Chapter 8
Role of Botanicals in Termite Management

Syed Kamran Ahmad, Natalie Dale-Skey, and Md. Aslam Khan

Contents

Abstract Plant-derived pesticides (botanical) deliver a potential alternative to highly hazardous synthetic pesticides for insect pest control. They can be derived by leaves, floral system, fruits or seeds, wood, and/or roots. The active chemical compounds are extracted via drying, grinding, and mixing the plant parts in suitable solvents. Some of the well-known botanical pesticides are pyrethrin, rotenone, sab-

S.K. Ahmad (✉)
Centre for Environmental Research and Studies (CERS), Jazan University, Jazan, Saudi Arabia
e-mail: entosaif@rediffmail.com

N. Dale-Skey
The Natural History Museum, London, UK

M.A. Khan
Department of Biology, Faculty of Science, Jazan University, Jazan, Saudi Arabia

M.A. Khan, W. Ahmad (eds.), *Termites and Sustainable Management*, Sustainability in Plant and Crop Protection,
https://doi.org/10.1007/978-3-319-68726-1_8

adilla, nicotine, ryanodine, etc. Little attention has been paid to explore the use of botanicals against termites. Most of the studies are limited to the extraction of plant chemicals with water and methanol and to the application against termites to assess their killing potential. The botanical bioassays against termites seem incomplete because either some aerial parts like leaves, fruits, seeds, and stems or roots have been utilized alone. Similarly, oil extraction and plant crude extracts were not assessed for the same plants. Isolation and synthesis of active compound are also very rare. In this chapter, we review the properties of various plant parts and their potential role in termite management, highlighting the gaps concerning the available informations.

Keywords Termite • Botanical insecticides • Resin • Essential oils

8.1 Introduction

Insect pest management relies heavily on synthetic chemicals. Calendar-based and non-judicious use of these pesticides for the control of agricultural and urban insect pests has created severe environmental hazards. Excess use of synthetic pesticides resulted in phytotoxicity, mammalian toxicity, pesticides residues, pesticide resistance in target insect pests, insect outbreaks, and increased production costs (Elango et al. 2012). Plants are well known to have a cumulative defense mechanism and to produce secondary metabolites in order to survive in the ecosystem facing insect infestations. Since immemorial times, the botanical remedies were the only options used against biting arthropods (Birkinshaw and Colquhoun 1998). Unfortunately, major scientific efforts have been directed toward the production of pharmaceuticals, cosmetics, and medicinal stuffs from plants, rather than developing botanical pesticides (Nakayama and Osbrink 2010). The deleterious effects of plant extracts on insects are manifested in several ways, including suppression of calling behavior (Khan and Saxena 1986), growth retardation (Breuer and Schmidt 1995), toxicity (Hiremath et al. 1997), oviposition deterrence (Zhao et al. 1998), feeding inhibition (Wheeler and Isman 2001), and reduction of fecundity and fertility (Muthukrishnan and Pushpalatha 2001). Frequent studies have documented the natural resistance of certain plant species to insect attacks, but most of the studies are incomplete as they were conducted without exploring up to the active compound. Also, the majority of studies are laboratory based, lacking the know-how about environmental errors. Developmental steps toward botanical insecticides are shown in Fig. 8.1.

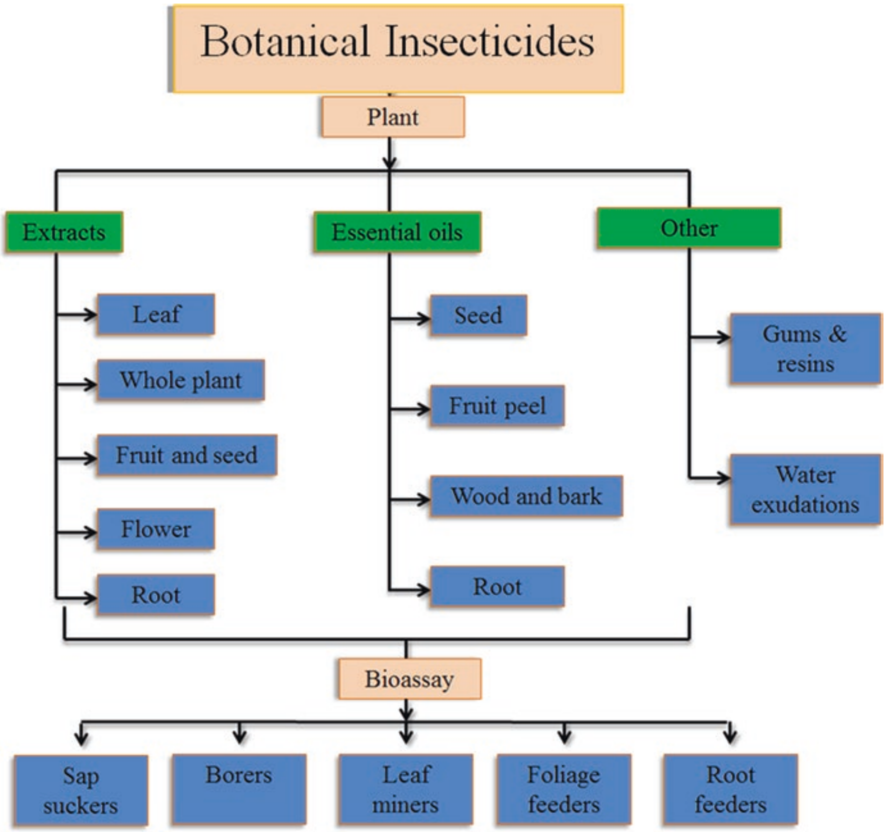

Fig. 8.1 Different plant parts for development of botanical insecticide

8.2 Popular Botanical Insecticides

Despite having a long history, the numbers of successfully isolated and commercialized botanical insecticides are countable on fingers. Rotenone, one of the oldest botanicals, is a colorless, crystalline isoflavone used as a broad-spectrum insecticide. The active chemical component was first isolated in 1895 by a French botanist, Emmanuel Geoffroy, who called it nicouline, from *Lonchocarpus nicou* (Ambrose and Harvey 1936). Later on, the Japanese chemist Nagai Nagayoshi isolated a pure crystalline compound from *Derris elliptica* in 1902 and named it "rotenone." Rotenone acts as a pesticide, an insecticide, and a fish killer (Fimrite 2007). It is a nonselective insecticide, effective against a range of insect pests like potato beetles, cucumber beetles, flea beetles, cabbage worms, raspberry and asparagus beetles, and various other arthropods. It is known to interfere with nicotinamide adenine dinucleotide (NAD) (a coenzyme found in all living cells) during the formation of ATP (adenosine triphosphate) which is the central unit of intracellular energy and metabolism (Hayes 1991). Rotenone can be extracted from seeds, stems, and roots of several tropical and subtropical plant species such as *Tephrosia virginiana*, *Pachyrhizus erosus*, *Deguelia utilis*, *Lonchocarpus urucu*, *Derris elliptica*, *Derris involuta*, *Mundulea sericea*, *Piscidia piscipula*, *Millettia*, and *Tephrosia* spp. (Nellis 1994; Barton and Meth-Cohn 1999; Fang and Casida 1999). The rotenone molecule shows the quality trait of being rapidly biodegraded, and the risk of hazardous residues associated with it is low.

