Status review of forest destroyer: White ant (Termite: *Microtermes* & *Odontotermes*)

Abstract

Termites are considered destructive and generalized feeders of plants, and they are reported to inflict major economic injuries on various crop species all over the world. There are about 3,105 species of termites known; close to 185 are globally recognized as serious pests. Especially members of the family Termitidae are known to cause major injuries to agricultural and horticultural crops. In India, Odontotermes obesus and Microtermes obesity species are major pests that attack agricultural crops like wheat, maize, barley, pulses, oilseeds, vegetables, fruits, sugarcane, cotton, and plantation during either vegetative or reproductive growth stages. In case of heavy infestation in the early crop development stages, the damage caused by termites may even result in total crop loss. For the past six decades, farmers have applied chemical insecticides for termite control. But no single method can be termed as permanently fulfilling this role. There, perhaps, lies the root for the much-needed integrated pest management (IPM), considering coupling such cultural, mechanical, biological (with agents like Beauveria bassiana, Metarhizium anisopliae, Steinernema carpocapsae, Heterorhabditis indica, Bacillus thuringiensis, and Pseudomonas fluorescens), and botanical methods with chemical ones for better results. Though chemical control is the most commonly used method by farmers, it is often neither sustainable nor economic. It is impossible to eradicate termites completely from farmland for either practical or ecological reasons. Traditional control practices for termites have long existed throughout the various lands, but the degree of effectiveness in some cases has been tied to certain local conditions that do not translate to broader, large-scale applicability. As standalone techniques, they do not give consistent or reliable results; however, when integrated thoughtfully within a sound Integrated Pest Management (IPM) system, they cannot only go far in reducing reliance upon chemical pesticides but also in ensuring less pollution of the environment.

Eco-friendly options worthy of research that conform to sustainable agriculture have been suggested for cultural, physical, and mechanical means, besides biological means involving insect-pathogenic fungi, bacteria, nematodes, and plant extracts. Biological control would appear to hold much promise as part of management programs. Entomopathogenic organisms, while highly potential for control of termite populations, have been hardly used, especially in the field, because of lack of focused research and application.Further research and field studies need to be done to bring this into true potential. Integrated methodology using these as biological agents could give more targeted and efficient control of pest populations. On the horizon, we envisage that a combined and strategic implementation of the various control practices will help pave the way to more sustainable, environmentally friendly methods for controlling termite infestations in commercially important crops.

Key words**:** *Microtermes, Odontotermes*, Termitidae, infestation of termite management strategies

Introduction

Termites are soil arthropods of the order Isoptera and are often called ecosystem engineers. Their roles in the degradation of wood in tropical dry forests make them important actors in ecological processes. Termites constitute a factor in soil formation and nutrient cycling and are thus biological and geochemical regulators of pedogenic activity. Their environment-friendly activities notwithstanding, termites pose a major threat as herbivorous pests in cultivated farms, forests, and urban ecosystems (Rashmi & Sundararaj, 2013).

Termites chiefly recognized as being dangerous to wood belong to families Rhinotermitidae, Kalotermitidae, Hodotermitidae, and Termitidae. These species have been broadly subdivided into wood dwellers and ground dwellers. About 80% of the termite species considered economically injurious are subterranean ones, which include mound-builders and arboreal types. This broad feeding behavior has made them one of the most destructive pests in crop farming, horticulture, agroforestry, and plantations (Paul et al. 2018).

In water-scarce areas, termite attacks can cause a great deal of damage to crop production (Mahapatro & Sreedevi, 2014). The termite species aiming at crops have varied types of colony structure-from very simple to small groups to very large and complex societies with highly elaborate nests. Depending on their feeding and nesting habits, termites are classified into wood-dwelling or ground-dwelling. The wood-dwelling ones usually reside either in wet wood or in dry wood, depending upon the preference of the species. The ground dwellers are categorized into subterranean and mound builders (Pearce, 1997).

Termites that dwell on the ground are broadly categorized into subterranean types and mound builders (Pearce, 1997). Some economically important types of mound builders are days of Odontotermes obesus (Rambur), O. redemanni (Wasmann), and O. wallonensis (Wasmann). Mainlines of subterranean termites include Heterotermes indicola (Wasmann), Coptotermes ceylonicus (Vietnam), C. heimi (Wasmann), Odontotermes homi (Wasmann), Microtermes obesi Holmgren, Trinervitermes biformis (Wasmann), and Microcerotermes beesoni Snyder (Rajagopal, 2002). It is pertinent to note that the genus Coptotermes contains 28 species found among the most destructive subterranean termites (Paul et al., 2018). O. obesus is regarded as the most destructive species among those mound-building termites attacking crops in all stages of growth and development (Pardeshi et al., 2010).Almost 70% of all known termite species are classified within Termitidae family (Kumar et al., 2013). Termites, while playing an important ecological role in the decomposition of woody materials and nutrient recycling, tend to become a serious economic threat once they invade cultivated fields (Meyer, 2005). Ordinarily, they consume rotting organic materials. However, when the availability of their alternative foods is reduced in the environment, they shift to active growing crops by constructing complicated mud galleries. Inside the fields, termites feed on plant tissues, especially the roots and stems that are rich in cellulose, and this ultimately blocks plant growth; thus, the plants slowly losing anchorage and can easily be pulled out of the soil (Chhotani, 1980). This ability to digest cellulose is aided by symbiotic protozoa in their hindgut secreting enzymes capable of breaking down complex plant fibers (Abdulahi, 1990).

