Bekasi region, West Java Province, *Coptotermes curvignathus* was the dominant species causing damage to housing. Furthermore, Arinana et al. (2016) stated that *Macrotermes gilvus* dominated the distribution of subterranean termites in the South Jakarta area of Indonesia. These three termites are common in tropical forests and are reliable decomposers. When subterranean termites reach urban areas, their role as decomposers becomes problematic. They are considered pests because they attack buildings, most of which in Indonesia still use wood as the primary material, either as a main building material or complementary furniture. Generas of significant economic importance include *Coptotermes*, *Reticulitermes*, *Odontotermes*, *Nasutitermes*, *Macrotermes*, *Microcerotermes*, and *Cryptotermes*. Moreover, two species of subterranean termites belonging to the genus *Coptotermes*, namely *C. formosanus Shiraki* and *C. gestroi Wasmann*, are the most destructive and widely distributed (Acda, 2018).

Attacks have been reported in 45 districts, nearly 10% of Indonesia's total districts. The dominant attack by subterranean termites has a significant economic and sociocultural effect. In traditional buildings in Aceh, attacks by *C. gestroi* and *Nasutitermes matureensis* were reported (Novita et al., 2020). Like traditional constructions in various regions, these buildings are considered valuable because they are the centers of cultural tourism and regional pride. In Ambon City, the attacks were dominated by *Coptotermes* species, with a damage percentage of 61% (Cahyono, 2012). In 8-14 year-old houses in the Mijen housing area of Semarang City, termite attacks were prevalent, especially on the door frames, window sills, and roof, with *M. gilvus* causing up to 71% of the damage and *C. curvignathus* causing up to 29% (Savitri et al., 2016). More broadly, termite attacks on various continents were widely reported. In China, around 90% of buildings south of the Yangtze River were reported to be attacked by termites (Maxwell Robinson Phelps, 2010; Zhong & Liu, 2002). Similarly, a survey of approximately 2,000 heritage sites in Japan found that 42.6% were affected by *Coptotermes formosanus* (Takahashi & Yoshimura, 2002). In Taiwan, attacks by *C. formosanus* and *C. gestroi* damaged more than 87% of buildings (Li et al., 2011), and in Korea, subterranean termite attacks affected about 182 heritage sites (Kim & Chung, 2022). Numerous other reports of damage from subterranean termite attacks have also been published.

Termite control has been carried out in various ways. This starts from pre-construction treatments, such as soil treatment, to post-construction methods, such as chemical treatment, baiting, and combinations of both. However, post-construction measures are most common, serving as a preventive and control effort. In Indonesia, baiting is preferred over chemical treatment because it is more accessible and has fewer risks (Rahman et al., 2020). Conversely, in the United States, chemical treatments are more common (Rust & Su, 2012). Consequently, pest control has become one of the world's most advanced and significant industries. In 2017, the global market's income reached US$18 billion, with predictions that it would reach US$23 billion by 2023 (Rentokil, 2018). In Indonesia, the market in 2013, with over 600 pest control companies in various cities, was estimated to have received US$22.5 million with an annual growth of 7-9%. The Association of Indonesian Pest Control Companies includes 86 companies, or 20%, headquartered in Jakarta, one of the concentrated urban areas. It is generally assumed that developed areas with a high risk of termite infestation will encourage consumers to consider termite control. However, Rahman et al. (2020) revealed that not all consumers exhibited such characteristics, as differences in awareness of termite attacks and tolerance thresholds might be influenced by educational and economic factors as well as building specifications.

In addition to the previously mentioned methods, termite attack prevention can be achieved through system detection of termites. This method has undergone many developments, especially in detecting termite presence. It ranges from identifying termite excrement markers to using acoustical-based tools combined with temperature changes. This allows for the detection of termites and the prediction of the population size of the termite colony without damaging the nest or objects containing termites. This innovation is part of a developed pest control management process (Nanda et al., 2021).