Nicotine is another important stimulant alkaloid found among Solanaceae. It has been widely used as an insecticide in the past (Ujváry 1999; Rodgman and Perfetti 2009). Nicotine is found in the leaves of *Nicotiana tabacum*, *N. rustica*, *Duboisia hopwoodii*, and *Asclepias syriaca*, in the range of 2–14% (Metcalf 2007). The active compound was isolated in 1828 by Posselt and Reimann. It is effective against various aphid species including other soft-bodied insects (Matsumura 1975) and acts as an anti-herbivore, disrupting the feeding and consequently killing the insects. Nicotine is an extremely nerve toxic alkaloid that competes with acetylcholine neurotransmitters causing uncontrolled nerve fringe in both insects and mammals (Weinzierl and Henn 1994).

Pyrethrin is derived from pulverized dried flowers of *Chrysanthemum cinerariifolium* and acts on the nervous systems of insects. The Chinese culture has been documented to be the first to use crushed *Chrysanthemum* plants as an insecticide, as early as 1000 BC. To extract pyrethrin, the dried flowers are grinded to produce a fine powder. The extract with organic solvents contains six types of pyrethrins: pyrethrin I, pyrethrin II, cinerin I, cinerin II, jasmolin I, and jasmolin II (Metcalf 2000). It is known to affect the closure of voltage-gated sodium ion channels in the nerve cells of insects, resulting in repeated and extended nerve firings that cause hyperexcitations. This condition leads to the loss of motor coordination and paralysis, followed by the insect death. Pyrethrin is also a potent insect repellent when applied at low doses. The active ingredient is easily photodegraded under the sunlight (Stenersen 2004). After the discovery of synthetic forms of pyrethrins, the use of natural pyrethrin sharply declined. Increase in pyrethroid use resulted in several environmental hazards such as the decline in pollinators (Gemmill-Herren 2016).

The compound sabadilla is an alkaloid derived from a plant known as tropical lily, also known as cevadilla or Indian caustic barley (*Schoenocaulon officinale*) in South and Central America. The extract of dried seed contains cevadine and veratridine alkaloids which are the most active compounds that kill insects (Hayes 1982). The insecticide can be prepared by heating or through an alkaline treatment, in order to activate the active compounds, followed by seed grinding to prepare the dust (Allen et al. 1944). Sabadilla acts similar to pyrethrins and affects the voltage-dependent sodium channels at axons in the nervous systems (Bloomquist 1996). Historically, sabadilla has been used against insect pests of crops, mammals, and human beings.

Ryanodine is another natural plant compound and a slow-acting stomach poison. It proceeds from the wood of Salicaceae plants (Roskov et al. 2014). This naturally occurring insect killer was isolated from the stem wood of *Ryania speciosa.* The alkaloid ryanodine is the major toxic component, corresponding approximately to

0.2% of the total dry wood weight. Much detail on mode of action is not available. However, after ingestion, the insects stop feeding followed by a slow paralysis. The compound is known to interact with open-form ryanodine receptors, a group of calcium channels found in the muscular system of the body (Gaetano and Andrew 2015). The purified form of ryanodine is 700 times toxic as compared to the crude wood dust form (Weinzierl and Henn 1994).

8.3 Botanicals Tested Against Termites

8.3.1 Extracts

Researchers recognized many plants with anti-termitic activities (Sakasegawa et al. 2003; Park and Shin 2005; Cheng et al. 2007; Ding and Hu 2010). Duke et al. (2010) suggested the term "greener termiticide" for the first time and elaborated the importance of botanicals in termite management. Plants are naturally supplied with certain chemicals like terpenoids, flavonoids, saponins, etc. or mixtures of chemicals that repel and kill termites or interfere with their gut flora (Boué and Raina 2003; Park and Shin 2005; Verma et al. 2009). Recently, few plant species such as *Pseudotsuga menziesii* (Mirb.), *Lysiloma seemanii* Britton & Rose, *Tabebuia guayacan* (Seem.), *Diospyros sylvatica* Roxb. (Ganapaty et al. 2004), *Curcuma aromatica* Salisb. and *Euphorbia kansui* Gan-Sui (Shi et al. 2008), *Eucalyptus globules* L., lemon grass, *Eucalyptus citriodora* (Hook.), cedar wood, clove bud and vetiver grass (Zhu et al. 2001a), *Taiwania cryptomerioides* Hay. (Chang et al. 2001), *Dodonaea viscosa* (L.) Jacq. (purple hop bush, a termite-resistant shrub), *Ocimum basilicum* L., *Cymbopogon winterianus* Jowitt, *Cinnamomum camphora* (L.) Nees and Eberm., *Rosmarinus officinalis* L. (Sbeghen et al. 2002), and *Coleus amboinicus* (Lour.) (Singh et al. 2004) have been explored for their antifeedant and termiticidal activities. Meepagala et al. (2006) isolated the active compounds "Vulgarone B" (from *Artemisia douglasiana*, Asteraceae), "cnicin" (from *Centaurea maculosa*, Asteraceae), and "apiol" (from *Ligusticum hultenii*, Apiaceae) that significantly caused mortality to subterranean termites in laboratory bioassays. Vulgarone B, cnicin, and apiol also possess other biological activities such as phytotoxic and antifungal properties, suggesting the ecological importance of secondary metabolites in these plants (Meepagala et al. 2003). These compounds reflect the importance of plant secondary metabolites in natural defense mechanisms.

8.3.1.1 Leaf Extracts

Plant leaves are one of the major flavonoid reservoirs with number of attributes. Alshehry et al. (2014) found hexane leaf extract of plants, namely, *Rhazya stricta* Decne, *Lantana camara* L., *Ruta chalepensis* L., and *Heliotropium bacciferum*

