Insecticides Derived from Natural Products: Diversity and Potential Applications

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Abstract

Termites are one among the pests that pose serious threat to live plants as well as cause harm to plant-based products. The urban environment and agriculture are most threatened by them as they are the most challenging pests. The annual and perennial crops face significant losses, and in the semiarid and subhumid tropics around the globe, wooden components are also destroyed by them. Among the successful methods, chemical control is of great importance, but the side effects of such chemicals lead to the production of serious health issues, especially respiratory problems, if present in the environment. Plant-based natural products are promising replacements for these chemical pesticides. Botanicals used for pest remediation especially the one derived from essential oils are target-specific. A safe environment and food free from residues are attained by their use as they are required in little amount and also possess a quick decomposition. The mode of action of these herbal pesticides may vary. Some may act as direct toxicant, while others might act upon as antifeedant, repellent or behavior modifiers, morphogenetic agents, or phagostimulants. The current chapter aims to discuss the different aspects of various natural herbal plants parts and their potential application in the management of pest particularly termites. A sneak peek to their mechanism of action will also be taken into consideration. Essential oil-bearing plants being abundantly grown for various purposes become a possible herbal alternate to chemical pesticides.

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6.1 Introduction

The substances that function as a pest-controlling agent are commonly known as insecticides or pesticides. They are very beneficial as they provide the protection to crops, food material preservation, and the restriction of diseases caused by the vectors. They are also used in different fields like agriculture, forestry, medicine, aquaculture, food industry, processing, transportation, and storage of wood and other biological products. Gross use of insecticide causes damage to public health and ecosystem. Indiscriminate use of pesticides induced resistance, resurgence, and residues in harvested produce and adverse impact on other organisms in the ecosystem including human beings. This resulted in the need for the development of ecologically safer chemicals with target specificity. The use of chemical pesticides is manifold in developing countries as in developed countries. In recent years, the disadvantages of the chemicals use in agriculture have been noticed. Therefore, a search for various efforts to find out the alternatives for chemical pesticides has been started throughout the world. The use of eco-friendly technologies for the production as well as protection of crops is necessary for sustainable agriculture. The renewed interest in environment and eco-friendly technologies has widened the scope for the use of biopesticides or natural insecticide, including plant derivatives and biocontrol agents. The ultimate aim is to get pesticide residue-free food for human consumption within the country and for export purposes.

In the agriculture and urban environment, termites are one of the most troublesome pests. Globally, approximately 2800 termite species are identified. In India, out of 300 species, 35 are known for their damaging effects (Lewis 1997). The highly susceptible crops of various regions of India have been recorded for the severe losses (Rajagopal 2002). The preventive measure that is commonly used to minimize the termite infestation is achieved by the means of chemical control. Across the world, various termiticides are known under different brand names such as spinosad, disodium octaborate tetrahydrate (DOT), calcium arsenate, chlorpyriphos, etc. Though termite protection by chemical means is a proven method, their extensive application is hazardous. For the termite control, researchers are seeking for new ways. Plant-derived natural products/botanicals possess low mammalian toxicity, no risk of developing pest resistance, less hazard to non-target organisms, and are less expensive and easily available. Biomass of certain plants possesses the insecticidal activity that can be exploited for the controlling termites.