Implications for Termite Management in Sustainable Green Building

The revolution in building construction is now leading towards environmental sustainability by promoting "Green Building." In this regard, the standards are issued by the USGBC Leadership in Energy and Environmental Design (LEED). LEED ratings determine whether a building should be considered green and how green it is. The architecture and materials used are the main factors determining a green building rating. Many architectural developments are currently using the concept of biomimicry, one of which is inspired by termite mounds. Specifically, termite mound biomimicry for structural sustainability is used in the structural topology of low-rise buildings, which usually consume significant energy, by manipulating the properties of the materials used, the shape of the building, and utilizing the surrounding environmental conditions (Claggett et al., 2016). Koigi (2015) states that new building models inspired by termite mound technology form modern models of energy-efficient buildings that naturally regulate temperature and air, with such buildings saving up to 40% in energy costs. The performative potential of the tunnel network in the termite mound acts effectively as a driver of airflow, which can be applied in building architecture to function as a microclimate regulator for building interiors (Andréen & Soar, 2023).

Pest control management is one of the indicators employed to determine the LEED rating, although it is not the main consideration. This is because pest control management is often the last thing considered by construction engineers, architects, and builders. Effective pest control creates healthier housing, increases property value and service life, reduces initial costs of construction materials or furniture, and is environmentally friendly by reducing the continuous use of insecticides and the cutting down of trees as the main construction material. Additionally, activities carried out inside buildings will be more effective. Pest control management, especially for termites, can be addressed by controlling buildings' pre- and post-construction stages.

Physical barriers are one of the controlling treatments pre-construction for subterranean termites to prevent tunneling and infestation in buildings that use wood as part of construction or for additional furniture. To prevent infestation in nontoxic ways through sustainable management, the barrier size must be small enough to prevent termites from passing through. The barrier is laid under foundation walls before the concrete is poured during construction (Acda, 2018). The materials that can be used include particles of sand, granite, crushed basalt, quartz and coral sand, and crushed cement-stabilized sludge (French & Ahmed, 1993; Myles, 1997; Su et al., 2016; Tamashiro et al., 1991; Yanase et al., 2000). Another material that can be used as a physical barrier is volcanic mudflow, made from ash, solid rock particles, and other volcanic debris washed down by rainwater. This material is frequently used in the Philippines. Laboratory and field trials indicated that an effective particle size of 1.18–2.36 mm would prevent tunneling and penetration of *C. gestroi*, *N. luzonicus*, and *Microcerotermes losbanosensis* (Acda & Ong, 2005). A small wooden house built in 1997 had a protective barrier consisting of prescreened volcanic mudflow particles installed beneath the floor and concrete foundation walls. Regular inspections over seven years revealed no signs of subterranean termite penetration inside or outside the structure (Acda, 2018).

In Indonesia, soil treatment is the primary physical barrier utilized to control subterranean termites in buildings and has been included in the Indonesian National Standards (*SNI*). Soil treatment consists of Pre-Construction Soil Treatment (SNI 2404:2015) and Post-Construction Soil Treatment (SNI 2405:2015). This process involves incorporating termiticide solutions into the soil beneath and around buildings to form a chemical barrier to prevent termite attacks. According to Rismayadi and Nandika, 2002), soil treatment effectively prevents subterranean termite attacks on buildings. However, when applying conventional soil treatment methods, termiticide solutions can only be reapplied by drilling into the building floor and injecting the termiticide into the drilled holes. This method, called post-construction soil treatment, has implications for damaging the floor of the building and results in less secure, uneven distribution of the termiticide solution under the floor. The efficacy of the various types of termiticides currently listed by The Pesticide Commission of the Republic of Indonesia only lasts 3-5 years on average. Consequently, if a termiticide applied by the pre-construction soil treatment method has expired, it cannot be reapplied with the same effectiveness. Therefore, soil treatment methods with a piping system (replenishment system) have been developed in the last five years. This system allows for the reapplication of termiticide without damaging the building floor.