Forssk., as promising against the subterranean termite *Psammotermes hybostoma* (Desneux). Yuan and Hu (2012) also reported the repellent, antifeedant, and toxic activities of *Lantana camara* leaf extract against *Reticulitermes flavipes*. Hexane and methanol leaf extracts of *Juniperus* sp. also showed effective performance against termites (Adams et al. 1988). Addisu et al. (2014) used water extracts of *Azadirachta indica* and *Jatropha curcas* leaves against *Macrotermes* spp. with satisfactory results. Similarly, Grace and Yates (1992) discovered Margosan-O (a neem insecticide formulation) with 0.3% azadirachtin and 14% neem oil, highly toxic against the subterranean termite. The leaf extract of *Flourensia cernua* with hexane, diethyl ether, and ethanol showed a high degree of termite toxicity (Tellez et al. 2001). Sharma et al. (1999) studied the toxic effects of six plants, viz., *Acorus calamus*, *L. camara*, *Parthenium hausteneum*, *Pongamia glabra*, *J. curcas*, and *Tagetes erecta*, for their toxic action against *Odontotermes obesus* and reported *A. calamus* rhizomes and aerial parts of *T. erecta* as the most toxic. Thambidurai (2002) achieved the successful prevention of termites for up to 50 days with the use of fermented leaf extracts of *Musa paradisiaca*. Fokialakis et al. (2006) reported *Echinops* sp. as most effective against termites, out of 220 crude extracts tested. A 5% chloroform extract of *L. camara* var. *aculeata* was effective against termites (Verma and Verma 2006), whereas the leaf extract of *Detarium microcarpum* with methanol appeared as an effective antifeedant. Adedeji et al. (2017) treated *Triplochiton scleroxylon* and *Vitex doniana* woods with stem bark and leaf extract compounds of henna (*Lawsonia inermis* Linn.) and reported a reduction in the attack of termites. Shiberu et al. (2013) observed 100% termite mortality with leaf extracts of *N. tabacum* and *Phytolacca dodecandra* after 24 h. Elango et al. (2012) further extended the list of anti-termitic plants with *Andrographis lineata* Wallich, *Aristolochia bracteolata* Lam. (Aristolochiaceae), *Datura metel* L. (Solanaceae), and *Eclipta prostrata* L. (Asteraceae).

8.3.1.2 Root Extracts

The toxic and repellent effect of *Zingiber officinale*, *Allium sativum*, *Dennettia tripetala*, and *Capsicum annuum*, as mixed and individual extracts, against *Macrotermes bellicocus* was studied under laboratory and field conditions. All extracts appeared promising, but the mixture of *Z. officinale* with *A. sativum* was the most toxic (Cynthia et al. 2016). Ganapaty et al. (2004) extracted quinines using chloroform from roots of *Diospyros sylvatica* which exhibited high toxicity against *Odontotermes obesus*. *Jatropha curcas* is another plant with insecticidal, molluscicidal, and fungicidal properties (Nwosu and Okafor 1995; Liu et al. 1997; Solsoloy and Solsoloy 1997). The root, stem, and bark solvent extracts of *Jatropha* exhibited potential termiticidal effects (Verma et al. 2013).

8.3.1.3 Fruit and Seed Extracts

The potentiality of plant seeds and fruit peels as termiticides has been investigated across the globe. The seeds of Indian neem tree, *Azadirachta indica*, are a major source of botanical insecticides. They contain many azadirachtin analogs, dominantly "azadirachtin A," with the remaining analogs sharing a little efficacy (Duke et al. 2010). Hexane extract of *Xylopia aethiopica* fruits and aqueous methanol extract of its seeds were studied for their antifeedant activity against workers of *Reticulitermes speratus*. The crude extract exhibited strong antifeedant activity at 1% concentration. Further isolation of hexane extracts resulted in the discovery of six ent-kaurane diterpenes of which ent-kaur-16-en-19-oic acid exhibited the strongest antifeedant activity against termites (Lajide et al. 1995). Addisu et al. (2014) found that seed extracts in water of *Maesa lanceolata*, *Chenopodium ambrosioides*, and *Vernonia hymenolepis* were effective against *Macrotermes* sp. Escoubas et al. (1995) prepared n-hexane and methanolic seed extracts of *Aframomum melegueta* and isolated various compounds. Among them, [6]-gingerol and [6]-shogoal showed the strongest termite antifeedant activity. Verma et al. (2011, 2013) observed 100% termite mortality with water extracts of nonedible oil seed cake of *J. curcas*. A 100% mortality of termites was also recorded with seed extract of Birbira (*Militia ferruginea*) after 24 h (Shiberu et al. 2013).

8.3.1.4 Wood Extracts

There are few woody plants showing resistance against termite attacks, due to the presence of some active components. These have been isolated and studied for their efficacy against various insect pests. The sapwood extracts of sugar pine, *Pinus lambertiana* Dougl., and related compounds were found having a feeding-deterrent effect against the western drywood termite, *Incisitermes minor* (Hagen) (Scheffrahn and Rust 1983). Similarly, the heartwood extract of *Taxodium distichum* (L.) Rich exhibited feeding deterrence against *Coptotermes formosanus* Shiraki (Scheffrahn et al. 1988). Besides promising termiticidal activity of leaf extracts, the fresh heartwood sawdusts of 12 *Juniperus* species exhibited termiticidal activities (Adams et al. 1988). *Juniperus procera* contains cedrol and cedrene, potentially toxic against termites (Kinyanjui et al. 2000). The heartwoods of *Erisma* sp., *Tabebuia* sp., and *Chamaecyparis thyoides* exhibit an apparent natural resistance to *Reticulitermes flavipes* (Arango et al. 2006). Teak wood and heartwood of *Caesalpinia echinata* Lam. are naturally resistant to termite attacks (Roszaini et al. 2006; Silva et al. 2007). The wood extract of *Catalpa bignonioides* contains four toxic compounds, catalponol, epicatalponol, catalponone, and catapalactone, of which the latter two were the most effective against *R. flavipes* (McDaniel 1992).

The heartwood of *Lonchocarpus castilloi* Standley is a source of some flavonoids such as castillen D and castillen E and showed dose-dependent feeding deterrence against *Cryptotermes brevis* (Walker) (Reyes-Chilpa et al. 1995). Toxifolin and quercetin isolated from Japanese larch wood might be useful as termite control agents (Ohmura et al. 2000). Also, the water extracts of Japanese larch wood, containing flavonoids in large quantities, proved to be an excellent feeding deterrent against termites (Chen et al. 2004). Two compounds, cedrol and a-cadinol, isolated from heartwood of *Taiwania cryptomerioides*, showed a high anti-termitic potential (Chang et al. 2001). Boue and Raina (2003) used five plant flavonoids, genistein, biochanin A, apigenin, quercetin, and glyceollin, for their impact on life attributes of termite *C. formosanus*. Apigenin proved to be the most fatal among all, while biochanin A was also noticed to reduce the fecundity of subterranean termites. The black heartwood of *Camellia japonica* holds some sesquiterpenes, showing termiticidal activity against *C. formosanus* (Arihara et al. 2004). Heartwood of white cypress pine *Callitris glaucophylla* exhibited the potential termite repellency (Watanabe et al. 2005). Finally, the wood vinegar from mixed wooden chips of *C. japonica*, *Pseudotsuga menziesii*, *Quercus serrata*, and *Pinus densiflora* showed high toxicity against *R. speratus* (Yatagai et al. 2002).

