



Termites and their management: A review

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Abstract

Termites (Isoptera) are ecologically important detritophagous insects that help with nutrient recycling, soil formation, and ecosystem function; yet, over 300 species are identified as devastating pests of agriculture, forestry, and urban infrastructure around the world. Their secretive lifestyle, eusocial colony structure, and efficient chemical communication mechanisms facilitate rapid colony expansion while making management extremely difficult. Termites are estimated to cost \$50 billion in structural and agricultural losses worldwide each year. Despite their economic importance, research on termite biology, ecology, and control in urban areas is scarce.

This review summarizes current understanding of termite taxonomy, biology, ecological roles, and pest status, followed by an assessment of primary management options such as physical and mechanical controls, cultural practices, biological agents, botanicals, and chemical termiticides. The strengths, limits, and environmental implications of each technique are highlighted, as is the emerging importance of Integrated Termite Management. Although biological and plant-based techniques show promise as environmentally benign alternatives, their field performance is uneven.

Overall, this study identifies significant research needs in urban termite ecology, species-specific behaviour, and sustainable control approaches. Strengthening region-specific studies and incorporating biological, botanical, and technological monitoring technologies into an ITM framework are critical for generating successful, ecologically safe, and commercially feasible termite management plans.

Keywords: Termites, Pest management, Biological control, Botanical extracts, Integrated Termite Management, Urban ecology

Introduction

Termites (order Isoptera) are eusocial, detritophagous insects that exist in both natural and human-dominated habitats. In terms of ecology, they are important lignocellulosic material decomposers and play a crucial role in soil fertility, water infiltration, nutrient recycling, and global carbon cycle (Siddiqui *et al.*, 2023; Aidoo *et al.*, 2023 [2, 47]; Figueirêdo *et al.*, 2015). There are more than 3,016 known living and extinct species worldwide, many of which are vital parts of terrestrial ecosystem. Despite these advantages, termites damage timber structures, buildings, plantations, and agricultural products, causing significant economic and social losses. Because of their mysterious feeding habits, termites are known as "silent destroyers" (Figueirêdo *et al.*, 2015). On an annual basis, the world's economy suffers expenditures that exceed \$50 billion, and the United States alone spending close to \$5 billion on prevention and repairs (Hassan *et al.*, 2024) [11]. There are 337 species from India (35 agricultural and structural pests) and 50 species from the USA (20 structure pests) (Murthy *et al.*, 2020) [35]. Nearly 80% of damage worldwide has been caused by subterranean termites. Anthropogenic disruptions and microenvironmental changes brought on by rapid urbanization in areas like Central Punjab, Pakistan, have made infestations even more severe (Sichilima *et al.*, 2018 [46]; Chellappan *et al.*, 2021; Hassan *et al.*, 2024) [4, 11]. Termite eusociality includes a caste-based division of labor between workers, soldiers, and reproductives, as well as cooperative brood care and overlapping generations (Hellemans *et al.*, 2025) [12]. Chemical communication governs colony coordination

Through trail, alarm, recognition, and mating pheromones, as well as primer pheromones in charge of caste differentiation and reproductive regulation. (Bagnères & Hanus, 2015; Mitaka & Akino, 2024; Kamiyama *et al.*, 2025 [20, 33]; Mitaka *et al.*, 2017; Dolejšová *et al.*, 2022) [8, 34]. Termites are classified into four biological groups: subterranean, drywood, dampwood, and Formosan termites, with subterranean species being the most destructive worldwide (Rust & Su, 2012). Increasing urbanization encourages termite colonization by modifying soil structure and providing ample cellulose-rich materials. Moisture leaks, heating systems, and structural flaws further facilitate this process (Sichilima *et al.*, 2018; Chellappan *et al.*, 2021) [4, 46]. However, scientific information on termite ecology, biology, and behaviour in Pakistan's urban ecosystems is insufficient, particularly in Central Punjab, hampering the development of region-specific management measures (Santos *et al.*, 2020) [45]. This review brings together current research on termite taxonomy, ecology, biology, and destructive behaviour, with a focus on commercially relevant species. It assesses existing management options, including pesticides, baiting systems, physical barriers, biocontrol agents, and botanical termiticides, and identifies limits in environmental and public health contexts. The review also delves into emerging sustainable techniques such as plant-based oils, entomopathogenic fungi, and environmentally friendly biopesticides. This paper establishes an example for future research and sustainable termite control by filling important knowledge gaps, particularly in rapidly urbanizing locations.



Fig 1: Termites mound



Fig 2: Termites attack on wood

1. Urban Termites: ecological importance and research imperatives

The wide range of human-altered environments poses distinct challenges to managing an urban termite infestation (Darlington *et al.*, 2021). In cities, however, termites target homes and other human-built structures rather than trees or other plants, as they do in rural settings. This has serious cost ramifications since termite damage is generally not discovered until it causes significant structural degradation. We all know how bad termites are in cities; the same is true in Pakistan, where the majority of the population lives in cities, and this amount adds to the problem. Every year, homeowners and businesses spend millions of rupees on termite-related repair costs. Understanding termite biology in urban contexts is critical for effective implementation and control tactics. For example, different termite species may

exhibit diverse behaviors and preferences when residing in urban surroundings (Pervez *et al.*, 2018) [42]. Certain species, for example, prefer to nest in subterranean crevices near building foundations, but others may establish nests inside wooden buildings. Of course, these behavioral differences necessitate proper termite identification because various species prioritize their own unique ecological requirements.