A unique elastic pipe installed below the building foundation allows for soil treatment along the left and right sides of the foundation. It has small horizontal holes positioned regularly as channels for the termiticide solution. These pipelines also have 1-2 intake holes (diameter: 2.5 cm) to pump the termiticide solution, enabling it to flow into all parts of the pipe and wet the soil around the foundation. The termiticide solution is injected through this installed pipe to create a chemical barrier around the building foundation. With this system, the re-treatment of a building with a termiticide solution can be implemented without damaging the floor. A field study was conducted to determine the working time needed to implement the system and to measure the termiticide residue level in the treated soil around the building foundation. Two units of building foundation (4.64 x 3.53 m^2) were constructed at Bogor Agricultural University as the targeted building foundation for the study. The termiticide solution, containing 20% fenvalerate as the active ingredient, was injected into the pipes using a low-pressure sprayer (600 psi) to distribute the solution along the installed pipes and flow through the soil around the building foundation. The activities were carried out by two professional termite control operators (skill level = 100). The total working time needed to implement the replenishment system on the 16.38 m^2 building foundation was 26.97 minutes. The soil around the sample foundation, classified as sandy clay, had a fenvalerate termiticide residue level of 1.66 ppm (Jasman, 2017). Accordingly, the reliability of soil treatment with a piping system is quite good, considering the standard time needed is short, with relatively high residual levels of termiticide. Hence, soil treatment can be considered an alternative subterranean termite control technique for house buildings in Indonesia.

There is also a treatment method called baiting. It is carried out after construction (post-treatment) and can only last up to one year, so repeat treatments are frequent and expensive. This method works by inserting a toxic substance into wood, which acts as bait and has a slow-acting toxicant effect, allowing the toxic substance to spread throughout the colony. This is achieved by taking advantage of the habit of worker caste termites feeding and transferring gut microbial proteins to other termites (trophallaxis). The active compound often used is hexaflumuron. Around <175-525 mg of hexaflumuron can kill a subterranean termite colony of hundreds of thousands to millions of termites. Recently, chlorfluazuron has been developed as an active compound to selectively eliminate subterranean termite colonies (Umar & Majid, 2020).

References

Acda, M. N. (2018). Sustainable Termite Management Using Physical Barriers. In M. A. Khan & W. Ahmad (Eds.), *Termites and Sustainable Management: Volume 2 – Economic Losses and Management*. Springer.

Acda, M. N., & Ong, H. B. (2005). Use of Volcanic Debris as Physical Barrier Against the Philippine Milk Termite (Isoptera: Rhinotermitidae). *Sociobiology*, *46*(1), 117–130.

Ahmad, F., Fouad, H., Liang, S. Y., Hu, Y., & Mo, J. C. (2021). Termites and Chinese Agricultural System: applications and advances in integrated termite management and chemical control. *Insect Science*, *28*(1), 2–20. https://doi.org/10.1111/1744-7917.12726

Andréen, D., & Soar, R. (2023). Termite-inspired Metamaterials for Flow-active Building Envelopes. *Frontiers in Materials*, *10*, 1–11. https://doi.org/10.3389/fmats.2023.1126974

Anugrah, S. F. (2022). Uji Efektivitas Beberapa Pestisida Nabati Terhadap Hama Rayap (Coptotermes curvignathus H.). *Jurnal Ilmiah Mahasiswa Pertanian*, *2*(2), 1–10.

Anwar, K., Sudirman, L. I., & Nandika, D. (2020). Comb Establishment of Fungus-Growing Termites Species Macrotermitinae (Isoptera: Termitidae) with Termitomyces cylindricus (Basidiomycota: Agaricales) Basidiospores. *Oriental Insects*, *54*(4), 591–606. https://doi.org/10.1080/00305316.2020.1762775

Arif, A., & Nurdianty, I. (2015). Morfometrik dan Karakteristik Serangan Coptotermes sp. pada Gedung Pemerintahan di Kabupaten Bantaeng, Sulawesi Selatan. *Prosiding Seminar Nasional Mikrobiologi Kesehatan Dan Lingkungan*, *29*, 157–163.

Arif, A., Putri, G., Lestari, P. I., Nurqalbi, M., & Saira, A. (2020). Keragaman Rayap Rhinotermitinae (Isoptera, Insekta) di Hutan Pendidikan Universitas Hasanuddin. *Perennial*, *16*(2), 59–67. https://doi.org/10.24259/perennial.v16i2.11699

Arif, A., Putri, G., & Muin, M. (2020). Hazard Mapping of Subterranean Termite Attacks in Makassar City, South Sulawesi, Indonesia. *Insects*, *11*(31), 2–14. https://doi.org/10.3390/insects11010031

Arifin, Z. (2018). Keberadaan Rayap Tanah (Macrotermes gilvus) dan Pertumbuhan Tanaman Karet di Kebun Karet Rakyat yang Dikelola Secara Alami: Suatu Contoh Pengelolaan Kebun Berwawasan Lingkungan. *Jurnal Pembelajaran Biologi*, *5*(2), 12–22.