8.3.2 Plant Resins

Dipterocarp (Dipterocarpaceae) timber plants are resin exudation trees. Almost all Southeast Asian dipterocarp timbers exude resins (Schulte and Schone 1996). These timber trees exhibit natural resistance against insect pests such as termites and cause substantial mortality to insects feeding on them (Moi 1980). Wood resins of the dipterocarp timber trees contain a variety of terpenoids (Diaz et al. 1966; Bisset et al. 1971). The dipterocarps with sesquiterpenes exhibit greater degree of defense against insects (Messer et al. 1990). The crude resin of *Dipterocarpus kerrii*, containing four sesquiterpenoids closely related to α-gurjunene, is responsible for termiticidal activity against *Zootermopsis angusticollis* (Richardson et al. 1989). Richardson et al. (1991) isolated two uncharacterized sesquiterpenes (1 and 20), from *D. kerrii* resin. Sesquiterpene 20 was more effective against *Neotermes delbergiae* as compared to sesquiterpene 1. Chemical components demonstrating insecticidal properties were isolated and identified from crude resins of many *Dipterocarpus* species. The compounds, viz., alloaromadendrene, humulene, and caryophyllene, are most effective against Southeast Asian termites *Neotermes* sp. (Messer et al. 1990). Sen-Sarma (1963) and Sen-Sarma and Chatterjee (1968) found *Shorea robusta* highly resistant to *Heterotermes indicola* and *Microcerotermes beesoni*. Particle boards made from the wood of *Shorea* spp. exhibited natural protection from *Cryptotermes cynocephalus* (Moi 1980).

8.3.3 Plant Essential Oils

Plant-derived essential oils are mixtures of natural organic compounds responsible for plants' defense against general herbivores (Lima et al. 2013). Also, the essential oils derived from plants may be considered as the most efficient alternative in controlling insect pests like termites (Alavijeh et al. 2014). The active compounds of essential oils are highly volatile and of short persistence in the environment because of their low molecular weights (Isman 2006). Hence, these oil-based compounds appear environmentally safe and as a feasible alternative to the hazardous insecticides used in pest control (Lima et al. 2010). Various oils from plants such as clove, peppermint, etc. are used by pest control operators against cockroaches, ants, and termites (Isman et al. 2011). Bultman et al. (1979) tested 42 tropical African woods and suggested that insecticidal and termiticidal activities of essential oils may be due to the volatile compounds they contain (Bultman et al. 1979). Pandey et al. (2012) reported a strong termiticidal activity of essential oils extracted from lemongrass (*Cymbopogon citratus*), eucalyptus (*Eucalyptus globulus*), clove (*Syzygium aromaticum*), oregano (*Origanum vulgare*), rosemary (*Rosmarinus officinalis*), cinnamon (*Cinnamomum verum*), and thyme (*Thymus vulgaris*) when tested against *Odontotermes assamensis*. Candlenut (*Aleurites moluccana*) oil, obtained by mechanical pressing of the nut from the kukui plant, was used to treat southern yellow pine (*Pinus* sp.) wood against *Coptotermes formosanus* attacks, with an excellent feeding-deterrent effect (Nakayama and Osbrink 2010). Himmi et al. (2013) applied defatted neem oil (DNO) formulation against *C. gestroi* and reported it as superior to the azadirachtin fraction (91% purity). Lima et al. (2013) tested toxicity of essential oils from *Corymbia citriodora*, *Croton sonderianus*, *Cymbopogon martini*, *Lippia alba*, *L. gracilis*, *L. sidoides*, and *Pogostemon cablin* against *Nasutitermes corniger*. All essential oils were noticed relatively toxic against workers rather than soldiers. The oils from *P. cablin* and *L. sidoides* were up to 25 times more toxic than that from *C. sonderianus*.

Scheffrahn et al. (1988) found ferruginol, manool, and nezukol, isolated from bald cypress *Taxodium distichum* L. wood, as antifeedant against *C. formosanus.* The oil extracted from marigold (*T. erecta*) and sweet orange *Citrus sinensis* proved to be an excellent repellent against *O. obesus*. The marigold oil exhibited maximum repellency, followed by sweet orange oil (Verma et al. 2016). Nagnan and Clement (1990) also studied the commercially available geranyllinalool for toxicity against termites. Carter et al. (1978) and Ikeda et al. (1978) isolated the essential oil components, viz., chamaecynone, an acetylenic terpenoid from false cypress *Chamaecyparis pisifera*; 7-methyljuglone, a naphthoquinone from American persimmon *Diospyros virginiana*; and torreyal from Japanese kaya, *Torreya nucifera*, and successfully tested their toxicity against termites. Adams (1991) discovered the repellent activity of essential oils of cedar wood, *Litsea cubeba*, and *Cinnamomum* sp. against termites, later reconfirmed by Lin and Yin (1995). The terpenoids of essential oils, viz., cedrol, citral, citronellal, eugenol, ferruginol, geraniol, limonene, manool, nezukol, and piperitone, are the repelling agents against subterranean termites (Sharma et al. 1994; Cornelius et al. 1997). Zhu et al. (2001b) found nootkatone (sesquiterpene) and other terpenoids in vetiver oil as highly efficient repellents and toxicants against subterranean termites.

Elango et al. (2012) investigated efficacy of solvent extracts of eight medicinal plants including *T. erecta* against the subterranean termite *C. formosanus*. All the crude extracts showed anti-termite activity in a dose-dependent manner and exhibited significant activity after 24 and 48 h of exposure. Data suggested they were a novel, safer, and renewable source of natural wood preservatives and termiticides. A field study was conducted by Aschalew et al. (2008) to evaluate the efficacy of 11 pesticidal plants against *Microtermes adschaggae* on hot pepper crops. They recorded lower percentages of damaged plants, higher stand counts at harvest, and higher amounts of dry pod yields with *T. minuta*. Similar results were obtained by Ahmed and Abraham (2014) on hot pepper. Aschalew et al. (2005) also reported that *Croton macrostachyus* and *T. minuta* have repellent properties against termites. Raina et al. (2007) used citrus peel and orange oil extract to control *C. formosanus*. They reported that d-limonene (92% constituent of orange oil extract) was responsible for termite mortality. Acda (2009) reported antifeedant, anti-tunneling, repellent, and termiticidal activities of *J. curcas* oil against *C. vastator*. Ede and Demissie (2013) obtained 100% termite mortality with *Jatropha* seed oil in 48 h against *Odontotermes obesus*. Singh and Kumar (2008) tested the leaf, root, and bark of *J. curcas* and oils of *T. erecta* and *Citrus sinensis* against *O. obesus* and *Microcerotermes beesoni* that showed significant losses in termite body weights.

8.4 Plant Extracts and Termite Gut Microbes

Apart from affecting the life and development of termites, some plant compounds are able to disrupt the activity of their gut microbes. However, studies of this kind are relatively rare. Soil treated with seeds of *Withania somnifera*, *Croton tiglium*, and *Hygrophila auriculata* disrupted the bacterial activities in the gut of *Microtermes obesi*. Seed extracts of *W. somnifera* and *H. auriculata* were noticed as highly toxic in a 6-day period. The areas of tunneling and the number of bacterial colonies were also reduced at 100% concentration of *W. somnifera* and *H. auriculata* (Ahmed et al. 2006). Three species of flagellated protists (*Spirotrichonympha leidyi*, *Holomastigotoides hartmanni*, and *Pseudotrichonympha grassii*) inhabit the hindgut of Formosan subterranean termites (Ohkuma et al. 2000). Doolittle et al. (2007) investigated the ability of three natural products (neem extract, capsaicin, and gleditschia) to reduce their numbers together with other spirochaetes. They noticed that neem extract significantly reduced the population of *P. grassi* and spirochaetes, with most potent effects at 1 ppm concentration, causing 100% termite mortality.