2. Global trends in termite activity across urban landscapes

Termites are pests in urban areas all over the world, particularly in tropical and subtropical locations where the climate is favourable all year. Every year, termite infestations cause billions of dollars of damage and are reported all over the world, particularly in big cities (Kalleswaraswamy *et al.*, 2022) [19]. The widespread effect and techniques of tracking quantifying urban termite control have been well-documented in various countries, including as Southeast Asia, Africa, and the southern United States, where diverse pest management programs are used to manage the threat. In these places, termite control consists of a combination of chemical treatments, baiting systems, and preventive measures. Studies have revealed that standard chemical treatments are not as suitable for termite management, however Integrated Pest Management (IPM) approaches are the right way to manage them by employing numerous controlling strategies (Karlsson Green *et al.*, 2020) [21]. Nonetheless, these methods necessitate a greater understanding of the species under consideration and its behavior in connection to the environment in which their activity is monitored.

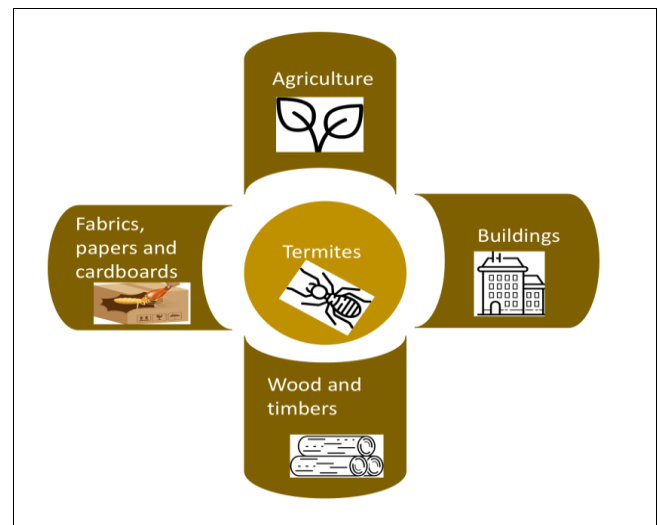


Fig 3: Major Sectors Affected by Termites Infestation

Integrated Termite Management Termites undoubtedly benefit humans and have a significant impact on the ecology, but we also acknowledge their destructive character. In the global agricultural system, they are now a serious issue. As an outcome, we must identify some potential strategies for managing it effectively. ITM is a sustainable program that aims to prevent or minimize termite activity in economically significant areas rather than eradicate the termite population. ITM can be stated as the combination of the available effective control strategies that are economically, socially and environmentally safe to humankind. However, the choice to manage termites should be made after gaining sufficient understanding of termite

biology and ecology, infestation level, soil properties, cropping systems, control costs, chemical and non-chemical termite management techniques, and the availability of appropriate termiticides, barriers, baits, and qualified experts. The termite management concept is represented by the pyramid shown in Fig 1. The tactics used in sustainable termite control can be broadly divided into three categories: chemical, non-chemical, and monitoring. Information about the threshold and resistance is necessary for the effective use of termiticides, and sampling and monitoring are necessary for control measures. Physical and mechanical control (dequeening, heating, freezing, electrical, microwaves, toxic and non-toxic barriers), cultural control (cultivation techniques, mulching, crop rotation, and intercropping), intrinsic heritable plant resistance, biological control (predators, parasitoids, entomopathogens, and botanicals), some contemporary techniques (like termatrac and attractive baits), and emerging biotechnology tools (like RNA interference). Active ITM techniques for termite management include a combination of various tactics, such as monitoring and baiting, chemical and physical barriers, baits, biological agents, or dust toxicants. Nonetheless, an ITM program's execution and success are still crucial. As a result, we compiled and aggregated pertinent data that sheds light on termite management strategies (Li *et al.*, 2011) [24]

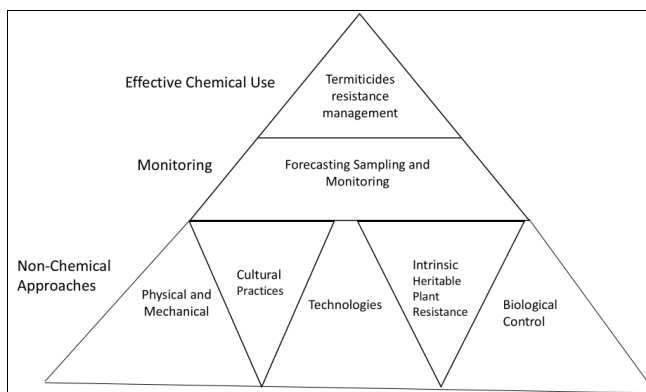


Fig 4: Pyramid

1. Physical and Mechanical Control Strategies

In order to maintain a specific population level, termites are commonly managed via mechanical and physical methods. Dequeening, or removing the monarch from the colony, is one of those actions that has the potential to harm the entire colony (Atsbha & Hintsa, 2018) [3]. Additionally, tillage and manual termite mound breaking offer a short-term control. However, because the mound is built deep underground and is difficult to reach the target, it is tough to eradicate this pest using this method. This method requires more work because the mound is large and composed of hard material. Additionally, it could be possible to revive the colony by replacing its queen. Termite survival is negatively impacted by extremely hot and low temperatures. At high temperatures, termites are effectively controlled. In India, it is common practice to suffocate the colony by burning crop residues at the mounds. However, because termites have a complex and highly sophisticated mound structure, it is very difficult to penetrate the smoke and heat deeply enough to kill reproductive alates. Additionally, soil becomes hydrophobic due to intense heating (Verma *et al.*, 2018) The barriers used to keep termites out of structures are either mechanical or physical. These obstacles could be non-toxic