Taxonomic specification

India is rich in termite diversity; harbors 286 species belonging to 52 genera under six families representing almost 10% of the world's termite fauna (Krishna *et al*. 2013). Except for a few scattered works the termite fauna of central India is insufficiently documented. Sarma *et al*. (1975) while studying the wood destroying termites of India, recorded 21 species under 10 genera. Verma & Thakur (1982) studied termite fauna of Madhya Pradesh and recorded 18 species under six genera of which six species were recorded for the first time. Recently, Saha & Basak (2011) published a detailed taxonomic account of 35 termite species under 14 genera and three families from central India including eight species from the state of Chhattisgarh. "India has 41 reported species under the genus Odontotermes, which include Odontotermes adampurensis Akhtar, O. anamallensis Holmgren & Holmgren, O. assmuthi Holmgren, O.

bellahunisensis Holmgren & Holmgren, O. bhagwatii Chatterjee & Thakur, O. boveni Thakur, O. brunneus (Holmgren), O. ceylonicus (Wasmann), O. distans Holmgren & Holmgren, O. escherichi (Holmgren), O. feae (Wasmann), O. feaeoides Holmgren & Holmgren, O. ganapati Bose, O. giriensis Roonwal & Chhotani, O. girnarensis Thakur, O. globicola (Wasmann), O. guptai Roonwal & Bose, O. gurdaspurensis Holmgren & Holmgren, O. horai Roonwal & Bose, O. horni (Wasmann), O. kapuri Roonwal & Chhotani, O. kulkarnii Roonwal & Chhotani, O. latigula (Snyder), O. latiguloides Roonwal & Verma, O. malabaricus Holmgren & Holmgren, O. microdentatus Roonwal & Sen-Sarma, O. mirganjensis Holmgren & Holmgren, O. mohandi Verma & Purohit, O. obesus (Rambur), O. paralatigula Chatterjee & Sen-Sarma, O. paralatiguloides Thakur, O. parvidens Holmgren & Holmgren, O. profeae Akhtar, O. proformosanus Ahmad, O. prolatigula Bose, O. redemanni (Wasmann), O. sasangirensis Thakur, O. singsiti Bose, O. vaishno Bose, O. wallonensis (Wasmann), and O. yadevi Thakur.The soldier caste of Odontotermes obesus can be identified by the head capsule which is yellowish to dark reddish brown". The head is oval, being narrow in front, and measures 1.10-1.47 mm in length and 1.07-1.37 mm in width. Antennae have normally 16-17 segments, where the third segment is the shortest. Mandibles are slender and sabre-shaped; the left mandible has a prominent tooth near the base of the distal third. The pronotum is about 0.50-0.65 mm long and 0.80-1.07 mm wide.

Infestation behaviour of termites

Termite attacks on live trees are basically divided into two types with one being attacks by monophagous colonies restricted to specific host plants and localized areas and the other being attacks by polyphagous species, which are capable of foraging in different landscapes and feeding on an array of hosts. The Odontotomies species infesting T. arjuna are polyphagous and, with their wide host range and distribution, have caused grave economic losses to the tasar sericulture sector of India.Termite presence and distribution are effected by various ecological factors, both biotic and abiotic. These key factors, such as elevation, soil drainage, and degree of tillage, also shape termite populations and species diversity. Termite colonies at Kargi Kota and Bilaspur showed a contiguous pattern of infestation, suggesting an aggregation pattern. Such grouping behavior aids termites to locate food sources, mates, nesting sites, and shelter from predators whereby all these factors favor their survival and reproductive ability.It was once assumed that termite mounds in the area were randomly scattered with each site having an equal probability of new colony formations. Field data found 24 termite mounds at Kargi

Kota and 8 at Bilaspur. According to Jean-Pierre et al., the density of the three types of termite mounds was very high, with numbers of scattered mounds at about 8.99 per hectare. Similarly, Bandiya et al. reported a mound density of 10.08 per hectare in the semi-arid areas of Nigeria. The seemingly random pattern of mound distribution can largely be attributed to the stability of the environment of these habitats. The termite infestation reduces plant vigor with symptoms of stunted, vine-like growth and generally a reduction in the number of branches. Continuous collection of records of termite locality was observed throughout the year on T. arjuna. These factors include instances of plant stress, crop residues, insufficient level of interculture, root injuries from faulty planting techniques, and unfavourable site conditions which aggregate termite damages.