8.5 Conclusion

The list of plants with pesticidal traits appears long enough, but active or principle compound responsible for their effects is just being uncovered. Most studies are confined to grinding plant parts and using them as hexane, ethanol, or water extracts. More detailed plant analyses about compounds characterizing oils extracted from wood, seeds, and bark and crude chemicals extracted from leaves, flowers, fruits, seeds, barks, stem, and root are needed. Finally, sustainable exploitation of these natural products requires the production of more experimental data on their selectivity and/or target ranges, as most bioassays involving botanical insecticides have been only conducted thus far against a low number of termite species.

References

Acda, M. N. (2009). Toxicity, tunneling and feeding behavior of the termite, *Coptotermes vastator*, in sand treated with oil of the physic nut, *Jatropha curcas*. *Journal of Insect Science, 9*, 1–8.

Adams, R. P. (1991). Cedar wood oil-analysis and properties. *Modern Method of Plant Analysis, 12*, 159–173.

Adams, R. P., McDaniel, C. A., & Carter, F. L. (1988). Termiticidal activities in the heartwood, bark/sapwood and leaves of *Juniperus* species from the United States. *Biochemical Systematics and Ecology, 16*, 453–456.

Addisu, S., Mohamed, D., & Waktole, S. (2014). Efficacy of botanical extracts against termites, *Macrotermes* spp., (Isoptera: Termitidae) under laboratory conditions. *International Journal of Agricultural Research, 9*, 60–73.

Adedeji, G. A., Ogunsanwo, O. Y., & Elufioye TO. (2017). Quantifications of phytochemicals and biocide actions of *Lawsonia inermis* linn. extracts against wood termites and fungi. *International Biodeterioration and Biodegradation, 116*, 155–162.

Ahmed, I., & Abraham, T. (2014). Studies on the effects of some potential botanicals against termite damage on hot pepper (Marakofana) at Mendi, West Wellega, Ethiopia. *International Journal of Innovative and Applied Research, 2*, 29–34.

Ahmed, S., Riaz, M. A., & Shahid, M. (2006). Response of *Microtermes obesi* (Isoptera: Termitidae) and its gut bacteria towards some plant extracts. *Journal of Food, Agriculture and Environment, 4*, 317–320.

Alavijeh, E. S., Habibpour, B., Moharramipour, S., & Rasekh, A. (2014). Bioactivity of *Eucalyptus camaldulensis* essential oil against *Microcerotermes diversus* (Isoptera: Termitidae). *Journal of Crop Protection, 3*, 1–11.

Allen, T. C., Dicke, R. J., & Harris, H. H. (1944). Sabadilla, *Schoenocaulon* spp., with reference to its toxicity to houseflies. *Journal of Economic Entomology, 37*, 400–408.

Alshehry, A. Z., Zaitoun, A. A., & Abo-Hassan, R. A. (2014). Insecticidal activities of some plant extracts against subterranean termites, *Psammotermes hybostoma* (Desneux) (Isoptera: Rhinotermitidae). *International Journal of Agricultural Science, 4*, 257–260.

Ambrose, A. M., & Harvey, B. H. (1936). Toxicological study of *Derris*. *Industrial and Engineering Chemistry, 28*, 815–821.

Arango, R. A., Green, F., III, Hintz, K., Lebow, P. K., & Miller, R. B. (2006). Natural durability of tropical and native wood against termite damage by *Reticulitermes flavipes* (Kollar). *International Biodeterioration and Biodegradation, 57*, 146–150.

Arihara, S., Umeyama, A., Bando, S., Imoto, S., Ono, M., & Yoshikawa, K. (2004). Three new sesquiterpenes from the black heartwood of *Cryptomeria japonica*. *Chemical & Pharmaceutical Bulletin, 52*, 463–465.

Aschalew, S., Diriba, G., & Demisse, A. (2005). *Termite in Mana-Sibu district of Oromiya, Special Research Report*. Addis Ababa: Ethiopian Agricultural Research Organization.

Aschalew, S., Ahimad, I., & Tadele, T. (2008). Management of termite (*Microtermes adschaggae*) on hot pepper using powdered leaves and seeds of some plant species at Bako, Western Ethiopia. *East African Jorunal of Sciences, 2*, 41–44.

Barton, D. H. R., & Meth-Cohn, O. (1999). *Comprehensive natural products chemistry* (Vol. 1). Oxford: Pergamon.

Birkinshaw, C. R., & Colquhoun, I. C. (1998). Pollination of *Ravenala madagascariensis* and *Parkia madagascariensis* by *Eulemur macaco* in Madagascar. *Folia Primatologica, 69*, 252.

Bisset, N. G., Chavanel, V., Lantz, J. P., & Wolff, R. E. (1971). *Constituants sesquiterpeniques* et triterpeniques des rdsines du gem'e shorea. *Phytochemistry, 10*, 2451–2463.

Bloomquist, J. R. (1996). Ion channels as targets for insecticides. *Annual Review of Entomology, 41*, 163–190.

Boué, S. M., & Raina, A. K. (2003). Effects of plant flavonoids on fecundity, survival, and feeding of the Formosan subterranean termite. *Journal of Chemical Ecology, 29*, 2575–2584.

Breuer, M., & Schmidt, G. H. (1995). Influence of a short period treatment with *Melia azedarach* extract on food intake and growth of the larvae of *Spodoptera frugiperda* (Lepidoptera; Noctuidae). *Journal of Plant Diseases and Protection, 102*, 633–654.

Bultman, J. D., Beal, R. H., & Ampong, F. F. K. (1979). Natural resistance of some tropical African woods to *Coptotermes formosanus* Shiraki. *Forest Products Journal, 29*, 46–51.

Carter, F. L., Garlo, A. M., & Stanely, J. B. (1978). Termiticidal components of wood extracts: 7-methyljuglone from *Diospyros virginiana*. *Journal of Agricultural and Food Chemistry, 26*, 869–873.

Chang, S. T., Cheng, S. S., & Wang, S. Y. (2001). Antitermitic activity of essential oils and components from Taiwania (*Taiwania cryptomerioides*). *Journal of Chemical Ecology, 27*, 717–724.

Chen, K., Ohmura, W., Doi, S., & Aoyama, M. (2004). Termite feeding deterrent from Japanese larchwood. *Bioresource Technology, 95*, 129–134.

Cheng, S. S., Chang, H. T., CL, W., & Chang, S. T. (2007). Anti-termitic activities of essential oils from coniferous trees against *Coptotermes formosanus*. *Bioresource Technology, 98*, 456–459.