or hazardous. One example of a poison barrier is the application of chemicals or insecticides (termiticides) in the soil to control termite populations. According to (Manzoor *et al.*, 2014) [31], pesticide is highly effective when applied to the soil. Termite damage in agricultural crops and commercial structures is prevented by non-toxic physical/mechanical barriers made of non-chemical materials such aggregates, metal mesh, sheeting, or sand or gravel. To prevent termite damage, fruit tree nurseries are covered with a layer of sand rather than dirt. Under both laboratory and field settings, Li and colleagues investigated the impact of gravel sands as a physical barrier against two termite species: *Reticulitermes flaviceps* and *Coptotermes formosanus* (Li *et al.*, 2011) [24]. According to their findings, gravel sands with the right thickness and particle sizes could be employed as a barrier material to lessen termite invasion (Li *et al.*, 2011) [24]. All aggregate ratios of particle sizes prevented termites from tunneling, according to research on the efficacy of aggregate particles as a physical barrier against subterranean termites. By creating a deep canal around the seedlings that prevents termites from building galleries, tree nurseries can be protected from termites (Keefer *et al.*, 2013) [22].

Colony expansion can be stopped with magnets. To stop termites from proliferating, for instance, powerful bar magnets are buried in the ground close to the termite mounds employed electromagnetic waves to manage *Coptotermes curvignathus* and *C. formosanus*, two subterranean termites. According to (Maayiem *et al.*, 2012) [29], burying animal remains, planting elephant grass, and applying a mixture of salt and shea butter residues all decreased termite outbreaks. Another alternative in a termite management strategy is the application of wood ash near and around crops and termite mounds. Additionally, it supplies the treated area with calcium and potassium. The effect of wood ash on termite infestation was examined by Atsbha and Hintsa (2018) [3]. They got good results when they applied wood ash to the hot pepper seedling beds. However, it requires more work to apply, we can only utilize this technique in small areas. The literature lacks a precise dosage rate and application technique. Additionally, it makes soil hydrophobic, which leads to runoff and may be detrimental to soil-beneficial bacteria.

2. Cultural Approaches to Termite Control

Clean cultivation, high-density sowing, soil management, balanced fertilizer use, appropriate irrigation, weeding, mulching, timely harvesting, crop rotation, intercropping, and more are examples of cultural management techniques. To keep crops safe from termite attack, the crop field, surrounding area, and high-termite attack region must be cleaned by clearing out all plant debris. Termite reservoirs and mounds are destroyed, termite foraging activity is decreased, and plant health is enhanced by pre-planting tillage, cleaning, and cultivation of field borders (Mahapatro & Chatterjee, 2018). In order to prevent significant financial losses from the removal of attacked and injured plants from the field, it is crucial to sow crops with a high seed rate (Mahapatro & Chatterjee, 2018). However, there may be rivalry between plants for food, space, light, and water due to the large number of plant seedlings in the field. This approach also raises the price of seeds. By eliminating termite galleries and mounds, the routine intercropping practice of tillage in the field also reduces termite damage.

Because termites like sandy or sandy loam soil, orchards should not be planted in these types of soil. Termites primarily target weak plants, such as those that are stressed, mechanically damaged, diseased, or afflicted with insect pests (Diouf & Rouland-Lefevre, 2018). Plant vigor is increased by the appropriate and balanced use of fertilizer, well-decomposed farm yard waste, frequent irrigation, and adherence to suggested agricultural practices. This ultimately lowers termite assaults (Negassa & Sileshi, 2018) [37]. Field crops are less vulnerable to termite infestation when nitrogen, phosphorus, and potassium are used optimally. However, improper usage or application of commercially available fertilizers can lead to soil pollution, plant damage, runoff, leaching, and salt buildup (Paul *et al.*, 2018). On the other hand, well-decomposed manure or organic fertilizer improves the pH and soil structure in addition to promoting plant growth and decreasing termite infestation. However, due to its limited availability, applying enough well-decomposed farmyard manure to crops is extremely difficult. Additionally, it takes more work to apply in the field. According to (Negassa and Sileshi 2018) [37], using manure and fertilizer together increases agricultural output, enhances soil fertility, stops soil deterioration, and lessens termite invasion. Additionally, they found that a higher fertilizer dose without organic input increased termite damage (Sane *et al.*, 2016). They suggested that a lack of water increases seedling mortality by making them more vulnerable to termite assault. However, floods or excessive irrigation water use decreases plant development and output due to waterlogging, nutrient leaching and runoff, increased weed pressure and root infections, and decreased air exchange between soil and atmosphere. Because weeds compete with crops for food, light, water, and space, which may leave the plant vulnerable to termites, removing weeds from the field increased plant vigor and reduced termite assault. A useful way to reduce crop exposure to pests like termites, who are drawn to and feed on an alternative food supply, is to mulch the field with dead plant litter or green plant biomass (Nyagumbo *et al.*, 2015) [38]. It also improves soil fertility, decreases weed germination, and boosts soil water-holding capacity. A very successful method is mulching with *Cassia siamea* and *Azadirachta indica* According to Nyagumbo *et al.* (2015) [38], mulching maize wastes in *Zea mays* crops lowers crop lodging caused by termite attacks because the termites preferentially feed on the residues. However, the overabundance of food could lead to an increase in the termite population. Another useful tactic for protecting crops from termites is the use of plant material. To lessen termites in the field, chopped plant leaf mixtures (like *Azadirachta indica*, *Tephrosia vogelii*, *Euphorbia tirucalli*, *Aloe graminicola*, *Melia azedarach*, and *Lippie javanica*) and fruits (like *Swartzia madagascariensis*) are frequently applied globally. In order to reduce termite damage, timely crop harvesting may also be a very successful and efficient strategy. By cultivating non-preferred crops, crop rotation and intercropping techniques enhance soil fertility, plant development, natural enemy fauna, and termite life cycle disruption. In addition to decreasing soil fertility and structure, the monoculture farming strategy also decreases plant vigor and ultimately increases termite damage. According to Mahapatro and Chatterjee (2018), push-pull is a very useful technique for controlling the quantity and distribution of beneficial insects and pests in the field. They