Infestation behaviour of termites on Standing and dead tree

Termites are among the invertebrates with the largest biomass and abundance in tropical forests (Vasconcellos, 2010). However, due to the great diversity of microhabitats they occupy (i.e., soil, decomposing wood, leaf litter, arboreal or soil mounds, inside the living trees and/or fallen branches that remain in the forest canopy), it is difficult to evaluate the density of these insects in the forest (Eggleton *et al.*, 1995). Termite density has been estimated based on the number of encounters with termites in transects of 200 m2 (Inoue *et al*., 2006), based on nest volume (Jeyasingh & Fuller, 2004) and in controlled experiments using baits (Davies *et al.*, 2015), although these estimations might not reflect the potential of colonization of dead wood available in the forest canopy. "In this study, we evaluated the occurrence of termites on living and standing dead trees in a tropical dry forest based on the density and proportion of trees in which termites are present, and in general, our results indicate that the availability of standing dead trees is associated with the density of trees with termites. This pattern can be explained by the difference in resource availability (i.e., necromass) for termites, which in turn can be related to the density and volume of dead wood present in each habitat". Periodic inundations of riparian habitats can also control termite populations since flooding events reduce termite populations, particularly subterranean termites (Ulyshen, 2014).

Necromass includes either suspended and soil wood materials, as well as standing dead material (Harmon et al., 1986). However, standing dead trees or snags constitute an important component of necromass (46–80%) in Chamela forest (Duran *et al.*, 2002; Maass *et al.*, 2002). Interestingly, our results indicate that 60–98% of standing dead trees in Chamela were associated with termites, and similar to a previous study evaluating the density and proportion of standing dead trees in Chamela (Segura *et al.*, 2003), our results also indicated that the density of standing dead trees was higher in deciduous (600–870 trees/ha) than in riparian forest (250–470 trees/ha).

High mortality rates in small trees (<10 cm of DBH) have been reported for other tropical ecosystems (Clark *et al.,* 2004). "Overall, these results suggest that standing dead tree availability might be the main factor regulating termite occurrence in Chamela forest. This hypothesis was confirmed by the positive relationship found between the density of standing dead trees and the density of trees associated with termites (r 2 = 0.72)". There is available evidence indicating positive correlations between the volume of dead wood and the volume of termite nests (Jeyasingh & Fuller, 2004), but interestingly, a positive correlation between standing dead wood and termite density at a broad regional scale (i.e., the USA) has been recently reported (Maynard *et al*., 2015).

A positive relationship between dead wood and insect density has also been reported for saproxylic borer beetles (Lachat *et al*., 2012). Tree mortality and dead wood production (i.e., necromass) is episodic and varies greatly over temporal and spatial scales (Palace *et al.,* 2012). Several factors and mechanisms have been reported to explain this variation (i.e., tree competition for nutrients and light, topography, root system characteristics of trees, among others), but disturbance appears to play a prominent role (Gale, 2000). In this sense, habitats subjected to frequent disturbance are expected to have high necromass production (Palace *et al.,* 2012). In Chamela forest, such disturbance events are reported to be associated with drought followed by windthrow related to frequent tropical summer storms, but it is recognized that drought events play a key role in tree mortality in this forest, particularly at higher elevation sites, such as deciduous forests, where the driest conditions prevailed (Duran *et al.,* 2002), explaining the high proportion of standing dead trees we found in deciduous forest. The decomposition of both standing and suspended dead wood is crucial in the dynamics of nutrient and energy flux in the ecosystem (Harmon et al., 1986). As we mentioned before, in Chamela forest, the biomass of standing dead trees and suspended branches (46–80%) exceeds the biomass of dead wood in the forest floor (20–53%), and in some sites, it exceeds the biomass of litter (Jaramillo *et al.,* 2003), indicating that the decomposition of suspended and standing dead wood is critical for this forest.

Infestation behaviour of termites on field crop

Among different insect pests attacking wheat, termites rank first as a pest not only in India but entire south Asia (Geddes and Iles, 1991). Chhillar *et al.* (2006) recorded about 16 species of termites damaging wheat crop in India. *Odontotermes obesus* and *M. obesi* were found to be the most predominant (Dhadwal *et al.*, 2014). In India, among different states, the situation is more alarming in Rajasthan and some parts of Madhya Pradesh as termites inflict heavy damage (Sharma *et al.,* 2004). In western Rajasthan, infestation is more severe in the rainfed light soils than in irrigated, heavy soils. According to Hakeem *et al.* (2016), the damage is generally low in clay and black soils, high in sandy loam soils and severe in red soils. The common Asian species that attack rice are Macrotermes gilvus (Hagen), Heterotermes philippinensis (Light), and Coptotermes formosanus Shiraki. In Africa, Microtermes and Macrotermes spp., had been recorded as pests of rainfed upland rice (Pathak and Khan, 1994). Six species of termites viz., *Microcerotermes parvus Haviland, Microtermes sp., Pseudocanthotermes militaris Hagen, A. evuncifer, Trinervitermes oeconomus Tragardh* and *Macroteremes bellicosus* (Smeathman) were observed infesting upland rice in Benin (West Africa) (Togola *et al.*, 2012). "Termites are widely distributed in all chickpea and pigeonpea growing areas of Asia and Africa. About 20 species are known to infest legumes in Africa and Asia but among them, *Microtermes* and *Odontotermes* spp. are the most damaging, while Macrotermes spp., occasionally attack legumes. Termites generally invade these crops from around 30-45 days to crop harvest. Termites attack chickpea crop at seedling stage and also near maturity (Cheema *et al.*, 2009). *Microtermes* and *Odontotermes* spp. cause damage to pigeonpea and chickpea by entering the root system and stems resulting in plant mortality. As crops progress towards maturity, the damage becomes more severe. In case of chickpea, infested plants show high mortality and disappear rapidly due to distortion of plant tissues". Pigeonpea crops are infested at maturity stage and is more severe in tropical areas (Ranga Rao *et al.,* 2013). The *Microtermes* spp. and *Odontotermes* spp. and Amitermes spp., had been observed groundnut but only O. obesus is the most common in India and African countries resulting in yield losses of 10 to 30% (Paul et al., 2018). Yadav et al. (2015) studied the insect pest complexof cabbage in Uttar Pradesh and *O. obesus* was a minor pest from the vegetative to the harvesting stage.