Cornelius, M. L., Grace, J. K., & Yates, J. R. (1997). Toxicity of monoterpenoids and other natural products to the Formosan subterranean termite (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 87*, 705–708.

Cynthia, O. C., Precious, O., & Lynda, O. S. (2016). The toxicity and repellency of some plant extracts applied as individual and mixed extracts against termites (*Macrotermes bellicosus*). *Journal of Entomology and Zoology Studies, 4*, 406–418.

Diaz, M. A., Ourisson, G., & Bisset, N. G. (1966). Etudes chimio-taxonomiques dans la famille des dipterocarpacaes–I. *Phytochemistry, 5*, 855–863.

Ding, W., & Hu, X. P. (2010). Antitermitic effect of the *Lantana camara* plant on subterranean termites (Isoptera: Rhinotermitidae). *Insect Science, 17*, 427–433.

Doolittle, M., Raina, A., Lax, A., & Boopathy, R. (2007). Effect of natural products on gut microbes in Formosan subterranean termite, *Coptotermes formosanus*. *International Biodeterioration and Biodegradation, 59*, 69–71.

Duke, S. O., Cantrell, C. L., Meepagala, K. M., Wedge, D. E., Tabanca, N., & Schrader, K. K. (2010). Natural toxins for use in pest management. *Toxins (Basel), 2*, 1943–1962.

Ede, A. G., & Demissie, A. G. (2013). Comparative bio-activity guided characterization of biocide from *Jatropha curcas* and *Ricinus communis* L seeds oil. *Journal of Pharmacognosy and Phytochemistry, 2*, 176–181.

Elango, G., Rahuman, A. A., Kamaraj, C., Bagavan, A., Zahir, A. A., Santhoshkumar, T., Marimuthu, S., Velayutham, K., Jayaseelan, C., Vishnu Kirthi, A., & Rajakumar, G. (2012). Efficacy of medicinal plant extracts against Formosan subterranean termite, *Coptotermes formosanus*. *Industrial Crops and Products, 36*, 524–530.

Escoubas, P., Lajide, L., & Mizutani, J. (1995). Termite antifeedant activity in *Aframomum melegueta*. *Phytochemistry, 40*, 1097–1099.

Fang, N., & Casida, J. (1999). Cubé resin insecticide: Identification and biological activity of 29 rotenoid constituents. *Journal of Agricultural and Food Chemistry, 47*, 2130–2136.

Fimrite, P. (2007). Lake poisoning seems to have worked to kill invasive pike. San Francisco Chronicle. Published on October 02, 2007.

Fokialakis, N., Osbrink, W. L. A., Mamonov, L. K., Gemejieva, N. G., Mims, A. B., Skaltsounis, A. L., Lax, A. R., & Cantrell, C. L. (2006). Antifeedant and toxicity effects of thiophenes from four *Echinops* species against the Formosan subterranean termite, *Coptotermes formosanus*. *Pest Management Science, 62*, 832–838.

Gaetano, S., & Andrew, M. (2015). Essential roles of intracellular calcium release channels in muscle, brain, metabolism, and aging. *Current Molecular Pharmacology, 8*, 206–222.

Ganapaty, S., Thomas, P. S., Fotso, S., & Laatsch, H. (2004). Antitermitic quinines from *Diospyros sylvatica*. *Phytochemistry, 65*, 1265–1271.

Gemmill-Herren, B. (2016). *Pollination services to agriculture: Sustaining and enhancing a key ecosystem service. Food and Agriculture organization of the United Nations*. New York: Routledge. 292pp.

Grace, J. K., & Yates, J. R. (1992). Behavioural effects of a neem insecticide on *Coptotermes formosanus* (Isoptera: Rhinotermitidae). *Tropical Pest Management, 38*, 176–180.

Hayes, W. J. (1982). Pesticides derived from plants and other organisms. In W. J. Hayes (Ed.), *Pesticides studied in man* (pp. 75–111). Baltimore: Williams and Wilkins.

Hayes, W. J. (1991). *Handbook on pesticides* (Vol. 1). Jamestown Road: Academic Press. 1174 pp.

Himmi, S. K., Tarmadi, D., Ismayati, M., & Yusuf, S. (2013). Bioefficacy performance of neem-based formulation on wood protection and soil barrier against subterranean termite, *Coptotermes gestroi* Wasmann (Isoptera: Rhinotermitidae). *Procedia Environmental Sciences, 17*, 135–141.

Hiremath, I. G., Young Joon, A., Kim-Soon, I., & Kim, S. I. (1997). Insecticidal activity of Indian plant extracts against *Nilaparvata lugens* (Homoptera: Delphacidae). *Applied Entomology and Zoology, 32*, 159–166.

Ikeda, T., Takahashi, M., & Nishimoto, K. (1978). Antitermitic components of Kaya wood, *Torreya nucifera* Sieb. Et Zucc. *MokuzaiGakkaishi, 24*, 262–266.

Isman, M. B. (2006). Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. *Annual Review of Entomology, 51*, 45–66.

Isman, M. B., Miresmailli, S., & Machial, C. (2011). Commercial opportunities for pesticides based on plant essential oils in agriculture, industry and consumer products. *Phytochemistry Reviews, 10*, 197–204.

Khan, Z. R., & Saxena, R. C. (1986). Effect of steam distillate extracts of resistant and susceptible rice cultivars on behavior of *Sogatella furcifera* (Homoptera: Delphacidae). *Journal of Economic Entomology, 79*, 928–935.

Kinyanjui, T., Gitu, P. M., & Kamau, G. N. (2000). Potential antitermite compounds from *Juniperus procera* extracts. *Chemosphere, 41*, 1071–1074.

Lajide, L., Escoubas, P., & Mizutani, J. (1995). Termite antifeedant activity in *Xylopia aethiopica*. *Phytochemistry, 40*, 1105–1112.

Lima, R. K., Cardoso, M. G., Moraes, J. C., Andrade, M. A., Melo, B. A., & Rodrigues, V. G. (2010). Caracterização química e atividade inseticida do óleo essencial de *Ageratum conyzoides* L. sobre a lagarta-do-cartucho *Spodoptera frugiperda* (Smith, 1797) (Lepidoptera: Noctuidae). *Bioscience, 26*, 1–5.

Lima, J. K. A., Albuquerque, E. L. D., Santos, A. C. C., Oliveira, A. P., Araújo, A. P. A., Blank, A. F., Arrigoni-Blank, M. F., Alves, P. B., & Santos, D. A. (2013). Biotoxicity of some plant essential oils against the termite *Nasutitermes corniger* (Isoptera: Termitidae). *Industrial Crops and Products, 47*, 246–251.

Lin, T. S., & Yin, H. W. (1995). The effects of *Cinnamomum* spp. oils on the control of the termite *Coptotermes formosanus* Shiraki. *Taiwan Forestry Research Institute New Series, 10*, 459–464.