claim that after harvesting the maize crop, planting three rows of wheat between the stubbles (0.75 m row spacing) may encourage termites to feed on the stubbles rather than the wheat crop. This method not only lessened termite damage to the wheat crop but also improved soil fertility through stubble decomposition. When soybeans or groundnuts are interplanted with maize, the number of termites is decreased and predatory ants are increased. They examined the impact of mulching, intercropping, and their combination on termite infestation in maize crops. They mulched with a mixture of neem seed powder and maize stover and interplanted with soybeans. According to their findings, intercropping, mulching, and applying mulching and intercropping together decreased termite attacks and increased the production of maize crops. Crop rotation and intercropping are undoubtedly excellent techniques, but they don't work well in small-scale settings. The government should implement some regional planting regulations. However, for better termite management, much more research is needed in the areas of intercropping, particular rotation, and seasonal production breaks.

3. Biocontrol Approaches for Termite Management

Predators, parasitoids/parasites, or infestations were used as biological control methods to keep termite populations below a predetermined threshold.

1. Natural Predators of Termites

Termites are typically killed by swarming reproductive alates and foraging workers by certain vertebrate and invertebrate predators. Ants, wasps, spiders, mantids, beetles, crickets, flies, dragonflies, cockroaches, centipedes, scorpions, and so forth are examples of invertebrate predators; birds, mammals, amphibians, reptiles, and so forth are examples of vertebrate predators. Ants are termites' worst predators. In many parts of the world, farmers utilize sugar and animal leftovers as bait to attract more predatory ants to termite-infested areas. Certain ant species, such as *Iridomyrmex purpureus* (Oberst *et al.*, 2017) [39], Termite predatory ants include *Plagiolepis pallescens*, *Polyrhachis lacteipenni*, *Pheidole teneriffana*, *Crematogaster antaris*, *Monomorium destructor* (Latifian *et al.*, 2018), *Myrmecaria cumenoides*, *Pheidole megacephala*, *Leptogenys processionalis*, *Camponotus sericeus*, *Anoplolepis longipes*, and *Oecophylla smaragdina* (Paul *et al.*, 2018). Reduviids love to eat termites and are the general predators of numerous arthropods. Numerous species of Salyavatinae (Hemiptera: Reduviidae) are specialized termite predators (Petráková *et al.*, 2015).

2. Bacterial Control of Termite

Bacterial pathogens are the first microorganisms to be considered as a biological control agent for a variety of agricultural pests. The groups Bacillaceae, Enterobacteriaceae, Pseudomonadaceae, and Streptococcaceae comprise the majority of pathogenic bacteria (Kalha *et al.*, 2014) [18]. However, only Bacillaceae species—more especially, *Bacillus* spp.—have been the subject of extensive research. Under laboratory conditions, *B. thuringiensis* and *B. thuringiensis* subsp. *israelensis* can cause over 80% mortality and are highly effective pathogens against termites (*Microtermes obesi* and *Microcerotermes besoni*) (Singha *et al.*, 2010). According to (Omoya and Kelly 2014) [40], *B. subtilis* is a highly efficient pathogen of

several termite species. (Ischaidar and Dali 2014) ^[17] indicated that *B. licheniformis* has good pathogenicity against termites when sprayed and employed as feeding (baits). *S. marcescens* was also recommended by (Omoya and Kelly 2014) ^[40] for termite control. Subterranean termites can be controlled by using hydrogen cyanide (HCN), which is produced by certain rhizobacteria species (Devi, 2012;). Three HCN-producing rhizobacteria species—*Aeromonas caviae*, *Alcaligenes latus*, and *Rhizobium radiobacter*—were reported to be effective against *Odontotermes obesus* *in vitro* by Devi (2012). According to Kothamasi (2009), *Pseudomonas fluorescens* kills termites by obstructing their respiratory systems and preventing them from producing HCN.