6.2 Termite Biology

Termites belong to the group *Isoptera* (Meyer 2005). The large colonies of termites depend either on wood entirely or on the entire or somewhat decomposed woody tissues. Termite colony basically comprises reproductively active termites, soldiers, sterile workers, and the young ones. The active reproductive termites are categorized into two main types: primary and supplementary. The king and queen (primary reproductive) are adults with pigmented and fully developed wings. They are responsible for production of egg and distribution by the means of colonizing flights. About 3000 eggs per day are laid down by the queen by the aid of an enlarged abdomen (Thompson 2000). The life span of the queen is approximately 25 years. The eggs are whitish-yellow colored, and after the incubation period of 50–60 days, they usually hatch. There is only one pair of primary reproductive in most of the colonies, but after their death replacement is usually carried out by the supplementary reproductive which are more pigmented and possess than workers. The absence of eyes and wings is generally found in sterile castes; the soldiers and workers are wingless and generally deficient in eyes (Myles 2005). Worker and soldier termites are 6 mm long and pale cream colored; the head is nearly half their body length with visible black jaws in the case of soldiers. The distinctive shelter tubes responsible mainly for damage are made by the workers and food collection for the members of the colony. In order to obtain certain secretions, they usually groom each other. The numbers of individuals in different castes are regulated by these secretions (Philip 2004). The maturation of workers takes around a year with a life span of 3–5 years. The maturation of soldiers occurs within a year and has 5 years of a life span (Myles 2005). In the month of April and May, winged reproductive (alates) appears in a mass nuptial flight. The first indication of termite infestation is shown by these flights (Philip 2004). The wings are shed by alates after a short period of flight. Nesting sites are searched by the females along with the males closely behind. The moist crevice with wooden materials is often selected by the pair for the formation of royal chamber and egg laying (Su and Scheffrahn 2000).

6.3 Termite Management

Termites are the most dominant social insects forming termitarium for large colonies. They mainly feed on wood or other cellulose-containing material as food source. It is a devastating pest of agricultural crops and forest. They are soft-bodied creatures, having pale cream complexion, with mouth parts used for biting and chewing to take cellulose as a food source; they belong to group of *Isopterans*. The termite colony consists of winged (king and queen) and wingless (soldiers, sterile workers, and immature individuals) reproductive forms. Pesticides are natural or synthetic agents which synthesize to kill or repel insects, weeds, rodents, fungi, and other organisms. United Nations Organization for Food and Agriculture (FAO) defines pesticides as a mixture of substances used for growing, destroying, and preventing any kind of pests, including vectors of human disease or animal disease. They are also used for controlling unwanted species of plants or animals that cause damage or are otherwise inquisitive in the production, processing, storage, or hampering transport and marketing facility. Agricultural products, wood and wood products, or animal feedstuffs or which may be administered to animals can be prevented from insects, arachnids, or other pests in or on their bodies (FAO Report 2018).

Although, termites have shown considerable contribution to most of the world's ecosystem diversity. Termites are of the most important species in recycling woody and other plant material. Their tunneling helps to aerate soils. Because of this activity, they improve soil composition and aeration fertility. Instead they turn to be a serious pest in urban ecosystem; they attack wooden dwellings and crops. Therefore, efficient methods are adopted to control them. Different control methods have been adopted and fundamentally accepted worldwide, and some of the novel methods are discussed further.

6.4 Physical Control Methods

There are several physical methods that can be used around the building's foundation to prevent the entry of termites; these can be classified into two classes: toxic and nontoxic. Toxic physical barrier: Chlorfenapyr is potent toxic chemical which shows delayed toxicity and is non-repellent and is frequently used for treatment of termite which is used in soil treatment before construction (Rust and Saran 2006).

Nontoxic physical barrier: It mainly includes a mechanical barrier which prevents termites to penetrate through them. Commonly used mechanical barriers are metal mesh or sheeting, sand or gravel aggregates, etc. Basaltic termite barrier (BTB) is made up of gravel, widely used in Hawaii before construction for preventing termite penetrance (Grace 1996). Many different forms of mechanical barriers such as nongraded stone products have become popular in some continents like Australia, Hawaii, Texas, and other parts of the USA in recent years. It includes solid steel sheets, stainless steel mesh, polymer sheets, and copper shields (Potter 2004; Baker 2005).

Australia developed and patented Termimesh®, a stainless steel wire mesh sized 0.66 × 0.45 mm which is a noncorrosive bendable steel mesh. It is planted within the walls of the foundations and in various field trials for effective prevention of termites (Lenz and Runko 1994; Grace 1996; Kard 1999). Various physical treatments too come under physical methods such as heating, freezing, electrical method, electromagnetic waves, and microwaves.

