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Review Paper

Termite diversity, damage on crop and human settlements and their potential sustainable management strategies in Africa

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Abstract

Termites are problematic insects due to their threat in agricultural fields and human settlements. They cause a significant loss to food and cash crops, wooden components in buildings and trees of economic importance, especially in warm environments of subtropical and tropical regions. For a long time, termite attack has been controlled using different chemical methods, though they cause human health and environmental problems. This review has been focused on termite diversity, damage caused by termites in crop plants and other infrastructures as well as three eco-friendly alternative methods such as insecticidal plants, biological method and cultural control. Methods discussed under cultural approach include animal by-products, dead animals, meat and sugarcane husks, wood ashes and intercropping system. For biological method the focus is on nematode, bacterial and fungal application while the insecticidal plants highlighted on the potential of Cupressus lusitanica, Tephrosia vogelii, Eucalpytus dalrympleana, Lantana camara and Azadirachta indica in the control of termites.

Keywords: Biological method, insecticidal plants, insect pests, termites.

Introduction

Termites are insects which usually possess a stable and an organized colony in warm terrestrial environments[1]. They contribute significantly to the ecosystems of the world through decomposing wooden components[2]. Termite activities in the soil lead to excellent aeration and improvement of soil nutrients by adding Nitrogen (N) and Carbon (C) through Nitrogen (N) fixation and Carbon (C) mineralization respectively[1,2]. They are known primarily for their damage to woody plant parts and constrain crop production[3]. In addition, they attack wooden structures of buildings and inhibit production of trees of economic importance to mostly African communities' farms, global tropical and subtropical areas[4,5]. The most known problematic termites species are *Heterotermes, Psammotermes* and *Coptotermes* (family Rhinotermitidae), *Hodotermes* and *Anacanthotermes* (family Hodotermitidae), *Neotermes* sp. (family Kalotermitidae) as well as *Syntermes, Procornitermes, Odontotermes, Microtermes, Microcerotermes, Macrotermes, Cornitermes, Ancistrotermes* and *Amitermes* (family Termitidae)[5-7]. Apart from causing crop damage and individual hardship to life, approximately $ 40 billion was used to buy synthetic pesticides purposely to manage termites and repair destroyed wooden property in 2010 globally[5,8]. African countries like Mozambique, Zambia, Uganda and Malawi had cases where maize were destroyed by termites before and after harvesting, while in Nigeria, Burkina-Faso, Niger and Mali at most 30% of harvested groundnuts were reported to be damaged by termites in 1996[9-11].

In East Africa, particularly Tanzania, damage by termites to both young and mature coconuts during dry seasons were reported[7]. In light of the above, there is a need to test and evaluate the less costly and reliable termite management strategy so as to encourage households and small scale farmers to engage in crop farming. In fact, having a sustainable way of controlling termites will result in the reduction of hunger in developing countries especially African countries where the problem of hunger has been reported most of times.

African Termite diversity

Favorable condition of Africa is the major reason for high abundance of termites with more than 664 termite species diversity recorded in the continent[12,13]. High abundance of termite animals has been documented from southern, western and eastern Africa, with few species recorded in Northern Africa[14,15]. In this study termite diversity has been described based on their morphology. Morphology is characterized by using body color (pale, grey, brown and red-black), body size (large or small), large and small heads with mandible position as well as soft and hard cuticle[16]. For example, in genus *Macrotermes*, species labeled A, B, C, G and H (Figure-1) differ among themselves in color with respect to their locations.

Therefore, few images compiled in Figure-1, justify that regions of Africa have high diversity of termite species and therefore, demands more studies to identify unknown ones.

Figure-1: Diversity of some African termite species.

Figure-1: Keys

Letter	Species name	Distribution	References
A	*Macrotermes bellicosus*	Northern and Western Africa	17, 18
B	*Macrotermes natalensis*	Southern African	19
C	*Macrotermes* sp.	Eastern Africa	20
D	*Microtermes* sp.	Western, Eastern and Southern Africa	20,21
E	*Microcerotermes* sp.	Western Africa	22,23
F	*Psammotermes hybostoma*	Northern Africa	24
G	*Macrotermes sp.*	Eastern and Western Africa	20
H	*Macrotermes* sp.	Southern Africa	25
I	*Neotermes* sp.	Western Africa	26
J	*Coptotermes* sp.	Eastern and Southern Africa	15,20
K	*Cubitermes* sp	Western, Eastern and Southern Africa	18,20,21
L	*Kalotermes* sp.	Northern Africa	15,26
M	*Amitermes* sp.	Eastern and Southern Africa	20,21
N	*Baucaliotermes hainesi*	Southern Africa	27
O	*Fulleritermes* sp.	Western Africa	23
P	*Heterotermes* spp.	Western Africa	28
Q	*Apicotermes* sp.	Southern Africa	27
R	*Nasutitermes* sp.	Western Africa	28
S	*Trinervitermes* spp.	Southern and Western Africa	18,23,26
T	*Odontotermes* sp.	Southern and Western Africa	19,22
U	*Hodotermes mossambicus*	Southern and Eastern Africa	14,27