3. Fungi in Termite Management

Antennopsis, Beauveria, Coreomyceptosis, Laboulbenia, Leboulbeniopsis, Metarhizium, Metirolella, Neotermus, and Termitaria are some of the well-known genera that have been identified as pathogenic against agricultural insect pests. Entomopathogenic fungi are cosmopolitan organisms that are isolated from soil and can cause mortality in all development stages of their hosts. However, the ability of their asexual spores or conidia to spread, transmit, attach, germinate, pierce the host cuticle for fungal growth and infection, and compete with other rapidly expanding adversaries and disease outbreaks in the termite colony is what determines their pathogenicity (Yii *et al.*, 2016) ^[49]. The spores can be given to termites or nests using baits or as a powder. The effectiveness of *Beauveria bassiana* and *Metarhizium anisopliae* against termites has been extensively studied globally. Several termite species, including *Coptotermes formosanus*, *Odontotermes* sp., and *Reticulitermes* sp., are successfully controlled by the fungus *M. anisopliae*. The strains of *M. anisopliae* are harmful to termites (*Odontotermes* sp.), according to a 2009 study by Balachander and colleagues. Additionally, after using five isolates of *M. anisopliae* spores with attractants like sugarcane bagasse, sawdust, and cardboard powder against *Odontotermes obesus*, Balachander and colleagues discovered that after 13 days, >95% of workers and >75% of soldiers died from the IWS-T-Ma13 isolate (Balachander *et al.*, 2013). (Ravindran *et al.*, 2015) observed termite mortality after four days of testing four isolates of *M. anisopliae* against *Coptotermes formosanus*. The effectiveness of the ARSEF6911 isolate of *M. anisopliae* against two termite species, *M. obesi* and *O. obesus*, was investigated in both laboratory and field settings. Both in the outdoors and in the lab, they saw a notable decline in the termite population. More than 95% of termites died when ten strains of *M. anisopliae* were tested against *Coptotermes curvignathus* (Samsuddin *et al.*, 2016). They also noted the rate of conidia sporulation and fungal growth. The TFFH3 and PKLG isolates had the highest rates of mycelia development (above 85%) and conidia sporulation (80%). They suggested using PR1 isolate as a powerful biopesticide against termites based on the isolates' performance. In order to combat *Coptotermes curvignathus*, Yii and colleagues utilized the termiticide fipronil both in combination and individually with *M. anisopliae* spores (Yii *et al.*, 2016) ^[49]. They came to the conclusion that a combination of sublethal fipronil and conidia may kill over 99% of *C. curvignathus* (Zulfiana *et al.*, 2020) ^[50]. employed four isolates from *M. anisopliae* and *B. bassiana* against *Macrotermes* sp., and

after seven days, all isolates killed 100% of the termites. They proposed the use of *B. bassiana* and *M. anisopliae* as safe biopesticides. Rana and Kachhawa studied the *in vivo* suppression of termites in a maize field using the spores of three different fungal species (*M. anisopliae*, *B. bassiana*, and *Paecilomyces fumosoroseus*) with farm yard manure (FYM). They claim that when the maize crop was sown, the soil treated with FYM + fungal spores produced greater germination, yield, and plant survival than the control (Rana & Dinesh, 2014). Few studies have shown that entomopathogenic fungi are ineffective in controlling termites, despite numerous researchers' confirmation that they are highly effective biological control microorganisms. Termites are known to be extremely sensitive to abiotic environmental influences. Their multi-defense methods against fungal infections are highly developed (Liu *et al.*, 2019) ^[28]. By avoiding fungus-infected places and persons, generating antifungal secretions, and using symbiotic microorganisms for nest materials, they stop infections from entering the colonies (Liu *et al.*, 2019) ^[28]. A strong sense of smell is essential for spotting and eliminating deadly conidial spores when pathogens enter the colony. Additionally, they rapidly eradicate diseases by burying (Liu *et al.*, 2019) ^[28], cannibalism, aggressive behavior, grooming (Poulsen, 2015) ^[44], antifungal secretions, and social immunization (Liu *et al.*, 2015; Cremer *et al.*, 2018) ^[5, 27]. Additionally, detoxification and antioxidation are crucial for enhancing social immunity (Cremer *et al.*, 2018) ^[5]; Liu *et al.*, 2019). (Hussain and Mingyi, 2013) ^[15, 28] discovered that fungus conidia were ineffective in controlling termites in the field. They came to the conclusion that entomopathogenic fungi might be employed as an efficient and environmentally safe IPM technique for termite management after considering all of the successes and failures of fungi. The efficiency of the fungi is dependent on their spore dispersion, transmission, germination, penetration into the host, and environmental circumstances, as we previously described in this review work (Yii *et al.*, 2016) ^[49]. Therefore, termite control with fungi can be a successful strategy in an IPM program by enhancing these characteristics.

4. Nematodes - Based Termite control

Many agricultural insects in soil habitats may be controlled by entomopathogenic nematodes (EPNs), which are highly significant parasites. According to Lin *et al.* (2015) ^[26], these diseases are employed as biological control agents to eradicate Macrotermitinae. They are quite effective against termites in the lab, but no research has shown that they are beneficial in the wild. Termites can be effectively infected by EPN families like Steinernematidae and Heterorhabditidae, which are significant obligatory insect parasites. Three strains of *S. riobrave* were employed to combat the subterranean termite species *C. formosanus*, *Heterotermes aureus*, and *R. flavipes*. After four days of treatment, their findings showed that *S. riobrave* is more effective against *Heterotermes aureus*. (Zadji *et al.*, 2014b) employed four EPN isolates—*H. indica* Ayogbel, *H. sonorensis* Azohoue, *H. sonorensis* Ze3, and *Steinernema* sp. Bembereke—against the termite species *Macrotermes bellicosus* and *Trinervitermes occidentalis*. They reported that both species were susceptible to every isolate of EPN. Findings indicated that the termite was more vulnerable to EPN strains. Murugan and Vasugi (2011) ^[36] achieved better

results against *R. flavipes* by combining EPNs and neem seed kernel extract. The EPN-based biopesticide (Pusa Nemagel) against subterranean termites in wheat and pearl millet fields. They utilized this biopesticide during planting with soil treatment and found more than 75% mortality relative to the control group. Although many scientists have assessed EPNs in the laboratory, their compatibility with pesticides and other characteristics make them useful as a biological control method. EPNs can be scale manufactured and developed as microbial biopesticides for commercial use.