Heat treatment: In this method, termites are killed by using nylon tarps which are used to cover buildings, and then the temperature is raised to 45 °C (120 F) for a time of 35 min and at 50 °C (130 F) for 1 h (Myles 2005). *Cryptotermes brevis* has been controlled using this method, experiment performed by Woodrow and Grace (1998). Freezing treatment termites can be killed by low temperature by pumping liquid nitrogen (−20 °F) into the infected area.

Electrical treatment: Electro-Gun is used to give electric shock to the termite infected area of wooden block or board, having low current (~0.5 amps), high voltage (90,000 volts), and high frequency (60,000 cycles) (Myles 2005).

6.5 Chemical Methods

Control of termites by chemical methods is the most efficient and commonly used solution so far. Bifenthrin, chlorfenapyr, cypermethrin, fipronil, imidacloprid, permethrin spinosad, disodium octaborate tetrahydrate, calcium arsenate, and chlorpyriphos are the variety of termiticides with active constituents which are registered for termite control all over the world.

Bifenthrin, chlorpyrifos, endosulfan, imidacloprid, and lindane are some common insecticides which are at present being used for controlling termites in stored wood and also for crops (Su et al. 1999). Smith and Rust (1990) reported that cypermethrin, bifenthrin and permethrin, chlorpyrifos (≥50 ppm), fenvalerate (<100 ppm) and isofenphos, chlordane, bifenthrin, cypermethrin, and permethrin formulations are used to treat soil and are the most effective chemical insecticides. High concentrations of cypermethrin (100 ppm), imidacloprid (1000 ppm), and fenvalerate (500 ppm) were found to be very helpful against subterranean termites (Kuriachan and Gold 1998). *Trinervitermes trinervius*, *Odontotermes meathmani*, and *Amitermes lucifer* were observed to cause lesser damage in cotton, rice, maize, sorghum, and sugarcane crop with the application of insecticides, namely, chlorpyriphos, lindane, or thiamethoxam (Ahmed et al. 2006; Bhanot and Singal 2007). Chlorpyriphos was most effective among all the insecticides studied against subterranean termite in sugarcane crop. Wheat, barley, and gram have been standardized by seed treatment with chlorpyrifos, endosulfan, formothion, and monocrotophos (Bhanot et al. 1991a, b, 1995). Chromated copper arsenate is used to treat southern yellow pine and radiata pine for wood preservation from attack of Formosan subterranean termites, *Coptotermes formosanus* (Grace 1998).

Subterranean termites are controlled by applying soil termiticide injection. It is done by drilling the groundwork wall/slab and injecting the termiticide under wall and also into the soil which is in contact with the base. Chemical fumigation is one of the best methods for controlling dry-wood termite infestation. Chemical fumigants used in this method are sulfuryl fluoride, methyl bromide, and carbon dioxide. Firstly, tent is used to cover the whole building, and after that fumigant is pumped in the construction; then the tent is separated, and pumping fumigants is also stopped. Those materials are also removed which absorb chemicals and allow to be fumigated (Myles 2005).

Carbon dioxide (asphyxiant), methyl bromide, phosphine, and sulfuryl fluoride (metabolic poison) are active ingredients present in a variety of fumigants; among all most common fumigant used is methyl bromide. Methyl bromide is a highly toxic gas, marking the concerns which involve atmospheric ozone layer, having aroma in the domestic materials treated with this, and also the long ventilation time for fumigants makes it inadequate for use (UNEP Report 2000). Photo-immobilizing the bifenthrin-embedded chitosan on the wooden exterior is the eco-friendly method for preventing termite growth which has been given by Guan et al. (2011). They united the efficacy of bifenthrin against termites and used chitosan as a carrier to insert bifenthrin in photo-immobilization technique and gave ultraviolet treatment on the wooden surface for immobilization. Immobilized bifenthrin shows very high competence in opposition to termite at a dose of 2.5 mg/cm^2 which gives long-term stability and protection.