Damage caused by termites in crop plants

Susceptible crop plants to termite pests in Africa include groundnuts, sweet potato, rice, millet, maize, cassava, soybeans, yam and sorghum[5,10,11]. The damage to crop plants caused by termite pests in many African countries is not quantified. For example, in Kenya, Namibia and South Africa, where termites were reported among the key maize damaging insects which cause reduction in yield, though no exactly figures of crop loss were reported[29-31]. Although it is difficult to find reliable information of crop losses in figures (percent), but still there are few scientific findings showing crop yield loss in percentage as presented in Table-1.

Table-1: Some African countries with crops affected by termite damage in figures.

Crop name	Country	% Crop yield loss	References
Groundnuts	Mali, Burkina-Faso, Niger and Nigeria	10-30	6
Groundnuts	Zambia	>90	4
Maize	Uganda and Nigeria	>50	32
Maize	Zambia and Malawi	20-30	11
Rice	Nigeria	50-100	33
Cassava	Nigeria	40.0	34
Maize, sugarcane, rice, millet, cassava, groundnuts andsorghum	Uganda	50-100	35,36
Groundnuts, cowpeas, sweet potato, rice, millet, maize, cassava, soybeans, yam, garden eggs and sorghum	Ghana	<100	5
Coconut seedlings	Tanzania	20-100	7
Maize	Ethiopia	45-50	37
Sorghum	Ethiopia	25	37

Damage caused by termites in other infrastructures

In tropical and subtropical countries, the destruction of buildings due to the termites have been reported as a major challenge due to the diversity of termites favored with good conditions in these geographical areas. For instance, Africa herself has over 664 distinct termite species[12,13,38]. Generally, in Africa scientific evidence on annual losses caused by termite damage in buildings are almost not available. But still, termites continue to destroy buildings which cost the owners for repairing and maintaining their buildings. In Southern Africa, especially in Zambia there is a wide infestation and termite damage in buildings[38].

This is in agreement with assertions by the reports of other scholars. For example, a research report has showed that 10 % of the budget from Building Research Institute is used for repairing damaged wooden components in buildings and buying synthetic chemicals to control termites in Western Africa[34]. Apart from damaging wooden structures in buildings, also termites attack live trees of economic importance. Vividly, it is indicated that Ugandan small scale farmers suffer from termite attack in their *Gravilea robusta*'s farms and the affected trees die before reaching maturity, leading to low timber production[4].

Considering the economic losses done by termites in crops, trees and wooden components in buildings, there is a need to carry out further studies to investigate the appropriate management strategies which can reduce termite activities to manageable levels and avoid possible damage in farmlands and buildings.

Termite control methods

Four methods namely i. chemical control ii. cultural control iii. biological control and iv. use of insecticidal plants are known as possible methods for termite management in buildings, wooden structures, crops and trees of economic importance.

Chemical method: Synthetic pesticides are artificial made compounds which have long half-life in the environment[39]. They are effective for protection of termites though they cause serious human health and environmental problems[40-42]. For instance, when methyl bromide is sprayed, it penetrates quickly inside the wooden structures and kills either dry wood termites or arboreal species[6]. Although methyl bromide control termites successfully, it is believed to cause atmospheric ozone layer depletion[6,43]. The ozone layer depletion turns into skin cancers which stands as a human health problem[44]. Other industrial chemicals that have been used for controlling termites in stored wood, wooden components in buildings and crops are chlorpyrifos, fipronil, bifenthrin, imidacloprid, endosulfan, lindane, aldrin, coldrane, dieldrin, endrin and heptachlor[43,45-47]. Chemical residues of these compounds are usually carried away from their sources by air and water to aquatic and terrestrial systems. For example, decrease by 80 % in fishes has been reported in different farming seasons of paddy cropping in Malaysia[48]. Synthetic pesticides have caused insect population reduction in United States of America[49] and bird populations in India[50]. Furthermore, synthetic pesticides have been reported to have negative effects to human health such as cancer[51]. In addition, synthetic pesticides have ability to cross cell membrane into the cells and result into cancer cells[52].