Arinana, Aldina, R., Nandika, D., Rauf, A., Harahap, I. S., Sumertajaya, I. M., & Bahtiar, E. T. (2016). Termite Diversity in Urban Landscape, South Jakarta, Indonesia. *Insects*, *7*(2), 1–18. https://doi.org/10.3390/insects7020020

Arinana, Haneda, N. F., Nandika, D., & Prawitasari, W. A. (2014, November 12). Damage Intensity of House Building and Termite Diversity in Perumahan Nasional Bumi Bekasi Baru, Rawalumbu Bekasi. *The Utilization of Biomass from Forest and Plantation For Environment Conservation Efforts. Proceedings of the 6th International Symposium of Indonesian Wood Research Society*.

Arinana, Yuwono, M. A., & Priyanto. (2023). Kelas Bahaya Serangan Rayap Tanah di Kota Bogor, Jawa Barat. *Jurnal Ilmu Lingkungan*, *21*(4), 1009–1020. https://doi.org/10.14710/jil.21.4.1009-1020

Arumugam, N., Kori, N. S. M., & Rahman, H. (2018). Termites Identification. In Md. A. Khan & W. Ahmad (Eds.), *Sustainability in Plant and Crop Protection Termites and Sustainable Management Volume 1-Biology, Social Behaviour and Economic Importance27* (pp. 27–46). Springer. http://www.springer.com/series/13031

Ayu, F., Bachry, S., Sari, V., & Saputra, A. (2023). Identifikasi Species Rayap di Perkebunan Karet Desa Naga Beralih Kec. Kampar Utama, Kampar. *Metrik Serial Teknologi Dan Sains*, *4*(1), 1–8. https://publikasi.kocenin.com/index.php/teksi

Bagaskara, D., Gunawan, S., & Santi, I. S. (2017). Kajian Sebaran Rayap Tanah (Macrotermes gilvus Hagen) dengan Pengaplikasian GIS (Geographic Information System) di Perkebunan Kelapa Sawit. *Jurnal Agromast*, *2*(2), 1–8.

Bouillon, A. (1969). Termites of the Ethiopian Region. In K. Krishna & F. M. Weesner (Eds.), *Biology of Termites*. Academic Press.

Cahyono, T. D. (2012). Identifikasi Tingkat Serangan dan Jenis Rayap yang Merusak Bangunan di Kota Ambon. *Bimafika*, *3*, 393–398.

Claggett, N., Surovek, A., Streeter, B., Nam, S., Bardunias, P., & Cetin, B. (2016). Biomimicry and Locally Responsive Construction: Lessons from Termite Mounds for Structural Sustainability. In A. Zingoni (Ed.), *Insights and Innovations in Structural Engineering, Mechanics and Computation* (pp. 827–832). Taylor & Francis.

Ervany, H., Syaukani, & Husni. (2019). Biologi Sarang Rayap Subfamili Nasutitermitinae di Stasiun Penelitian Suaq Balimbing Taman Nasional Gunung Leuser. *Jurnal Biotik*, *7*(1), 28–40.

French, J. R. J., & Ahmed, B. (1993, May 16). Termite Physical Barrier: Is Retrofitting With Granitgard and Option? *International Research Group on Wood Preservation*.

Habibi, Diba, F., & Siahaan, S. (2017). Keanekaragaman Jenis Rayap di Kebun Kelapa Sawit PT Bumi Pratama Khatulistiwa Kecamatan Sungai Ambawang Kabupaten Kubu Raya. *Jurnal Hutan Lestari*, *5*(2), 481–489.

Hassan, B., & Morrell, J. J. (2021). Termite Testing Methods: A Global Review. *Journal of Testing and Evaluation*, *49*(6), 1–30. https://doi.org/10.1520/JTE20200455

Heriza, S. (2023). Keanekaragaman Spesies Rayap di Perkebunan Kelapa Sawit di Kabupaten Dharmasraya Provinsi Sumatera Barat. *Jurnal Riset Perkebunan*, *4*(1), 45–52.