Infestation behaviour of termites on horticultural crops

Tenon et al. (2016) reported *Trinervitermes geminates* (Wasmann), *T. togoensis* (Sjostedt), and *Cubitermes fungifaber* (Sjostedt) as important pests of mango in West Africa. Termite infestation starts at anaverage height of 2.26± 3.14 m (Mandal *et al.,* 2010).The termite feeding causes severe damage to the rootsresulting in drying of above plant parts like shoots, branches and trunk. In West Africa, *Ancistrotermes crucifer* (Sjostedt), *M. bellicosus*, *Microtermes* sp., *Odontotermes pauperans* (Silvestri) and *Pseudacanthotermes spiniger* (Sjostedt) attacks 68% of papaya trees out of which 5% died (Moise *et al.,* 2018). Termites are the major soil pests of coconut in nurseries and can cause damage up to 20% (Mahapatro and Kumar, 2015) but in drought conditions sometimes the damage may exceed upto 30-40%.

Management strategies

Cultural control: In order to destroy the foraging tunnels and the workers present in the subterranean regions, deep summer ploughing is recommended before the onset of monsoon (Kumar, 1991). Deep ploughing exposes termites to sun light/ desiccation and to avian predators, thus reducing their numbers (Khan *et al.,* 2016). Left over stubbles of previous crop and other decaying matter should be removed from the field as they attract termites (Paul *et al.,* 2018). Only well decomposed farmyard manure (FYM) should be applied to the field because partially decomposed FYM acts as an attractant to foraging workers due to the presence of cellulose and optimum moisture (Kumari *et al.,* 2013). Farmers should follow crop rotation especially including non-preferred crops (Kumari *et al.,* 2013). Sekamatte *et al.* (2003) studied the effect of intercropping maize with soybean, groundnut and common beans against termites and found a significant reduction in termite attack and increased nesting sites of predatory ants (*Myrmicaria* and *Lepisiota*) in maize fields. The smallscale farmers of sub Saharan Africa are practicing intercropping of maize and beans to reduce termite attack (Khan et al., 2016). "Frequent irrigations should be used to avoid water stress conditions as it makes plant more vulnerable to termite attack. Jayanthi *et al.* (1993) reported that the activity of termites in drip-irrigated plots was higher than in surface-irrigated plots of groundnut crop. Weeds surrounding the fields compete with crops for nutrients, light and water and may lead to stress and hence increased susceptibility to termite attacks. Application of wood ash around the base of the trunk of coffee bushes and date palms has been recorded as a preventive measure against termite infestation". Fertilization with nitrogen, phosphorus, and potassium in wheat, barley, and yam has been recorded to reduce termite incidence (Khan *et al.,* 2016).

Biological control: Several entomopathogenic fungi, such as *Beauveria*, *Metarhizium* and *Aspergillus*; bacteria, such as *Bacillus*, *Serratia* and *Pseudomonas*; and nematodes, such as *Heterorhabditis*, *Steinernema*, and *Neosteinernema*, had been reported as biocontrol agents (Muralidhara *et al*., 2013). Myles (2002) listed 2 viruses, 5 bacteria, 17 fungi, 5 nematodes and 4 mites as natural enemies. These biocontrol agents offer an environment friendly and cost effective control (Federici *et al.,* 2008).

B. alibiflora showed 90% mortality at 100 ppm and 1000 ppm, respectively, after 24 hr (Ramdev *et al.,* 2013). According to Coghlan (2004), the plant extracts like neem (neem seed oil or neem powder), extract of *Ageratum conyzoides*, wild tobacco and dried chilli can be utilised for termite management. In Uttar Pradesh, various bioassays were conducted to evaluate the anti-termite efficacy of plant latex-based formulations extracted from *Calotropis procera* to control population of Indian white termite. Results revealed that crude latex, its fractions and combinatorial fractions have very high toxicity against *O. obesus* (Upadhyay, 2013). In Gujarat, Gadhiya *et al.* (2015) evaluated the efficacy of eleven organic amendments against termite in wheat. Among the tested organic amendments, the soil application of castor cake, vermicompost and neem cake @ 1 t/ ha each at the time of land preparation before sowing were found to be very effective.