Biological resistant method has been studied against *Anacanthotermes vagans* termite. Copper- and zinc-salicylate were used to treat wood particles, and then it is exposed to termites. Minimum lightness was recorded in the specimen treated with copper-salicylate (4.7%), whereas maximum lightness was recorded in control (16.3%). The result established considerable defense of copper salicylate against termite. It showed that copper-salicylate can be used for prevention against *A. vagans* termite in industries (Bayatkashkoli et al. 2016).

The most effective method for controlling termite growth is chemical methods. However, their extreme use results in side effects which are toxic in nature, pesticide remaining in soil and water, and pest resistance having adverse effect on human and environment. Alternative methods can be used to substitute and lessen the use of chemical insecticides being practiced worldwide for termite management. Eco-friendly and new methods are being developed by the researchers to prevent termite growth. Some unusual methods for termite control are produced from natural products derived from plants, bacteria, nematodes, and some entomopathogenic fungi. Botanicals which are used as termiticides are discussed with other biological methods.

6.6 Diversity and Applications of Natural Insecticides for Termite Control

A number of efforts have been conceded toward the attainment of controlling insect growth with the help of biopesticides and green pesticides which means naturally occurring pesticides having partial or no harmful effect on the surroundings and non-targeted organisms including humans (Stevenson et al. 2017; Benelli 2018; Fig. 6.1).

6.6.1 Biological Control Strategies

Plants are used as latent alternatives to control insects as they comprise an immense supply of bioactive chemical components. More than 2000 plants belonging to 60 plant families are recognized to have insecticidal actions (Dev and Koul 1997). Insecticides, ecdysones, insect growth regulators (IGRs), juvenile hormones, anti-feedants, attractants, repellents, arrestants, etc., are present as bioactive chemicals, showing that plants can be an important substitute for chemical pesticides (Kannaiyan 1999). Natural products and biocontrol methods derived from plants show potential replacement to chemical control. Initiative for optional strategies to control termites was started in 1935, where citrollenellic acid was used to block cellulose blocks to check beside termites (Trikojus 1935). Different parts of plants as leaves, fruit, bark, root, flower, stem, resin etc., as well as their extracts, were tested

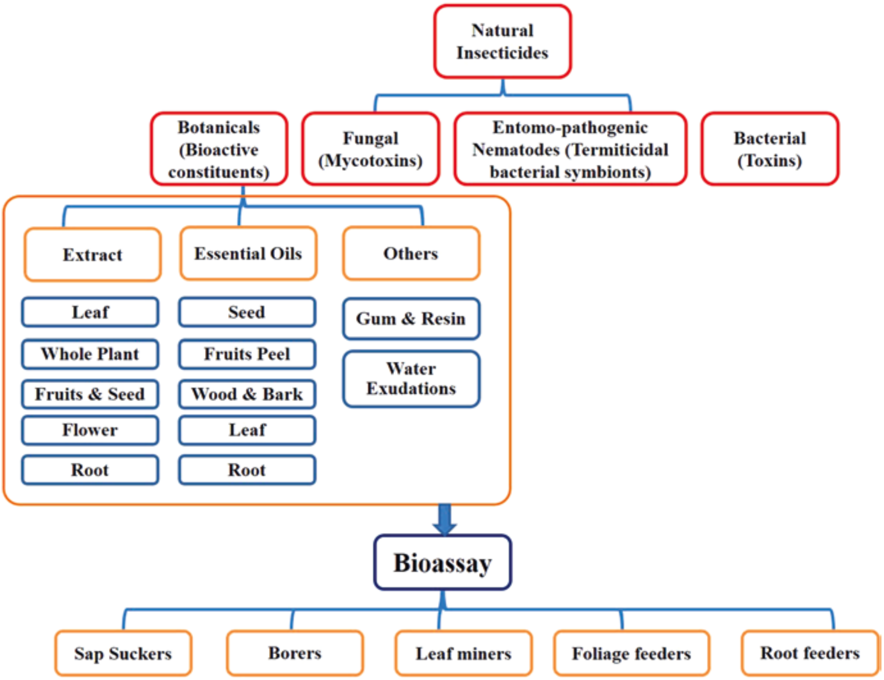

Fig. 6.1 Development of different natural insecticides for termite control and their bioassay