Heriza, S., Buchori, D., Harahap, I. S., & Maryana, N. (2022). Komposisi Rayap Dapat Menentukan Tingkat Ketergangguan Habitat: Studi Kasus di Kabupaten Dharmasraya Provinsi Sumatera Barat. *Jurnal Ilmu Lingkungan*, *20*(3), 678–684. https://doi.org/10.14710/jil.xx.x.xxx-xx

Jasman, G. P. (2017). *Keterandalan Perlakuan Tanah dengan Sistem Pemipaan (Replenishment) untuk Pengendalian Rayap pada Bangunan Gedung*. Institut Pertanian Bogor.

Johari, A., Adawia, A. R., & Wulandari, T. (2022). Tipe Sarang dan Sebaran Jenis Rayap (Isoptera) di Hutan Kota dan Perkebunan Sawit Wilayah Jambi. *Al-Kauniyah: Jurnal Biologi*, *15*(2), 191–198. https://doi.org/10.15408/kauniyah.v15i2.16689

Kim, S. H., & Chung, Y. J. (2022). Analysis of Factors Affecting Termite Damage to Wooden Architectural Heritage Buildings in Korea. *Forests*, *13*(3). https://doi.org/10.3390/f13030465

Koigi, B. (2015). *Termite Technology Inspires Green Architecture*. Fair Planet. https://www.fairplanet.org/story/termite-technology-inspires-green-architecture

Krishna, K., Grimaldi, D. A., Krishna, V., & Engel, M. S. (2013). Treatise on the Isoptera of the World. *Bulletin of the American Museum of*

Natural History, *377*(7), 973–1495. https://doi.org/10.1206/377.4

Kusumawardhani, D. T., Nandika, D., Karlinasari, L., Arinana, & Batubara, I. (2021). Architectural and Physical Properties of Fungus Comb from Subterranean Termite Macrotermes gilvus (Isoptera: Termitidae) Mound. *Biodiversitas*, *22*(4), 1627–1634. https://doi.org/10.13057/biodiv/d220406

Lee, K. E., & Wood, T. G. (1971). *Termite and Soil*. Academic Press.

Li, H.-F., Su, N.-Y., Wu, W.-J., & Hsu, E.-L. (2011). Termite Pests and Their Control in Taiwan. *Sociobiology*, *57*(3), 575–586. https://www.researchgate.net/publication/270573438

Libertus, F. G., & Diba, F. (2020). Studi Serangan Rayap pada Tanaman Akasia (Acacia crassicarpa) di Lahan HTI PT Muara Sungai Landak Kabupaten Mempawah. *Jurnal Hutan Lestari*, *8*(1), 211–216.

Lukmandaru, G., Hasanah, M., & Retnaningrum, N. I. (2017). Ketahanan terhadap Rayap, Sifat Kimia, dan Warna Kayu Jati dari Hutan Rakyat di Kulon Progo. *J. Ilmu Teknol. Kayu Tropis*, *15*(2), 118–132.

Mandagi, P. T., Pinaria, A. G., Watung, J. F., Paat, F. J., Kaligis, J. B., & Pakasi, S. E. (2023). Pengendalian Hama Rayap Subteran Coptotermes sp (Blattodea: Rhinothermitidae) Menggunakan Asap Cair Berbahan Tempurung Kelapa. *Jurnal Agroekoteknologi Terapan*, *4*(2), 370–380. https://ejournal.unsrat.ac.id/index.php/samrat-agrotek

Maxwell Robinson Phelps. (2010). *Maxwell Robinson Phelps Termite Report*.

Mubin, N., Hararap, I. S., & Raffiudin, R. (2015). Kekerabatan rayap tanah Macrotermes gilvus Hagen (Blattodea: Termitidae) dari dua habitat di Bogor. *Jurnal Entomologi Indonesia*, *12*(3), 115–122. https://doi.org/10.5994/jei.12.3.115

Myles, T. G. (1997). Comparison of Penetrability of Smooth and Crushed Sand by Subterranean Termites (Isoptera, Rhinotermitidae). *Sociobiology*, *30*(3), 295–303.

Nanda, M. A., Seminar, K. B., Maddu, A., & Nandika, D. (2021). Identifying Relevant Features of Termite Signals Applied in Termite Detection System. *Ecological Informatics*, *64*. https://doi.org/10.1016/j.ecoinf.2021.101391

Nandika, D. (2015, April 17). Satu Abad Perang Melawan Rayap. *Proceedings of the Workshop Mitigasi Bahaya Serangan Rayap Pada Bangunan Gedung*.