Also they cause hardness in breathing, skin pill off, vomiting, stomach ache and disrupt hormonal balance system in humans and wildlife[53,54]. Although one may apply synthetic chemicals on farms and protect crops from insect pests and diseases but on the other hand they affect and kill massive non-targeted organisms / biodiversity (Figure-7).

Considering the effects synthetic pesticides on human, environment and non-target insects, there is a need to develop new approaches to control termites in sustainable and eco-friendly ways. Therefore, this study suggests to use cultural control, biological method and insecticidal plants to control termites since these methods they have no negative effects to non-targeted organisms, environment and human health as well.

Cultural control: Cultural control refers to indigenous knowledge. Indigenous knowledge is the knowledge and skills that is not obtained from research findings and is normally practiced locally in rural areas[55]. Indigenous knowledge is much common and it has been used for a long time in developing countries before an invention of synthetic pesticides[55,56]. Many African countries practice different local methods in trying to reduce termite incidence. For example, in Uganda, Kenya, Zambia, Malawi, Mozambique and Nigeria small scale farmers use cow's urine, fresh cow dung, goat dung, dead animals, meat, fish viscera and sugarcane husks to reduce termite destruction on wooden properties and agricultural crops such as maize[4,35,57,58]. Moreover, wood ashes are commonly used to control termites on crop fields and buildings in Kenya, Uganda and Zambia[11,36,59]. In Tanzania, farmers use wood ashes to suppress insect pests in stored cereals, groundnuts and common beans[60].

Intercropping system strategy is highly appreciated in Uganda. For example, in this country, farmers experienced low termite damage on maize in maize - soybean intercrop system[10]. This is similar with the results obtained in Zambia thereby it showed a reduced termite attack to maize crop in intercropped maize with legumes[61]. To farmers, cultural control strategy is less effective because usually crops are not free from insect pests and diseases, but it is of beneficial practice to non-targeted organisms / biodiversity (Figure-7). Therefore, it is important to put into consideration these indigenous practices because there are information gaps which call for further scientific researches to justify the mechanism behind of these methods in protecting agricultural crops, trees of economic values and wooden materials in buildings from insect pests and termites.

Biological method: Biological method of insects is defined as natural enemies manipulations (i.e. pathogens, predators and parasitoids) for maintaining, reducing or eliminating insect pest populations from areas of interest, for example in cropping farms[62,63]. Majority of scientists and researchers prefer this strategy because it is environmental - friendly method and affects only target species[6,64]. Bacteria, viruses, nematodes, protozoa and fungi are potential biological agents for integrated pest management (IPM)[65,66]. Every agent mentioned here is very important and can be applied as alternative method to synthetic pesticides. Therefore, the introduction of bacteria or fungi in bio-control have to be put into consideration for controlling insect pests in eco-friendly way resulting to the maintenance of biodiversity and good crops (Figure-7).

In this review our focus has been only on three biological control agents namely; fungi, nematodes and bacteria.

Fungal application: Fungal agents are entomopathogens which can be produced massively and have ability to affect the target species through contact[65]. The *Paecilomyces* sp., *Beauveria bassiana*, *Isaria fumosorosea* and *Metarhizium anisopliae* are potential candidates of fungi species in the management of termites[67,68]. A fungus *Isaria fumosorosea* has caused a significant mortality of termites, *Coptotermes formosanus* in the laboratory[67]. *Metarhizium anisopliae* has shown a remarkable degree of mortality on subterranean termites, *Globitermes sulphureus* compared with *Beauveria bassiana* and *Paecilomyces* sp. in Malaysian laboratory[68]. This corresponds to the research data which revealed thathigh efficacious mortality of tea termites, *Microtermes obesiin vitro* was induced by *Metarhizium anisopliae* while *Beauveria bassiana* demonstrated better results in field condition, India[69]. This could be attributed by the highest repellency of *Metarhizium anisopliae* compared with *Beauveria bassiana* strains. For example, documented information has proven that the virulent strains of *Metarhizium anisopliae* possess repellent properties which trigger alarm, isolation and defensive reactions among untreated termites[70,71]. Based on this background information, more research designs about strain selections of fungi to control termites under field conditions are recommended.