5. Viruses in Termite Management

Although some viruses have the potential to be effective microbial control pathogens against agricultural insects, they have received little attention globally. There have been very few research on the efficacy of viruses against termites in the laboratory. NPV is expected to be a significant microbiological agent against termites. However, its efficiency against termites in field conditions has yet to be determined. (Zhang and Mo, 2014) investigated the harmful effects of *Autographa californica* NPV (AcNPV) on workers of *Coptotermes formosanus* Shiraki. They treated filter paper or *Pinus massoniana* wood dust with varying concentrations of NPV before feeding it to termites. Their findings demonstrated that AcNPV has a high infection capability against termites. They also stated that treating *P. massoniana* wood dust with NPV is a highly efficient termite control method. Although microbial termite control with entomopathogenic bacteria, fungi, and nematodes has produced excellent results and can be utilized as potential biopesticides, there are significant restrictions to their use. For example, they become dormant in adverse situations. These microorganisms also contaminated soil and water through leaching. Furthermore, the use of these entomopathogens as biopesticides is complicated by environmental conditions (such as temperature, humidity, sunlight, rainfall, and so on), which reduce their pesticidal effectiveness due to decreased persistence. Similarly, we cannot keep these microbial pesticides for an extended period of time since these biocontrol agents require highly sophisticated storage methods, increasing application costs.

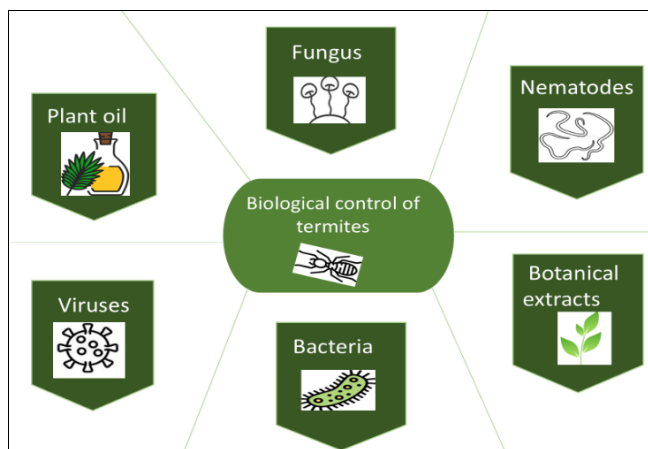


Fig 5: Biological Termite Control

5. Plant -Based Termite Control

Botanicals are phytobased products or plant-derived pesticides that are regarded as the most promising alternatives to very toxic synthetic pesticides. They are

generated from plant roots, stems, leaves, flowers, fruits, seeds, and wood. More than 2000 plant species from 60 families contain pesticidal properties; many of them are used as insect growth regulators, ecdysones, behavior modulators, feeding deterrents, repellents, attractants, and so on. (Verma *et al.* 2018). Many researchers have explored the effects of plant-derived compounds against termites in both laboratory and outdoor environments. The hexane leaf extract of four plant species, *Heliotropium bacciferum*, *Lantana camara*, *Rhazya stricta*, and *Ruta chalepensis*, is effective against the subterranean termite *Psammodermes hybostoma*. (Ibrahim and Demisse 2013) ^[16] used 11 plants against hot pepper termites and found that *Maesa lanceolata* and *Azadirachta indica* were highly efficient. The fumigant toxicity of four plants, *Chamaemelum nobile*, *Erioccephalus punctulatus*, *Ormenis multicaulis*, and *Santolina chamaecyparissus*, against the termite *Reticulitermes speratus*. After two days of treatment, *Chamaemelum nobile* outperformed all other plants in terms of fumigant toxicity to termites. Tested the leaf extracts of the plants *Azadirachta indica* and *Jatropha curcas* against *Macrotermes* spp. and discovered that the extract is effective against termites. The effect of a methanolic extract of *Jatropha curcas* on termites and found good results. The reduction in termite attack on *Triplochiton scleroxylon* and *Vitex doniana* wood was seen when treated with *Lawsonia inermis* stem bark and leaf extracts. Bajya and colleagues performed a laboratory experiment to test the repellent properties of *Crotalaria burhia* root extract and *Anacardium occidentale* leaf extract against *O. obesus*. They reported that *C. burhia* repelled more than 70% of *O. obesus*, while *A. occidentale* repelled up to 60% of *O. obesus*. The seed extracts of the plant species *Chenopodium ambrosioides*, *Maesa lanceolata*, and *Vernonia hymenolepis* greatly reduced *Macrotermes* sp. assault. The plant species *Andrographis lineata*, *Aristolochia bracteolata*, *Datura metel*, and *Eclipta prostrata* have anti-termite properties (Hu *et al.* 2015) ^[14] conducted experiments to determine the efficiency of *Camellia oleifera* against *Reticulitermes flavipes* and discovered satisfactory results. *Lantana camara* leaf extracts are antifeedant, repulsive, and poisonous to *Reticulitermes flavipes* (Yuan & Hu, 2012). Qureshi and coworkers used a different concentration of *Melia azadirachta* in water and methanol against *M. obesi* and *O. obesus* and found effective results against *O. obesus* (Khalid, 2023) ^[23] used three concentrations, that is, 5%, 10% and 20% from a different solutions including garlic, neem and tobacco against *Heterotermis indicola* under laboratory conditions, and better results were recorded for all solutions, even though high mortality by garlic and tobacco was reported. Liu *et al.* (2015) ^[27] evaluated the termite-repelling potential of *Aristolochia bracteolata* leaf hexane extract, *A. paniculata* ethyl acetate extract, *Datura metel*, and *Euphorbia prostrata*, and *Acacia lineata* and *D. metel* methanol extract. They reported that all therapies resulted in promising mortality after one day of administration. Termites are effectively controlled using a variety of plant compounds and secondary metabolites, including as alkaloids, steroids, essential oils, terpenoids, flavonoids, resins, and so on. Isolated monoterpenes from aromatic plants and tested their effectiveness against termites, with positive findings. Himmi and colleagues investigated neem oil against *Coptotermes gestroi* and discovered that the azadirachtin fraction with 91% purity has the highest termite mortality