Nandika, D., Yudi, R., & Farah, D. (2015). *Rayap: Biologi dan Pengendaliannya* (2nd ed.). Muhammadiyah University Press.

Noirot, C. H. (1969). Formation of Castes in The Higher Termites. In K. Krishna & F. M. Weesner (Eds.), *Biology of Termites*. Academic Press.

Novita, N., Amiruddin, H., Ibrahim, H., Jamil, T. M., Syaukani, S., Oguri, E., & Eguchi, K. (2020). Investigation of Termite Attack on Cultural Heritage Buildings: A Case Study in Aceh Province, Indonesia. *Insects*, *11*(6), 1–12. https://doi.org/10.3390/insects11060385

Novitasari, Jayuska, A., & Wibowo, M. A. (2014). Bioaktivitas Anti Rayap Minyak Atsiri dari Daun Jeruk Sambal (Citrus microcarpa Bunge) Terhadap Rayap Tanah Macrotermes sp. *JKK*, *3*(1), 57–62.

Nurmalina. (2019). Suntik Rayap Upaya Pelestarian Bahan Pustaka di Perpustakaan UIN Raden Fatah Palembang. *Maktabatuna: Jurnal Kajian Kepustakawanan*, *1*(2), 101–110.

Pratama, A. O. S., Kuswanto, E., & Suryanto, E. (2023). Studi Arsitektur Sarang Rayap Macrotermes gilvus Hagen (Isoptera: Termitidae) di Bumi Agung, Way Kanan, Lampung. *Jurnal Biologi Indonesia*, *19*(2), 119–124.

https://doi.org/10.47349/jbi/19022023/119

Qian, Q., Li, S.-F., & Wen, H.-A. (2011). Fungal Diversity of Fungus Comb in Termite Nests. *Mycosystema*, *30*(4), 556–565. http://journals.im.ac.cn/jwxtcn

Rafli, M. A., Madusari, S., & Soesatrijo, J. (2020). Komparasi Efektivitas Metode Pengendalian Rayap Macrotermes gilvus di Perkebunan Kelapa Sawit. *Jurnal Agrosains Dan Teknologi*, *5*(2), 77–86. jurnal.umj.ac.id/index.php/ftan/index

Rahman, M. M., Nandika, D., & Simangunsong, B. C. H. (2020). Demand Analysis of Termite Control Service in Jakarta. *Jurnal Sylva Lestari*, *8*(1), 10–19.

Ravan, S., Khan, I. A., Manzoor, F., & Khan, Z.-U.-D. (2015). Feeding Habitats and Wood Preferences of Termites in Iran. *Journal of Entomology and Zoology Studies*, *3*(5), 20–23.

Reinprecht, L. (2016). *Wood Deterioration, Protection, and Maintenance*. Willey Blackwell.

Rentokil. (2018). *The Rentokil Pest Control Report 2018: Insight from Pest Control Markets Across the Globe*.

Rismayadi, Y., & Arinana. (2007). *Usir Rayap dengan Cara Baru dan Ramah Lingkungan*. Gramedia.

Rismayadi, Y., & Nandika, D. (2002). Perkembangan Mutakhir Teknologi Pengendalian Hama Permukiman dan Bangunan. *Pengendalian Secara Terpadu: Pengendalian Rayap Masa Depan*.

Roberts, E. M., Todd, C. N., Aanen, D. K., Nobre, T., Hilbert-Wolf, H. L., O'Connor, P. M., Tapanila, L., Mtelela, C., & Stevens, N. J. (2016). Oligocene Termite Nests with In Situ Fungus Gardens from The Rukwa Rift Basin, Tanzania. *PLoS ONE*, *11*(6), 1–17. https://doi.org/10.1371/journal.pone.0156847

Rust, M. K., & Su, N. Y. (2012). Managing Social Insects of Urban Importance. *Annual Review of Entomology*, *57*, 355–375. https://doi.org/10.1146/annurev-ento-120710-100634

Savitri, A., Martini, I., & Yuliawati, S. (2016). Keanekaragaman Jenis Rayap Tanah dan Dampak Serangan Pada Bangunan Rumah di Perumahan Kawasan Mijen Kota Semarang. *Jurnal Kesehatan Masyarakat*, *4*(1), 100–105. http://ejournal-s1.undip.ac.id/index.php/jkm

Simanjuntak, O. E., Suryantini, R., & Nurhaida. (2019). Intensitas Serangan Rayap pada Eucalyptus pellita di Areal Hutan Tanaman Industri PT. Wana Hijau Pesaguan Kabupaten Ketapang. *Jurnal Hutan Lestari*, *7*(1), 492–498.