Nematode application: Families Steinernematidae, Heterorhabditidae, Allantonematidae and Mermithidae belong to nematodes[64]. Among these, Heterorhabditidae and Steinernematidae families have diverse species which are potentialin the management of terrestrial insect pests[64,72]. Species of these families have a tendency of forming a mutualistic association with bacteria called nematode-bacteria complex, thereby the association is useful in infecting host insects[73,74]. At infective juvenile stage, nematodes become active and free living that are able to search for host insects. Wherever they get host insects, they use open space like mouth and anus to penetrate into haemocoel of host insects and release their mutualistic bacteria[75,76]. Usually, the released bacteria produce lethal toxins which cause fatal septicemia and death to host insect. The host cadaver is used to serve as source of food in reproducing another infective juvenile generation of nematodes[77].

Few studies have been conducted to study the potentiality of nematodes on termite control. For example, high mortality has been found to termites, *Reticulitermes flavipes* exposed to parasitic nematodes[78].

A study conducted in Benin using parasitic nematodes such as *Heterorhabditis sonorensis* and *Heterorhabditis indica*showed a significant mortality to subterranean termite, *Macrotermes bellicosus*in laboratory[72]. This is in line with the laboratory report which justified that nematodes; *Steinernema feltiae* (Filipjev-UK76), *Heterohabditis bacteriophora* (Poinar - HP88), *Steinernema carpocapsae* (Weiser-Mexican 33) and *Steinernema riobrave* (Cabanillas, Poinar, and Raulstonn - 355) are able to cause severe mortality in termites of *Reticulitermes flavipes* (Kollar), *Gnathamitermes perplexus* (Banks) and *Heterotermes aureus* (Synder)[79].

Apart from laboratory trials, also experiments under field conditions have been done. A study under field conditions concluded that nematodes, *Steinernema carpocapsae* alone can control termites, *Reticulitermes tibialis*[80]. This is related to study designed to use nematodes in eliminating termites of *Odontotermes obesus* from millet and wheat crops[81]. Again it remains a challenge to researchers because high rates of reports are laboratory based and very few successes from field trials. Further studies are required so as to identify the limitations that hinder entomopathogenic nematodes in controlling or eliminating termites under the field conditions.

Bacterial application: Some rhizobacteria are good sources of Hydrogen cyanide for example, *Pseudomonas aeruginosa*. The Hydrogen cyanide is the chemical compounds which is effective in the management of undesirable soil microorganisms[6,82]. For example, Hydrogen cyanide from *Pseudomonas aeruginosa* has served as agent control towards nematodes in the fields[82,83]. All hydrogen cyanide - producing rhizobacterial species can be very useful to termite control by applying them directly to the termite mounds, thereby localizing cyanide production and also to minimize menace effects on other soil living animals. Bacteria which produce harmful metabolites may play part in biological control of termites. For instance, three different hydrogen cyanide - producing rhizobacterial species, *Aeromonsa caviae*, *Alcaligenes latus* and *Rhizobium radiobacter* have been tested under *in vitro* conditions and demonstrated positive results to kill termites of *Odontotermes obesus*[1,84]. Although, less information is available on negative effects of Hydrogen cyanide released from rhizobacterial species, therefore, this review proposes numerous studies to investigate the negative effects of Hydrogen cyanide (HCN) to other living soil fauna compared with conventional insecticides.

Use of insecticidal plants: Insecticidal plant compounds occur naturally, degrade easily when exposed to the sunlight and therefore have short half-life of persistence to the environment[85]. Generally, plant pesticides are known to control insect pests in eco-friendly way because they do not have negative effects on non-targeted insects, human health, environment and crops (Figure-7). Studies show that compounds derived from plants usually degrade into harmless substances ranging from few seconds, hours and even a day[54,86].

On the other side, synthetic pesticides are known to have negative effects on beneficial insects, human health, environment and insect pests do resist to them which lead to their failure in controlling insect pests[39]. Due to undesirable effects of synthetic pesticides, much attentions have been taken in developing alternative methods such as use of insecticidal plants so that to minimize health and environmental problems[39].