by many scientists worldwide to take advantage of their pest control competence. The botanicals used in this purpose have low cost and are locally present; they are highly effective in termite control. Laboratory and field studies have renowned studies showing broad range of plants with toxic and repulsive and antifeedant properties in opposition to termites; numerous have been well studied in order to use as insecticides (Stoll 1986; Gerrits and Van Latum 1988; Harborne 1988).

In fact botanical pesticides are being used in Indian agriculture for more than a century in order to reduce fatalities that are caused by different pests and diseases (Prakash et al. 1990; Parmar and Devkumar 1993). Botanical pesticidal formulations are much advantageous than synthetic pesticides, which include the following:

1. Pesticides obtained from botanicals add up to least or no health issue and ecological pollution as they have low mammalian toxicity.
2. If the products are used in its innate form, then there is no use to develop pest resistance.
3. They are least hazardous toward nontargeting organisms, and only synthetic pyrethroids have been reported as effective against pests.
4. It has undesirable effects on plant growth along with viability of seeds and therefore on cooking of grains.
5. Botanical pesticidal formulations are cheap and accessible because they are available naturally in oriental countries. Such are neem, bel, senwar, pyrethrum,

tobacco, karanj, mahua, sweet flag etc., which have previously attained the position of potential pesticides to be used as IPM in crop fields against insects as well as in storage ecosystems (Prakash and Rao 1997).

6.6.2 Mechanism of Botanical Action on Termites

The mechanism of botanical action of any termiticidal component depends on a variety of factors, which mainly include chemical composition, mode of entry of insecticide into the body of the insect, mode of action, toxicity, and stage specificity.

6.6.3 Essential Oils

Essential oils being volatile in nature possess powerful aromatic attribute, characteristic odor, and taste. Plants usually have generally lower density than that of water. Plants produce secondary metabolites that are by-products of plant metabolism which contains volatile oils; those are lipophilic (fat soluble) in nature found in glandular hairs of plant cell walls, and they are present in different parts such as droplets of fluid in the bark, leaves, stems, flowers, roots, fruits, etc. They are found in different compositions such as monoterpenes, phenols, and sesquiterpenes which are complex mixtures of plant secondary metabolites.

Essential oils have many characteristic properties like insecticidal in nature, oviposition deterrents, antifeedants, repellents, growth regulation, and antivector against many disastrous pests and plant pathogenic fungi (Koul et al. 2008). Table 6.1 enlists the termiticidal properties of various plant essential oils derived from secondary metabolites. Nakashima and Shimizu (1972) evaluated insecticidal activity of essential oil. Isman (2000) concluded that there are some plants containing essential oils not only used as repellants toward insects but also have fumigating insecticidal activities against specific pest.

Antitermite activity was evaluated in fruit essential oil of *Myristica fragrans* against *Microcerotermes beesoni*, in which fruit essential oil contains LC50 value 28.6 mg/g and the compound studied *myristicin* caused 100% mortality against termites at a dosage of 5 mg/g after 14-day experiment (Pal et al. 2011).