Liu, S. Y., Sporer, F., Wink, M., Jouurdane, J., Henning, R., Li, Y. L., & Ruppel, A. (1997). Anthraquinones in *Rheum palmantum* and *Rumex dentatus* (Polygonaceae) and phorbol esters in *Jatropha curcas* (Euphorbiaceae) with molluscicidal activity against the *Schistosome* vector snails *Oncomelania*, *Biomphalaria* and *Bulinus*. *Tropical Medicine & International Health, 2*, 179–188.

Matsumura, F. (1975). *Toxicology of insecticides Fumio Matsumura*. Lower John Street: Plenium Press. 493pp.

McDaniel, C. A. (1992). Major antitermitic components of the heartwood of southern catalpa. *Journal of Chemical Ecology, 18*, 359–369.

Meepagala, K. M., Kuhajek, J. M., Sturtz, G., Wedge, D. E., & Vulgarone, B. (2003). The antifungal constituent in the steam-distilled fraction of *Artemisia douglasiana*. *Journal of Chemical Ecology, 29*, 1771–1780.

Meepagala, K. M., Osbrink, W., Sturtz, G., & Lax, A. (2006). Plant-derived natural products exhibiting activity against Formosan subterranean termites (*Coptotermes formosanus*). *Pest Management Science, 62*, 565–570.

Messer, A., McCormick, K., Sunjaya Hagedorn, H. H., Tumbel, F., & Meinwald, J. (1990). Defensive role of tropical tree resins: Antitermitic sesquiterpenes from Southeast Asian dipterocarpaceae. *Journal of Chemical Ecology, 16*, 3333–3352.

Metcalf RL (2000) Insect control: Ullmann's Encyclopedia of Industrial Chemistry. doi:https://doi.org/10.1002/14356007.a14_263.

Metcalf, R. L. (2007). *Insect control: Ullmann's Encyclopedia of Industrial Chemistry* (7th ed.). New York: Wiley. 9 pp.

Moi, L. C. (1980). A new laboratory method for testing the resistance of particle boards to the drywood termite *Cryptotermes cynocephalus*. *Malaysian Forest, 43*, 350–355.

Muthukrishnan, J., & Pushpalatha, E. (2001). Effects of plant extracts on fecundity and fertility of mosquitoes. *Journal of Applied Entomology, 125*, 31–35.

Nagnan, P., & Clement, J. L. (1990). Terpenes from the maritime pine *Pinus pinaster*: Toxins for subterranean termites of the genus *Reticulitermes* (Isoptera: Rhinotermitidae). *Biochemical Systematics and Ecology, 18*, 13–16.

Nakayama, F. S., & Osbrink, W. L. (2010). Evaluation of kukui oil (*Aleurites moluccana*) for controlling termites. *Industrial Crops and Products, 31*, 312–315.

Nellis, D. N. (1994). *Seashore plants of South Florida and the Caribbean* (p. 160). Sarasota: Pineapple Press.

Nwosu, M. O., & Okafor, J. I. (1995). Preliminary studies of the antifungal activities of some medicinal plants against *Basidiobolus* and some other pathogenic fungi. *Mycoses, 38*, 191–195.

Ohkuma, M., Ohtoko, K., Iida, T., Tokura, M., Moriya, S., Usami, R., Horikoshi, K., & Kudo, T. (2000). Phylogenetic identification of hypermastigotes, *Pseudotrichonympha*, *Spirotrichonympha* and *Holomastigotoides*, and parabasalian symbionts in the hindgut of termites. *The Journal of Eukaryotic Microbiology, 47*, 249–259.

Ohmura, W., Doi, S., Aoyama, M., & Ohara, S. (2000). Antifeedant activity of flavonoids and related compounds against the subterranean termite *Coptotermes formosanus* Shiraki. *Journal of Wood Science, 46*, 149–153.

Pandey, A., Chattopadhyay, P., Banerjee, S., Pakshirajan, K., & Singh, L. (2012). Antitermitic activity of plant essential oils and their major constituents against termite *Odontotermes assamensis* Holmgren (Isoptera: Termitidae) of North East India. *International Biodeterioration and Biodegradation, 75*, 63–67.

Park, I. K., & Shin, S. C. (2005). Fumigant activity of plant essential oils and components from garlic (*Allium sativum*) and clove bud (*Eugenia caryophyllata*) oils against the Japanese termite (*Reticulitermes speratus* Kolbe). *Journal of Agricultural and Food Chemistry, 53*, 4388–4392.

Raina, A., Bland, J., Doolittle, M., Lax, A., Boopathy, R., & Folkins, M. (2007). Effect of orange oil extract on the Formosan subterranean termite (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 100*, 880–885.

Reyes-chilpa, R., Viveros-rodriguez, L. N., Gomez-garibay, Z. F., & Alavez-solano, D. (1995). Antitermitic activity of lonchocarpus castilloi flavonoids and heartwood extracts. *Journal of Chemical Ecology, 21*, 455–463.

Richardson, D. P., Messer, A. C., Greenberg, S., Hagedorn, H. H., & Meinwald, J. (1989). Defensive sesquiterpenoids from a dipterocarp (Dipterocarpus kerrii). *Journal of Chemical Ecology, 15*, 731–747.

Richardson, D. P., Messer, A. C., Newton, B. A., & Lindeman, N. I. (1991). Identification and preparation of antiinsectan dienols from *Dipterocarpus kerrii* tree resins. *Journal of Chemical Ecology, 17*, 663–685.

Rodgman, A., & Perfetti, T. A. (2009). *The chemical components of tobacco and tobacco smoke* (p. 1840). Boca Raton: CRC Press.

Roskov, Y., Kunze, T., Orrell, T., Abucay, L., Paglinawan, L., Culham, A., Bailly, N., Kirk, P., Bourgoin, T., Baillargeon, G., Decock, W., De Wever, A., & Didžiulis, V. (2014) .Species 2000 and ITIS catalogue of life: 2014 annual checklist. Species 2000: Reading, UK. Retrieved 20 March 2017.

Roszaini, K., Salmiah, U., & MohdDahlan, J. (2006). Natural resistance of timbers to attack: Laboratory evaluation of the resistance of Malaysian wood against *Coptotermes curvignathus* (Holmgren). *Journal of the Institute of Wood Science, 17*, 178–182.

Sakasegawa, M., Hori, K., & K Yatagi, K. (2003). Composition and anti-termite activities of essential oils and *Melaleuca* species. *Journal of Wood Science, 49*, 181–187.

Sbeghen, A. C., Dalfovov, V., Serafini, L. A., & De-Barros, N. M. (2002). Repellence and toxicity of basil, citronella, ho-sho and rosemary oils for the control of the termite, *Cryptotermes brevis* (Isoptera: Kalotermitidae). *Sociobiology, 40*, 585–594.

Scheffrahn, R. H., & Rust, M. K. (1983). Drywood termite feeding deterrents in sugar pine and antitermitic activity of related compounds. *Journal of Chemical Ecology, 9*, 39–55.