In Africa and other developing countries, different insecticidal plants have been reported to be effective in controlling insect pests both in field crop and stored products in different crops[85,87]. For instance, candidate pesticidal plants that are applied by Ugandan farmers in the control of insect pests on basin of the Lake Victoria are *Phytollacca dodecandra*, *Cofea species*, *Carica papaya*, *Cupressus* spp., *Tagetes* spp., *Nicotiana tabacum*, *Capsicum frutescens*, *Tithonia diversifolia*, *Lantana camara, Musa spp*., *Aloe* spp., *Tephrosia vogelii*, *Eucalyptus* spp., *Moringa oleifera*, *Azadirachta indica* and *Vernonia amygdalina*[87]. In Tanzania, farmers have been applying a mixture of powdered rice husks and neem parts, mixture of soap solvents and neem components, neem parts mixed with cow's urine, combination of red pepper, tobacco and neem components[60]. Several scholars support the use of insecticidal plants with some modified application techniques. For instance, appreciated positive results have been obtained in the test involving fresh ground leaves, mixed and soaked overnight[88]. A boiled combination of detergent soap and parts of pesticidal plants has demonstrated positive results in the control of insect pests[89]. Another technique involving soaking of the sun dried plant materials into organic solvents (acetone) has shown some promising results in protecting leaves of crop plants from rust problem inboth field and greenhouse conditions[90]. All mentioned techniques show efficacious results in controlling some pest insects. This calls for diverse research approaches to assess the effective application method. For example, what will happen when plant parts are boiled or soaked in soap solution and organic solvents with the aim of wider scale application on the termite and insect pest control.

Potential of *Cupressus lusitanica*, *Tephrosia vogelii*, *Eucalpytus dalrympleana*, *Lantana camara*and *Azadirachta indica* in controlling termites: Five plant species including *Cupressus lusitanica*, *Tephrosia vogelii*, *Eucalpytus dalrympleana*, *Lantana camara* and *Azadirachta indica* are selected as potential candidates in controlling termites. The selection of these botanicals has been done due to their efficacious results demonstrated in management of insect pests and termites on field crops, stored food cereal and legume grains as well as wooden properties[11,91]. In developing countries especially in the villages, these botanicals are used to control insect pests and termites in agricultural crops, stored grains and wooden properties[87]. Therefore, it is of paramount important to conduct researches that serve for rising awareness of people especially farmers and households on how to use the locally available pesticidal plants in the control of insect pests.

Cupressus lusitanica: Cupressus lusitanica (mexican cypress) belongs to the family cupressaceae and possesses aromatic compounds and essential oils such as β-cedrene, bornyl acetate, α-cedrene, epimanool, cedrol and agathadiol as depicted in (Figure-2)[92,93]. Essential oils possess antimicrobial, antifungal and insecticidal properties[94,95]. Growth inhibition has been observed to *Aspergillus niger* and *Bacillus cereus* after exposing to volatile essential oils[96]. Other studies, found that essential oils have a fumigant and repellency effects against insect pests in stored food grains[93,97]. In addition, leaf extracts and leaf powders are used to protect crops from termites[98,99]. This body of knowledge might be useful for insect pests and termite pests control in field crops, buildings, wooden structures and trees of economic importance. Therefore, many more studies are required to identify the active compounds from *Cupressus lusitanica* and test their efficacy to insect pests including problematic termites.

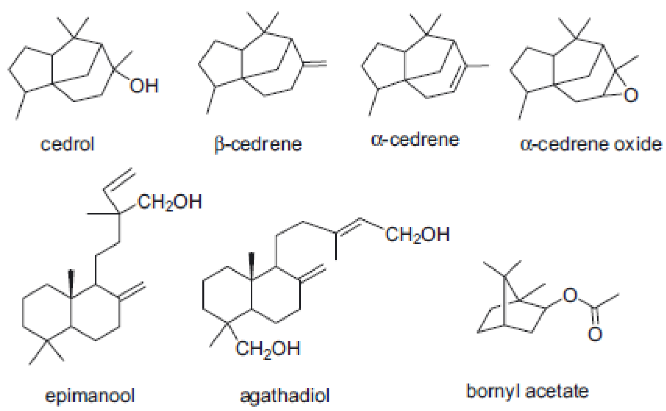

Figure-2: Some terpenic compounds in *Cupressus lusitanica*[92].

Eucalpytus dalrympleana: There are many varieties of eucalyptus species which belong to the family myrtaceae[93,100]. *Eucalyptus dalrympleana* and other *Eucalyptus* spp. have strong essential oils including, aromadendrene, limonene, α-pinene, 1,8-cineole, p-cymene, α-terpineol, citronellyl acetate, eucamalol, linalool, γ-terpinene and citronellal[100,101]. Among these components, the 1, 8-cineole has been reported as the most active monoterpene[102]. Many studies have reported similar results on 1, 8-cineole as shown in Figure-3. The study which used oil components of synthesized 1, 8-cineole and natural monoterpenes founda fumigant toxicity against *Musca domestica*(L.)[103]. In addition to this, severe mortality of first-instar nymphs of *Rhodnius prolixus* has been observed when introduced into volatile essential oils and monoterpenes composed of 1, 8-cineole[104].