rate (Himmi *et al.*, 2013) [13]. Investigated the fumigant toxicity of essential oils from four plants, *Chamaemelum nobile*, *Eriocephalus punctulatus*, *Ormenis multicaulis*, and *Santolina chamaecyparissus*, against the Japanese termite *Reticulitermes speratus* and discovered strong results after two days of treatment. Verma *et al.* (2016) discovered that the plant essential oils of marigold and sweet orange have strong repellent properties. Lima *et al.* (2013) [25]. Essential oils from seven plant species (*Corymbia citri odors*, *Croton sonderianus*, *Cymbopogon martini*, *Lip pie alba*, *L. gracilis*, *L. sidoides*, and *Pogostemon cablin*) were tested against *Nasutitermes corniger* and found to be effective against termite workers. After 48 hours of treatment, *Jatropha* seed oil killed *Odentotermes obesus* completely. Pandey and colleagues employed essential oils from seven plants, *Cymbopogon citratus*, *Eucalyptus globulus*, *Syzygium aromaticum*, *Origanum vulgare*, *Rosmarinus officinalis*, *Cinnamomum verum*, and *Thymus vulgaris*, to combat *Odentotermes assamensis*. They studied if phenolic compounds produced more effective effects than other

substances. They also reported that acetate, alcohol, and aldehyde produced satisfactory outcomes. Investigated three new carbohydrate-based enzyme inhibitors against *R. flavipes*: cellobioimidazole (CBI), fluoro-methyl cellobiose (FMCB), and fluoromethyl glucose. Their findings indicated that FMCB and CBI had potential as termite control agents. Some plants are resistant to several subterranean termite species (Pandey *et al.*, 2012). For example, Franca *et al.* (2016) found that two plant species, *Khaya ivorensis* and *K. senegalensis*, naturally repel termites. Great work has been done on phyto-based materials against insect pests during the last few decades, but the optimal mix of these chemicals has yet to be discovered. Furthermore, much research is required to determine the precise concentration and application rates of these plant extracts. Furthermore, commercially available products are prohibitively expensive and only provide short-term protection. Certainly, we cannot compare plant extracts to chemical pesticides. However, they are less harmful to the environment and can be utilized as one of the most effective tactics in termite IPM.

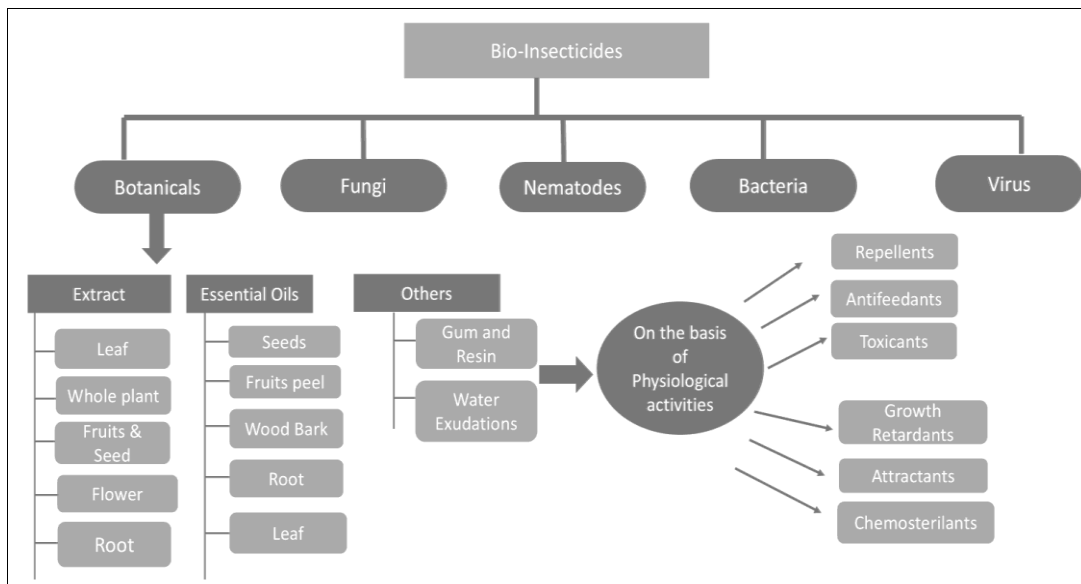


Fig 6: Bio-insecticides: source and mode of action

Chemical Approaches for Termite Management

Even though chemicals are harmful to the environment, farmers all over the world use them extensively to manage crop pests. Managing termites using termiticides is difficult because termites are eusocial insects that reside in mounds or many inches beneath the soil surface to defend themselves from outside threats. However, several termiticides, such as imidacloprid, chlorpyrifos, fipronil, spinosad, chlorfenapyre, bifenthrin, cypermethrin, permethrin, disodium octaborate tetrahydrate, calcium arsenate, lindane, endosulfan, and chlorantraniliprole, have been used worldwide to control termites. Generally, farmers employ these termiticides during agricultural irrigation. However, injections of termiticides are also employed to control termites in field crops, woods, and structures. Fumigation methods use fumigants such as carbon dioxide, methyl bromide, sulfurfluoride, and phosphine to suppress termites that attack dry timbers and stored grain goods. Iqbal and Saeed (2013) tested the efficiency of six insecticides against *Microtermes mycophagus*: imidacloprid, indoxacarb, fipronil, spinosad, thiamethoxam, and chlorfenapyre.