Singh *et al.* (2010) found powder of neem seed kernel and leaves very effective in managing wheat termites. The leaf extract of plants viz., *Lantana camara*, *Rhazya stricta*, *Rutacha lepensis*, and *Heliotropium bacciferum* were tested against subterranean termite, *P. hybostoma* and were found to be very effective (Alshehry *et al.,* 2014).

Mechanical and physical control

Locating the termite mounds in or near the crop fields and destroying them manually by digging, flooding is an effective practice to disturb daily routine of termites. Dequeening on other hand is of great help to disturb lifecycle, but it is a time consuming and labour intensive process and required well trained workers (Khan *et al.,* 2016). Lighting of fire after queen removal to destroy the colony must be followed immediately. Burning of crop residues on top of termite mounds is another practice being followed in Indian villages to reduce the population by suffocating. According to Rath and Bhanja (2007) the winged individuals of termites can be collected by poultry farmers during swarming for poultry feed.

Chemical control

"In India, the most commonly used insecticide for termite management is chlorpyriphos. Farmers, all over the country use chlorpyriphos and other conventional chemicals with irrigation water irrespective of the crop grown. But, scientists from different regions of the world evaluated a plethora of new chemistry of insecticides having comparatively fewer negative effects". In northeast India, Bhagawati *et al.* (2017) studied field efficacy of some newer insecticides (thiamethoxam 25WG, imidacloprid 17.8SL, acephate 50%+ imidacloprid 1.8%SP, thiamethoxam 35FS, imidacloprid 600FS and clothianidin 50WDG against *O. obesus* in preserved setts and found clothianidin 50% WDG as the most effective. In Thailand, Charoenkrun (2014) also observed clothianidin as the most effective against subterranean termites even at a very low concentration. They reported that with increase in 0.15% dosage, the damage was reduced up to 5%. Smith *et al.* (2008) reported that the combined application of acetamiprid and bifenthrin was more toxic as compared to their alone application. Baiting is anothereffective strategy in which the contaminated individual disseminates the chemical in its colony through trophallaxis. Hexaflumuron and flufenoxuron bait matrixes were found to have high efficacy in eliminatingsubterranean termites (Ahmed Shidayand French, 2013).

“Termites are managed indigenously by physically destroying the termite mound and its queen, application of ash or crushed fruits, clean cultivation, regular agronomic practices, crop rotation and intercropping of non-host plants. The spraying of chemicals in the off-season protects the infestation of termites”. Application of 0.5% aldrin emulsion to the pits before planting of the plants, stems protected by spraying with 5% aldrin in the root zone for protection of T. arjuna plants from termite attack during the 1900s (Sing and Goel, 1992). “The present study on feeding inhibition of termite on T. arjuna found that the imidacloprid 17.8 SL @ 0.6 ml, imidacloprid 17.8 SL @ 0.4 ml and chlorpyrifos 20 EC @ 2 ml were highly effective and prevented host plants from termite attack”. Other studies have reported that imidacloprid, carbofuran, chlorpyrifos, phorate, quinalphos and methyl parathion were found effective against termites in different crop (Singh and Singh, 2002).

Conclusions

Termites constitute polyphagous pest species among which some cause huge damage to agrarian crops and horticulturally valued crops, forest trees, and stored materials. They have a devastating effect on crop production if infestations take place during the initial stages of crop growth, leading to sometimes 100% crop failure. This approach can neither be termed sustainable nor economically viable for many farmers, who mostly prefer it as a termite control measure; also, causing the complete removal of termites from croplands is neither practicable nor environmentally sustainable.

There exist several traditional and indigenous methods for termite control; these methods often possess local application only, and when results are generalized, they do not yield consistent results. Using these techniques alone is never sufficient to provide termite control; rather, using them in an integrated manner within an Integrated Pest Management (IPM) system would reduce reliance on chemicals and environmental pollution.

Scientists have, in the recent past, developed a range of control measures that are environment-friendly and acceptable to the farmers for the cultural, physical, and mechanical methods, while the biological methods involve the use of entomopathogenic fungi, bacteria, nematodes, and plant extracts. Having great potential in termite control, these biological control agents have, however, been scarcely given attention to, especially for field application.

For long-term and environmentally sound management, research should thereby be intensified in the practical deployment of bioagents in various agricultural environments. Incorporating the use of entomopathogens in integrated management will allow for pest suppression that is both more targeted and more effective. Thus, in the future, the combined use of several compatible approaches under an IPM system may be the best sustainable and efficient way of reducing termite-induced losses.

Suggestions for further work

1. Specific IPM modules with special reference to mechanical control of termite queen has not be done till now at particular forest depot in Chhattisgarh.
2. The study on different species of forest tree and different species of termite should be confirmed in Chhattisgarh forest region.
3. Extent of damage by termite in different forest range can be separately evaluated.
4. Since the climate change factor is continuously influence pest actively. Hence population dynamics study should be further continued.
5. New effective IPM modules recommended from time to time by scientists at different places may be incorporated and compared in further trials.

Reference

Abdulahi, A. (1990). Foraging activity and control of termites in western Ethiopia, PhD thesis, University of London, 227 p.