Scheffrahn, R. H., Hsu, R. C., NY, S., Huffman, J. B., Midland, S. L., & Sims, J. J. (1988). Allelochemical resistance of bald cypress, *Taxodium distichum*, heartwood to the subterranean termite, *Coptotermes formosanus*. *Journal of Chemical Ecology, 14*, 765–776.

Schulte, A., & Schone, D. (1996). *Dipterocarp forest ecosystems: towards sustainable management*. Ltd, Ferrar Road: World Scientific Publishing co. Pvt. 949 pp.

Sen-Sarma, P. K. (1963). Studies on the natural resistance of timbers to termites. I. Observations on the longevity of the test termite *Heterotermes indicola* Wasm in the saw dust from forty common Indian timbers. *Indian Forest Bulletin (N.S.) Entomology, 220*, 1–3.

Sen-Sarma, P. K., & Chatterjee, P. N. (1968). Studies on the natural resistance of timbers to termite attack. V. Laboratory evaluation of the resistance of Indian wood to *Microcerotermes beesoni* Snyder (Termitidae, Amitermitinae). *Indian Forest, 94*, 694–704.

Sharma, R. N., Tungikar, V. B., Pawar, P. V., & Vartak, P. H. (1994). Vapour toxicity and repellency of some oils and terpenoids to the termite, *Odontoterme brunneus*. *Insect Science Application, 15*, 495–498.

Sharma, R. N., Tare, V., & Pawan, P. (1999). Toxic action of some plant extracts against selected insect pest and vectors. *Pestology, 23*, 30–37.

Shi, J., Li, Z., Izumi, M., Baba, N., & Nakajima, S. (2008). Termiticidal activity of diterpenes from the roots of *Euphorbia kansui*. *Zeitschrift für Naturforschung. Section C, 63*, 51–58.

Shiberu, T., Ashagre, H., & Negeri, M. (2013). Laboratory evaluation of different botanicals for the control of termite, *Microterms* spp (Isoptera: Termitidae). *Open Access Scientific Reports, 2*, 1–3.

Silva, A. C., Monteiro, M. B. B., Brazolin, S., Lopez, G. A. C., Richter, A., & Braga, M. R. (2007). Biodeterioration of brazilwood *Caesalpinia echinata* lam. (Leguminosae: Caesalpinioideae) by rot fungi and termites. *International Biodeterioration and Biodegradation, 60*, 285–292.

Singh, N., & Kumar, S. (2008). Anti termite activity of *Jatropha curcas* Linn. Biochemical. *Journal of Applied Sciences and Environmental Management, 12*, 67–69.

Singh, G., Singh, O. P., Prasad, Y. R., De-Lampasona, M. P., & Catalan, C. (2004). Chemical and insecticidal investigations in leaf oil of *Coleus amboinicus* Lour. *Flavour and Fragrance Journal, 17*, 440–442.

Solsoloy, A. D., & Solsoloy, T. S. (1997). Pesticidal efficacy of the formulated physic nut, *Jatropha curcas* oil on pests of selected field crops. *The Philippine Journal of Science, 124*, 59–74.

Stenersen, J. (2004). *Chemical pesticides: Mode of action and toxicology* (p. 265). Boca Raton: CRC Press/LLC.

Tellez, M., Estell, R., Fredrickson, E., Powell, J., Wedge, D., Schrader, K., & Kobaisy, M. (2001). Extracts of *Flourensia cernua* (l): volatile constituents and antifungal, antialgal, and antitermite bioactivities. *Journal of Chemical Ecology, 27*, 11.

Thambidurai, S. (2002). Termite control using natural products. *Indigenous Agriculture News, 1* 9.

Ujváry, I. (1999). Nicotine and other insecticidal alkaloids. In I. Yamamoto & J. Casida (Eds.), *Nicotinoid insecticides and the nicotinic acetylcholine receptor* (pp. 29–69). Tokyo: Springer-Verlag.

Verma, R. K., & Verma, S. K. (2006). Phytochemical and termiticidal study of *Lantana camara* Var. *aculeata* leaves. *Fitotrapia, 77*, 466–468.

Verma, M., Sharma, S., & Parshad, R. (2009). Biological alternatives for termite control. *International Biodeterioration and Biodegradation, 63*, 959–972.

Verma, M., Pradhan, S., Sharma, S., Naik, S. N., & Prasad, R. (2011). Efficacy of karanjin and phorbol ester fraction against termites (*Odontotermes obesus*). *International Biodeterioration and Biodegradation, 65*, 877–882.

Verma, S., Verma, M., Sharma, S., & Malik, A. (2013). Determination of phytocomponents by GC-MS analysis of *Jatropha curcas* root and its termiticidal activity. *Journal of Ecology and Environmental Sciences, 39*, 159–169.

Verma, S., Sharma, S., & Malik, A. (2016). Termiticidal and repellency efficacy of botanicals against *Odontotermes obesus*. *International Journal of Research in Biosciences, 5*, 52–59.

Watanabe, Y., Mihara, R., Mitsunaga, T., & Yoshimura, T. (2005). Termite repellent sesquiterpenoids from *Callitris glaucophylla* heartwood. *Journal of Wood Science, 51*, 514–519.

Weinzierl, R., & Henn, T. (1994). Botanical insecticides and insecticidal soaps. In A. R. Leslie (Ed.), *Handbook of integrated pest management for turf and ornamentals* (p. 627). Washington, DC: US Environmental Protection agency.

Wheeler, D. A., & Isman, M. (2001). Antifeedant and toxic activity off *Trichilia Americana* extract against the larvae of *Spodoptera litura*. *Entomologia Experimentalis et Applicata, 98*, 9–16.

Yatagai, M., Nishimoto, M., Ohira, K. H. T., & Shibata, A. (2002). Termiticidal activity of wood vinegar, its components and their homologues. *Journal of Wood Science, 48*, 338–342.

Yuan, Z., & Hu, X. P. (2012). Repellent, antifeedant and toxic activities of *Lantana camara* leaf extract against *Reticulitermes flavipes* (Isoptera: Rhinotermitidae). *Journal of Economic Entomology, 105*, 2115–2121.

Zhao, B., Grant, G. G., Langevin, D., & MacDonald, L. (1998). Deterring and inhibiting effects of quinolizidine alkaloids on the spruce budworm (Lepidoptera: Tortricidae) oviposition. *Environmental Entomology, 27*, 984–992.

Zhu, B. C. R., Henderson, G., Chen, F., Fei, H., & Laine, R. A. (2001a). Evaluation of vetiver oil and seven insect-active essential oils against the Formosan subterranean termite. *Journal of Chemical Ecology, 27*, 1617–1625.

Zhu, B. C. R., Henderson, G., Chen, F., Maistrello, L., & Laine, R. A. (2001b). Nootkatone is a repellent for Formosan subterranean termite (*Coptotermes formosanus*). *Journal of Chemical Ecology, 27*, 523–531.