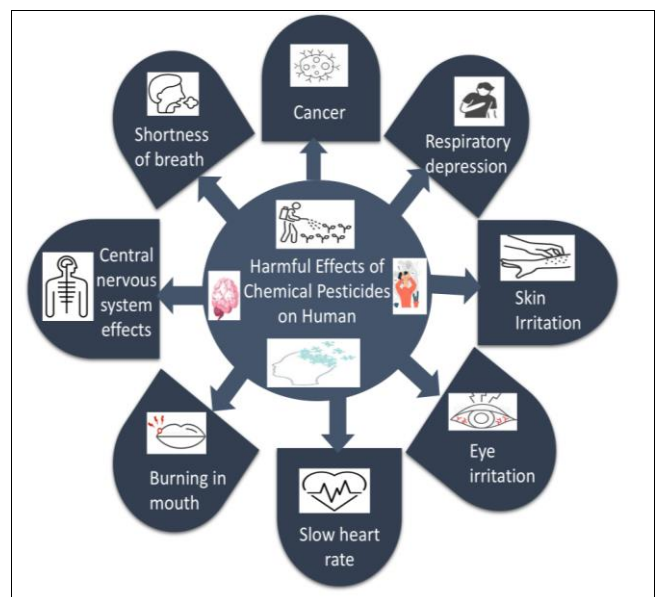


Fig 7: Effects of Chemical Pesticides

They reported that all insecticides had satisfactory results, although chlorfenapyre and spinosad were the most effective. Ahmed *et al.* (2015) studied pesticides against *Psammotermes hypostoma* and discovered that chlorpyrifos, acetamiprid, and thiamethoxam were the most effective insecticides for termite control. Treated sugarcane sets in the field with clothianidiazin and an acephate + imidacloprid combo. Clothianidiazin was shown to be as effective at reducing termite infestation as acephate and imidacloprid when used together. Manzoor *et al.* (2014) [31] conducted a laboratory investigation to assess the toxicity and repellent properties of imidacloprid against *Microtermes obesi*. Researchers found that imidacloprid, a non-repellent pesticide, caused greater than 90% death. They also researched termite tunneling behavior and discovered that a high dosage of imidacloprid reduced tunnel numbers and cumulative tunnel lengths. The effectiveness of three pesticides, fipronil, spinosad, and lufenuron, against subterranean termites *Heterotermes indicola*. They reported that all insecticides were efficient against termites, although fipronil and spinosad outperformed the others. Chen and coworkers assessed the toxicity of ten insecticides, chlorpyrifos, phoxim, carbofuran, propoxur, bifenthrin, cypermethrin, imidacloprid, fipronil, abamectin and ivermectin against *Reticulitermes speratus* under laboratory conditions. They documented that all insecticides are effective against termites, but abamectin, ivermectin, fipronil and imidacloprid showed strong toxicity to reveal the sublethal effects of lufenuron insecticide on *Coptotermes formosanus* physiology and behavior. Their results showed that all concentrations significantly reduced survivorship, running speed, food consumption and tunneling. Furthermore, they discovered that lufenuron hindered the termites' carcass-burying and particle transport behaviors. According to Grimbball *et al.* (2017), cyclohexylamine is a new termiticide with hydrogen phosphate salts that preserve its toxicity. The toxicity and repellency of spinosad and spinetoram against *Coptotermes formosanus* in a laboratory setting and found that both insecticides were harmful and non-repellent against termites. Tested fipronil bait made of straw pulp and white sugar against *O. formosanus* in the field and obtained satisfactory results conducted an experiment to determine whether fipronil might be transferred from exposed *O. formosanus* workers to unexposed nestmates. They employed a basic donor-recipient paradigm to achieve this. Their findings demonstrated that treating 15 to 20 donors with 5 ppm fipronil and exposing them for 6 hours resulted in considerable recipient death. (Li *et al.* 2010) successfully tested three different baits, sulfluramid baits, hexaflumuron baits, and fipronil baits, against the subterranean termite, *Reticulitermes chinensis*, in rural Chinese homes. Without a doubt, termites may be effectively managed by chemical methods, but we must not overlook their harmful impacts on humans, animals, and birds. Furthermore, the discriminatory use of pesticides leads to insect resistance and environmental contamination.

Conclusion

Termites are a growing concern to the global farming sector. While much progress has been made in different aspects of ITM, more new approaches are still required. Managing termites remains challenging due to their ability to hide in mounds or beneath the soil, making it difficult to reach their

target areas. Farmers should enhance their cultural management techniques, as the saying goes, "prevention is better than cure". Integrating conventional practices with new methods can improve management effectiveness. While termiticides can be effective against termites, they should only be used as a last resort for ecological management. These approaches pose significant harm to both individuals and the environment. Research has shown that termite control methods such as entomo-pathogens, botanicals, toxic and non-toxic barriers, mulching, dequeening, clean cultivation, plant vigor improvement, intercropping, rotation, and baits are both effective and environmentally friendly. Farmers are often unaware of effective termite IPM measures, therefore mass dissemination is necessary. To combat this challenging challenge, researchers and extension officers should improve communication and collaboration.

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