Ahmed Shiday, B.M. and French, J.R.J. (2013). The efficacy of flufenoxuron as potential bait toxicant against termites. *African Journal of Agricultural Research,* 8: 3688-3694.

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

Bandiya, H.M., Majeed, Q., Ibrahim, N.D. and Shindi, H.A. (2012). Density and Dispersion Pattern of Mounds of *Macrotermes bellicosus* (Isoptera: Termitidae) in Some Local Government Areas of Sokoto, *Semi-arid Zone of Nigeria. Research in Zoology,* 2(1):1-4.

Bhagawati, S., Bhattacharyya, B., Mishra, H. and Gogoi, D. (2017). Chemical management of termites (*Odontotermes obesus*) in preserved setts of sugarcane (*Saccharum officinarum*). *Journal of Entomology and Zoology Studies*, 5(1): 856-859.

Charoenkrun, K.A. (2014). Field trial in Thailand to evaluate the efficacy of a new non-repellent termiticide (clothianidin: neonicotinoid) in preventing structural damages caused by subterranean termite. Proceedings. 10th Pacific termite research group conference (B T Forschler (ed.), Kuala Lumpur, Malaysia. 7-11.

Cheema, H.K., Sharma, P., Singh, R., Taggar. G.K., Veena. K. and Kooner, B.S. (2009). Efficacy and compatibility of insecticides, fungicide and Rhizobium inoculants in combination for seed treatment in chickpea (*Cicer arietinum*). *Indian Journal of Agricultural Sciences*, 79(3): 190-194.

Chhillar, B.S., Saini, R.K. and Roshanlal, K. (2006). Emerging trends in economic entomology. CCSHAU Press, Hissar, Haryana. pp.191-192.

Chhotani, O.B. (1980). Termite pests of agriculture in Indian region and their control. Technical Monograph 4: 1-84.

Clark, D.B., Soto-Castro, C., Alfaro, L.D. and Read, J.M. (2004). Quantifying mortality of tropical rain forest trees using high-spatial-resolution satellite data. *Ecology Letters* 7:52–59.

Coghlan, A. (2004). Green pesticide is irresistible to ants. *New Scientist* 184(2476): 26 pp.

Davies, A.B., Eggleton, P., Van Rensburg, B.J. and Parr, C.L. (2015). Seasonal activity patterns of African savanna termites vary across a rainfall gradient. *Insects Sociaux* 62:157–165.

Dhadwal, R., Sharma, P.K., Sumit, V., Surjeet, K. and Verma, K.S. (2014). Insect pest complex of wheat (*Triticum aestivum* L.) in Himachal Pradesh. *Journal of Entomological Research*, 38 (2): 147-152.

Duran, E., Balvanera, P., Lott, E., Segura, G., Pérez-Jímenez, A., Islas, A. and Franco, M. (2002). Estructura, composición y dinámica de la vegetación. In: Noguera F, Vega-Rivera JH, García-Aldrete AN, Quesada M, eds. Historia natural de Chamela. México: Instituto de Biología-UNAM, 443–472.

Eggleton, P., Bignell, D.E., Sands, W.A., Waite, B., Wood, T.G. and Lawton, J.H. (1995). The species richness of termites (Isoptera) under differing levels of forest disturbance in the Mbalmayo Forest Reserve, southern Cameroon. *Journal of Tropical Ecology*, 11:85–98.

Federici, B.A., Bonning, B.C. and Leger, R.J. (2008). Improvement of insect pathogens as insecticides through genetic engineering. In: Pathobiotechnology. C Hill, R Sleator (eds.). Austin: Landes Bioscience, pp. 15-40.

Gadhiya, V.C., Borad, P.K. and Deb, S. (2015). Effect of some organic amendments on termite infestation in wheat. *GAU Research Journal*, 40(1): 36-38.

Gale, N. (2000). The relationship between canopy gaps and topography in a western Ecuadorian rain forest. *Biotropica* 32:653–661.

Geddes, A.M.W. and Iles, M. (1991). The relative importance of crop pests in South Asia. *National Research Institute Bulletin*. 39 pp.

Hakeem, K.R., Akhtar, M.S. and Abdullah, S. N. A. (2016). Plant, soil and microbes: Vol. I: Implications in crop science. Khan M A et al. (eds.). Springer. 366 pp.

Harmon, M.E., Franklin, J.F., Swanson, F.J., Sollins, P., Gregory, S.V., Lattin, J.D., Anderson, N.H., Cline, S.P., Aumen, N.G., Sedell, J.R., Lienkaemper, G.W., Cromack, K. and Cummins, K.W. (1986). Ecology of coarse woody debris in temperate ecosystems. *Advances in Ecological Research*, 15:133–302.

Inoue, T., Takematsu, Y., Yamada, A., Hongoh, Y., Johjima, T., Moriya, S., Sornnuwat, Y., Vongkaluang, C., Ohkuma, M. and Kudo, T. (2006). Diversity and abundance of termites along an altitudinal gradient in Khao Kitchagoot National Park, Thailand. *Journal of Tropical Ecology* 22:609–612.