Soesatrijo, J. (2024). Uji Permethrin Terhadap Hama Rayap (Coptotermes curvignathus Holmgren) pada Tanaman Kelapa Sawit. *Syntax Literate*, *9*(2), 898–906. https://doi.org/10.36418/syntax-literate.v9i2

Su, N.-Y., Scheffrahn, R. H., & Ban, P. M. (2016). Uniform Size Particle Barrier: A Physical Exclusion Device Against Subterranean Termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology*, *84*(3), 912–916. http://jee.oxfordjournals.org/

Subekti, N., Yoshimura, T., Rokhman, F., & Mastur, Z. (2015). Potential for Subterranean Termite Attack Against Five Bamboo Species in Correlation with Chemical Components. *Procedia Environmental Sciences*, *28*, 783–788. https://doi.org/10.1016/j.proenv.2015.07.092

Takahashi, M., & Yoshimura, T. (2002). Recent Development in Controlling Japanese Subterranean Termites. *Sociobiology*, *40*, 13–24.

Tamashiro, M., Yates, J. R., Yamamoto, R. T., & Ebesu, R. H. (1991). Tunneling Behavior of the Formosan Subterranean Termite and Basalt Barriers. *Sociobiology*, *19*, 163–170.

Tampubolon, E. M., Diba, F., & Nurhaida. (2016). Studi Laju Konsumsi Umpan Rayap Copton

0.5 RB dalam Pengendalian Rayap Coptotermes curvignathus Holmgren pada Perkebunan Kelapa Sawit Elaeis guineensis Jacq. *Jurnal Hutan Lestari*, *4*(3), 335–343.

Trianto, M., Marisa, F., Nuraini, & Sukmawati. (2020). Keanekaragaman Jenis Rayap pada Perkebunan Kepala Sawit dan Perkebunan Karet di Kabupaten Banjar Kalimantan Selatan. *Bioma: Jurnal Biologi Makassar*, *5*(2), 199–209. http://journal.unhas.ac.id/index.php/bioma

Umar, W. A. S. W., & Majid, A. H. A. (2020). Sustainable Termite Management Using Innovative and Selective Termite Baiting Method. *IOP Conference Series: Earth and Environmental Science*, *549*(1), 1–8. https://doi.org/10.1088/1755-1315/549/1/012043

Yanase, Y., Shibata, M., Yoshihisa, S., Okumura, K., Iwatomo, T., Nogiwa, T., & Yoshimura, I. Y. (2000, May 14). Feasibility of Termite Control Using Crushed Cement Stabilized Sludge (polynite) As A Physical Barrier and Acoustic Emission (AE) Monitoring. *International Research Group on Wood Preservation*. https://www.irg-wp.com/irgdocs/details.php?1f580682-88d3-4aa2-b0b8-94ae7fbd27e5

Zhong, J. H., & Liu, L. L. (2002). Termite Fauna in China and Their Economic Importance. *Sociobiology*, *40*, 25–32.

Zulkahfi, Suparmin, S., Suparmin, S., & Arif, A. (2017). Pengendalian Serangan Rayap Tanah Coptotermes sp. Menggunakan Ekstrak Daun Belimbing Wuluh (Averrhoa bilimbi L). *Hasanuddin Student Journal*, *1*(1), 1–8. http://journal.unhas.ac.id/index.php/jtHSJ

Zulkaidhah, Musyafa, Soemardi, & Hardiwinoto, S. (2014). Kajian Komunitas Rayap Akibat Alih Guna Hutan Menjadi Agroforestri di Taman Nasional Lore Lindu, Sulawesi Tengah. *J. Manusia Dan Lingkungan*, *21*(2), 213–219.