6.6.4 Plant Resin

Tree species of *dipterocarp* (two-winged fruit tree) timbers are familiar to be immune from attack by pests. High resistance was shown by *Shorea robusta* (sal tree) against the termite species *Microcerotermes beesoni* and *Heterotermes indicola* (Sen-Sarma 1963; Sen-Sarma and Chatterjee 1968). Particle boards and other furniture items which are made from sal wood were also protected from *Cryptotermes cynocephalus* (Moi 1980). Due to this resistance property of

Table 6.1 Plant essential oil from various plant parts used in termite control

S. no.	Plant name	Plant part	Active compound	Termite	Effect	References
1.	*Azadirachta indica*	Seed	Limonoid	*Reticulitermes speratus*	Antifeedant	Serit et al. (1992)
2.	*Taiwaniacryptomeriodes*	Wood	Cedroland α-cadinol	*Coptotermus formosanus Shiraki*	Toxic	Chang et al. (2001)
3.	*Tagetes erecta*	Leaf	(z)-Ocimene	*Odontotermes obesus*	Mortality	Singh et al. (2002)
4.	*Citrus*	Peel	d-Limonene	*C. formosanus*	Toxic	Raina et al. (2007)
5.	*Moneses uniflora*	Aerial part	Naphthoquinones, 2,7-dimethyl-1,4-napthoquinone & 3 hydroxy2,7 dimethyl-1,4 naphthoquinone	*C. formosanus*	Toxic	Kobaisy et al. (2001)
6.	*Piper nigrum*	Seed	Guineensine	*C. formosanus*	Toxic	Meepagala et al. (2006)
7.	*Kalopanax septemlobus*	Wood	Saponins	*C. formosanus*	Toxic	Saeki et al. (1970)
8.	*Cryptomeria japonica*	Wood	Wood vinegar	*R. speratus*	Toxic	Yatagai et al. (2002)
9.	*Ephedra distachya*	Areal part	Ethyl benzoate benzaldehyde	*C. formasanus*	Toxic	Chang and Cheng (2002)
10.	*Taxodium distichum*	Wood	Ferruginol, manool, nezukol	*C. formosanus*	Toxic	Scheffrahn et al. (1997)
11.	*Thujopsis*	Wood	B-Thujaplicin and carvacrol		Toxic	Nakashima and Shimizu (1972)
12.	*Chamaecyparis pisifera*	Wood	Chamaecyone and isochamaecyone	*Coptotermus formosanus*	Toxic	Saeki et al. (1973)
13.	*Cryptomeria japonica*	Wood	β- Eudesmol and cedrol	–	Toxic	Yatagai et al. (1991)
14.	*Vetiveria zizanioides*	Root	Nootkatone (a sesquiterpene, alcohol, and cedrene)	*C. formosanus*	Arrestants, antifeedant repellent, and toxic	Maistrello et al. (2001), Zhu et al. (2001) Maistrello et al. (2003), Nix et al. (2006)
15.	*Tagetes erecta*	Leaf	(Z)-Ocimene	*Odentermes obesus*	Mortality	
16.	*Lepidium meyenii*	Leaf	Benzylthiocynate 3-methoxyphenylace-tonitrile and β ionone	*C. formosanus*	Feeding deterrent	Tellez et al. (2002)

(continued)

Table 6.1 (continued)