Jaramillo, V.J., Boone, K.J., Rentería-Rodríguez, L., Cummings, D.L. and Ellingson, L.J. (2003). Biomass, carbon, and nitrogen pools in Mexican tropical dry forest landscapes. *Ecosystems*, 6:609–629.

Jayanthi, M., Sing,h, K.M. and Singh, R.N. (1993). Succession of insect pest on high yielding groundnut variety under Delhi conditions. *Indian Journal of Entomology*, 55: 24-29.

Jean-Pierre, Billardey, S. and Smith, Allen (2015). Spatial distribution and density of termite mounds in a protected habitat in the south of Cote D’ivoire: case of National Floristic Center (CNF) of Ufhb of Abidjan. *European Scientific Journal*, 11(3):242-259.

Jeya singh, P.D. and Fuller, C.A. (2004). Habitat-specific life-history variation in the Caribbean termite Nasutitermes acajutlae (Isoptera: Termitidae). Ecological *Entomology* 29:606–613.

Khan, M.A., Ahmad, W., Paul, B., Paul, S., Khan, Z. and Aggarwal, C. (2016). Entomopathogenic nematodes for the management of subterranean termites. Plant, soil and microbes. K R Hakeem et al. (eds.). Springer International Publishing, Switzerland. 317-352.

Krishna, K., D.A. Grimaldi, V. Krishna & M.S. Engel (2013). Treatise on the Isoptera of the World, Bulletin of the American Museum of Natural History 1–7: 1–2704.

Kumar, K., David, G., Valerie, K. and Michael, E. (2013). Treatise on the Isoptera of the World. *Bulletin of the American Museum of Natural History*, 377(7): 1-200.

Kumar, N.G. (1991). Studies on the ecology of subterranean termite, *Odontotermes hornii* (Wasmann) (Isoptera: Termitidae) and its foraging effect on nutrient status. Ph.D. thesis, University of Agricultural Sciences, Bangalore. 254 pp.

Kumari, K., Patil, K. and Sharma, S. (2013). Farmer friendly ways to control termites. Popular Kheti 1(2): 25-29.

Lachat, T., Wermelinger, B., Gossner, M.M., Bussler, H., Isacsson, G. and Müller, J. (2012). Saproxylic beetles as indicator species for dead-wood amount and temperature in European beech forests. *Ecological Indicators*, 23:323–331.

Maass, J.M., Martínez-Yrízar, A., Patiño, C. and Sarukhán, J. (2002). Distribution and annual net accumulation of above-ground dead phytomass and its influence on throughfall quality in a Mexican tropical deciduous forest ecosystem. *Journal of Tropical Ecology* 18:821–834.

Mahapatro, G.K. and Kumar, S. (2015). Review on the incidence and management of coconut termites. *Indian Journal of Entomology*, 77(2): 152-159.

Mahapatro, G.K. and Sreedevi, K. (2014). Indigenous approaches for the management of termite and white grub in upland rice. *Current Biotica*, 8(1): 97-108.

Mandal, B.K., Bashar, K., Howlader, A.J. and Rahman, K.M.Z. (2010). Incidence of termite infestation to tree species in Jahangirnagar University Campus, Bangladesh. *Bangladesh Journal of Life Sciences*, 22(2): 7-15.

Manzoor, F., Abbas, M. and Latif, M.U. (2015). Comparative Study of Resistance and Feeding Preference of 24 Wood Species to Attack by Heterotermes indicola (Wasmann) and *Coptotermes heimi* (Isoptera: Rhinotermitidae) in Pakistan. *Sociobiology*. 62(3):417-425.

Maynard, D.S., Crowther, T.W., King, J.R., Warren, R.J. and Bradford, M.A. (2015). Temperate forest termites: ecology, biogeography, and ecosystem impacts. *Ecological Entomology*, 40:199–210.

Meyer, J.R. (2005). Isoptera. Department of Entomology, NC State University. http://www.cals.ncsu.edu/course/ent425/compendium/ termites.html.

Moise, A.A.A., Perrine, K.T.A., Seraphin, D.Y.K., Tenon, C. and Herve, K.K. (2018). Diversity and damages of termites on papaya trees (*Carica papaya*) in M'brimbo (south of Côte d'ivoire). *International Journal of Entomology Research*, 3(6): 60-64.

Muralidhara, S., Prasad, B. and Singh, R. (2013). Colonization and antagonistic activity of entomopathogenic Aspergillus sp. against tea termite (*Microcerotermes beesoni* Snyder). *Current Science*, 105: 1216-1619.

Myles, T.G. (2002). Isolation of *Metarhizium anisopliae* (Deuteromycotina: Hyphomycetes) from *Reticulitermes flavipes* (Isoptera: Rhinotermitidae) with convenient methods for its culture and collection of conidia. *Sociobiology* 40: 257-262.

Nageswara, Rao and Sammaiah, A. (2012). Intensity of foraging activity in subterranean termites at Mulakalapally forest region, Khammam district, Andhra Pradesh India. *International Journal of Pharmaceutical Research and Biomedical Analysis*. 1(3):1-9.