S. no.	Plant name	Plant part	Active compound	Termite	Effect	References
17.	*Lantana camara var. aculeate*	Leaves	Triterpenoid, 22 β-acetoxylantic acid	*O. obesus*	Toxic	Verma and Verma (2006)
18.	*Jatropha curcas*	Seed oil	Anacardic acid, cardanol, methyl anacardate	*Microcerotermes beesoni*	Toxicity	Singh and Kumar (2008)
19.	*Ocimum canum*	Whole plant	Alkaloids, matrine, and oxymatrine	*C. formosanus Shiraki*	Antifeedant, repellent	Owusu et al. (2008)
20.	*Ocimum gratissimum*	Whole plant	Alkaloids, matrine, and oxymatrine	*C. formosanus Shiraki*	Antifeedant, repellent	Owusu et al. (2008)
21.	*Protium javonica*	Leaves	Scopoletin	*C. formosanus*	Toxic	Adfa et al. (2010)
22.	*Xylopia aethiopica*	Fruits and seeds	Diterpenes and amides	*R. speratus*	Antifeedant	Lajide et al. (1995)
23.	*Calotropis procera*	Leaves	Monoterpenes and sesquiterpenes	*Reticulitermes* sp.	Toxic	Tellez et al. (2001)
24.	*Sophora flavescens Aiton*	Seed	Alkaloid, matrine, and oxymatrine	*C. formosauns Shiraki*	Antifeedant and acute residual toxicity	Mao and Henderson (2007)
25.	*Ganophyllum falcatum*	Wood	o- Methoxycinnamaldehyde and torreyal	*C. formosauns*	Toxic	Yazaki (1982)
26.	*Pometia pinnata*	Wood	Saponins	*R. flavipes*, *R. virginicus*, and *C. formosauns*	Toxic	McDaniel (1989)
27.	*Ternstroemia japonica*	Wood extract	Barrigenol glycoside (saponin)	*C. formosauns*	Toxic	Saeki et al. (1968)
28.	*Myracrodruon urundeuva*	Wood extract	Lectin	*Nasutitermes corniger*	Repellent and termiticidal	Sa et al. (2008)
29.	*Sextonia rubra*	Wood	Rubrynolide	*R. flavipes*	Toxic	Rodrigues et al. (2011)

dipterocarp woods, it causes significant increase in mortality rates of insects feeding on them.

Moi (1980) observed in a 3-month test period on sal species that 86% to 99% mortality occurred when termites fed on this plant, while with non-dipterocarp *Dyera costulata*, only a 13% death rate was recorded. Wood resins contain an array of terpenoids which have been found in the Palaeotropical plant family Dipterocarpaceae (Bisset et al. 1966, 1971; Diaz et al. 1966). Bee nests have been protected from termites due to the presence of fresh resins of *Anisoptera thurifera* Purified fractions of *Dipterocarpus kerrii* crude resin containing composition of four sesquiterpenoids, which are chemically similar to α-gurjunene, are responsible for termiticidal action against *Zootermopsis angusticollis.*

6.6.5 Termite Control by Fungi

Pathogenic fungal species were the first cosmopolitan organisms to be used as biocontrol agents for insect pests. They are the most satisfying alternative to chemically control pests. The entomopathogenic fungal species play a considerable role in integrated pest management (IPM) (Carrunthus et al. 1991). The actual meaning of "entomogenous" means arising in insects. Fungus that attacks houseflies was first explained by De Geer (1776) and De Geer (1782). More than 750 species (56 genera) of fungus are known to be pathogenic toward insects, many of which possess great probability toward pest management. It is the pathogenic capability of a fungus to perforate the cuticle lining of insect and compromise the insect immune system. In order to prevent such fungal attack, the insect shows complex relationship with fungal growth. Huxham et al. (1989) suggested that specific pathogenic strains of fungal species attacks particular host species; it will not show the same growth pattern and pathogenicity in another insect species.

Stranes et al. (1993) reported that fungal species of both tropical and temperate regions *Beauveria bassiana* (Balsamo) Vuillemin reveal to be highly pathogenic toward many insect species. There are some fungal species that are very sensitive and require special care and handling technique, such as *Metarhizium aniospliae* (BioBlast), which is a biological control agent. *Streptomyces avermitilis* fungus produces ivermectin, a metabolite, which is lethal toward termites, and it also decreases their food consumption and tunneling ability of workers of species *C. formosanus* (Mo et al. 2006).

6.6.6 Termite Control by Nematode

Entomopathogenic nematodal species have excellent potential for controlling insects; these are being merchandized and used to control many pests. Nematode families such as Steinernematidae and Heterorhabditidae are obligate insect parasites (Poinar Jr 1979), which are associated by symbiotic relationship with bacterial species *Xenorhabdus* and *Photorhabdus* (Boemere et al. 1993; Forst et al. 1997).