Palace, M., Keller, M., Hurtt, G. and Frolking, S. (2012). A review of aboveground necromass in tropical forests. In: Sudarshana P, Nageswara-Rao M, Soneji JR, eds. Tropical forests. *Rijeka: InTech Open*, 215–252.

Pardeshi, M.K., Kumar, D. and Bhattacharyya, A.K. (2010). Termite (Insecta: Isoptera) fauna of some agricultural crops of Vadodara, Gujarat. Zoological Survey of India 110: 47-59.

Paul, B., Khan, A., Paul, S., Shankarganesh, K. and Chakravorty, S. (2018). Termites and Indian Agriculture. Khan M, Ahmad W (eds). Termites and sustainable management, sustainability in plant and crop protection. *Springer International Publishing*. 51-96.

Pearce, M.J. (1997). Termites: biology and pest management. 1st ed. Chatham: CAB International. 172 pp.

Rajagopal, D. (2002). Economically important termite species in India. *Sociobiology* 40(1): 33-46.

Ramdev, A., Richa, B. and Sharma, M.L. (2013). Bioeffacy of two traditional botanical insecticides against subterrenean termites (*Coptotermes heimi*). *Indian Journal of Fundamental and Applied Life Sciences*, 3(3): 24-28.

Ranga Rao, G.V., Rameshwar Rao, V. and Ghaffar M.A. (2013). Handbook on chickpea and pigeonpea insect pests identification and management. Information Bulletin No. 57. International Crops Research Institute for the Semi-arid Tropics, Patancheru, Andhra Pradesh. 96 pp.

Rashmi, R.S. and Sundararaj, R. (2013). Host range, pest status and distribution of wood destroying termites of India. *Journal of Tropical Asian Entomology*, 2: 12-27.

Rath, A.C. and Bhanja, P.K. (2007). Farmers' indigenous traditional knowledge for pest management, Proceedings. National symposium on sustainable pest management for safer environment. OUAT, Bhubaneshwar, Orissa. 72-74.

Saha, N. and Basak, J. (2011). Insecta: Isoptera, pp. 85–104, In: Fauna of Madhya Pradesh (including Chhattisgarh), State Fauna Series -15. *Zoological Survey of India*. 202pp.

Sarma, P.K.S., Thakur, M.L., Misra, S.C. and Gupta, B.K. (1975). Studies on Wood destroying Termites in relation to Natural termite resistance of Timber (Final Technical Report). Forest Research Institute, Dehra Dun, 187pp.

Segura, G., Balvanera, P., Durán, E. and Pérez, A. (2003). Tree community structure and stem mortality along a water availability gradient in a Mexican tropical dry forest. *Plant Ecology*, 169:259–271.

Sekamatte, M.B., Ogenga, L.M. and Russell, S.A. (2003). Effects of maize–legume intercrops on termite damage to maize, activity of predatory ants and maize yields in Uganda. Insect Science and its Application 22: 87-93.

Sharma, A.K., Babu, K.S., Nagarajan, S., Singh, S.P. and Kumar, M. (2004). Distribution and status of termite damage to wheat crop in India. *Indian Journal of Entomology,* 66(3): 235-237.

Singh, R.A., Sharma, V.K., Singh, M.K. and Singh, P.V. (2010). Eco-friendly management of pest and diseases with neem kernels and leaves. *International Journal of Agricultural Sciences,* 6 (1): 232-233.

Singh, R.N., Goel, A.K. and Thangavelu, K. (1992). Succession of insect pests in tasar ecosystem in Bihar. *Indian Journal of Ecology*. 19:177-182.

Singh, S.K. and Singh, G. (2002). Comparative evaluation of chemical and botanical insecticides against termites. *ENTOMON*, 27:153-160.

Tenon, C., Akpesse, A.A.M., Boga, J.P., Yapi, A., Kouassi, K.P. and Roisin, Y. (2016). Change in termite communities along a chronosequence of mango tree orchards in the north of Côte d'Ivoire. *Journal of Insect Conservation*, 20: 1011-1019.

Thakur, M.L. (1981). Revision of the termite genus *Odontotermes Holmgren* (Isoptera: Termitidae: Macrotermitinae) from India. Indian Forest Records (New Series) *Entomology* 14(2): 1–34.

Togola, A., Kotoklo, E.A., Nwilene, F.E., Amevoin, K., Glitho, I.A., Oyetunji, O.E. and Kiepe, P. (2012). Species diversity and damage of termites on upland rice in Benin. *Journal of Entomology*, 9(6): 352-360.

Ulyshen, M.D. (2014). Interacting effects of insects and flooding on wood decomposition. PLOS ONE 9:e101867.

Vasconcellos, A. (2010). Biomass and abundance of termites in three remnant areas of Atlantic Forest in northeastern Brazil. *Revista Brasileira de Entomologia* 54:455–461.

Verma, S.C. and Thakur, R.K. (1982). Termites from Madhya Pradesh, India with new distributional records (Insecta: Isoptera). *Records of the Zoological Survey of India*, 79: 311–318.

Yadav, R.S., Kumar, D., Singh, U. and Singh, D.K. (2015). Insect-pests complex of cabbage in eastern Uttar Pradesh. Vegetable Science 42(2): 90-92.