These bacterial species are nonmotile, gram-negative, and anaerobic; they are broadly classified as biological control agents (Gaugler and Kaya 1990). The infantile stage of such nematodal species (free living in soil) infects the insect host and the symbiotic relationship of bacteria, and nematode are used and released into the insect hemocoel, causing septicemia and death of pests (Kaya and Gaugler 1993).

Trudeau (1989) found high mortality in termite *Reticulitermes flavipes* (Kollar) by using nematode, although experiments with termite species *R. tibialis* (Epsky and Capinera 1988) and *Coptotermes formosanus* (Pemberton 1928) were not successfully recorded. Weeks and Baker (2004) worked on two entomopathogenic nematodal species *Heterorhabdidtis bacteriophora* (Poinar) and *Steinernema carpocapsae* (Weiser), respectively; based on their survivability, detectability, and mortality of *Heterotermes aureus* (subterranean termite) nematode, *S. carpocapsae* proved to be more effective in causing termite mortality in *H. Aureus* as compared to *H. bacteriophora*.

6.6.7 Termite Control by Bacteria

There are many rhizospheric bacteria which produce hydrogen cyanide (HCN) into the rhizosphere (region of soil in the vicinity of plant roots). Release of HCN by rhizospheric bacteria into the soil is reported poisonous to other subterranean animals. It was found that *Pseudomonas aeruginosa* produces HCN which have toxic effects on nematodes (Darby et al. 1999; Gallagher and Manoil 2001). Termite pests are also controlled by rhizospheric bacteria which produce HCN; these are selectively introduced into termite mounds due to localized use of cyanide production; it minimizes injurious effects on other soil fauna.

To facilitate biocontrol of termites, there are various nonparasitic rhizobacterial species which produce harmful metabolites. Devi et al. (2006) experimentally concluded that three different species of HCN-producing rhizobacteria, *Alcaligenes latus*, *Rhizobium radiobacter*, and *Aeromonas caviae*, were experimented to check the mortality rate of *O. obesus* which was found to be more effective toward termite control under in vitro conditions.

6.7 Conclusion and Future Prospects

Agrochemicals such as chemical insecticides and fertilizers have been used for a long time although they are considered as a major approach to control pests in agriculture field, and it also increases the productivity. But, due to increased use of agrochemicals and its application on a large scale, it resulted to a pest-resistant population, reduction in fertility of soil, and negative impact on human as well as environment. After years of the profound use of agrochemicals, it has been realized now that they are causing critical damage to human health, ecosystems, and groundwater. If the trend continues, this will be a threat to present and future generations. There is an imperative need to move toward environment-affable methods to enrich fertility of soil and disease caused by pests in crop field also controlled. This can be accomplished with the transition to sustainable agriculture. Products of the new generation have been created by using biopesticides as an influential tool. They are the most prone alternatives to some of the most difficult chemical pesticides used recently. Even though synthetic chemicals are more effective than bioinsecticides, it is harmful for other life forms, and it also increases resistant populations. On the other hand, biopesticides are not as harmful; it does not emerge a resistant population and also minimizes the elimination of beneficial species and also lessens human health hazards. Biopesticides are being used in IPM programs, and nowadays it has become an effective and eco-friendly substitute. Termites are the major pests of wooden structures in buildings, human dwellings, and agricultural and forestry crops. So far the only method of their control is to permanently utilize chemical insecticides; also these chemicals are reported to cause injurious effects to ecosystem; the search for alternative means is ongoing with the use of biocontrol agents (fungi, bacteria) and botanicals. Though much research has been done on botanicals in controlling a number of pests and plant diseases, not much success has been achieved in controlling termites. Hence, it is imperative and worthwhile to work on botanicals separately as well as in combination to get success in this case. Insecticidal activities also have been found in around more than 2000 plants belonging to some 60 families. This vast pool of natural pesticides should be explored and tested alone and in combination to obtain a potent termiticidal product.

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