Moreover, the extracts of 1,8-cineole from *Eucalpytus dalrympleana* is effective for the reduction of *Haematobia irritans* (Horn fly) incidence in cattle[105]. Other scholars have quantified that essential oils from *Eucalyptus dalrympleana* have insecticidal and repellent activity against stored food grains insect pests[101]. Similarly, essential oils of *Eucalyptus dalrympleana* have shown antifeedant, repellency and insecticidal properties on termite workers of the *Odontotermes obesus*[100]. Based on these findings, essential oils could be useful in the management of insect pests, flies and termites. However, essential oils are very volatile compounds which are difficult to handle them, meaning that they can escape easily when exposed to sun light[106]. Any study to investigate essential oils stability should be done with the purpose of improving their half-life so that to minimize the frequent application.

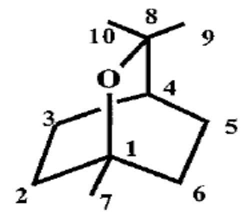

Figure-3: Chemical structure of 1,8-cineole[107].

Tephrosia vogelii: Tephrosia vogelii is a legume which belongs to the family Fabaceae[108,109]. *Tephrosia vogelii* is the most effective insecticidal plant which is used in the management of insect pests in both field crops and stored products[109]. It is also used to increase soil fertility through biological nitrogen fixation[109]. The effectiveness of *Tephrosia vogelii* is due to bioactive compounds such as chemotype 2 (C2) and chemotype 1 (C1) (Figure-4)[110]. C1 has been reported to be the most effective compound in *Tephrosia vogelii* resulting to the repellency of insect pests[54,110,111]. For these reasons, the pesticides from *Tephrosia vogelii* possess insecticidal effects. For example, the pesticides from *Tephrosia vogelii* are commonly used in remote areas of Africa for illegal fishing[112,113]. The pesticides from *Tephrosia vogelii*are already confirmed to exhibit antifeedant, repellent and insecticidal properties towards golden flea beetle[114].

In Malawi, Mozambique and Zambia, farmers who used extracts from crushed leaves of *Tephrosia vogelii* managed to protect field crops from termites[11]. However, there are inadequate scientific studies to verify the potentiality of using *Tephrosia vogelii* to control problematic termites[4]. Therefore, there is an urgent need to identify other bioactive compounds of *Tephrosia vogelii* which may control termites effectively.

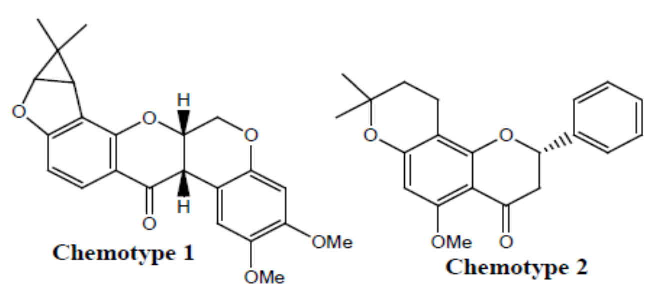

Figure-4: Chemotype 1 (C1) and Chemotype 2 (C2)[109].

Azadirachta indica: *Azadirachta indica* is a native plant in India[115]. It belongs to Meliaceae family with known more than 200 compounds[39]. Among these compounds, Azadirachtin is the most active constituent in *A. indica* compared with salannin and nimbin (Figure-5). Azadirachtin has strong repellent, antifeedant and insecticidal effects to insects. Azadirachtin has ability to interfere chemoreceptors, block sugar and receptor cells, affect growth and moulting, affect reproduction through inhibiting oogenesis and ovi position in female and interrupt mature sperm production in male insects[39]. Documents on *A. indica* support the botanical use of this plant. For example, a practical report has reported that the *A. indica* extracts have strong antifeedant effects against termites, *Reticulitermes speratus*[116]. Similar studies have been conducted using different species apart from termites. For instance, it has been found that *A. indica* extracts strongly inhibited growth in *Pseudaletia unipuncta* and *Trichoplusia ni*, after laboratory exposure[117]. The *A. indica* oil extracts minimized significantly the number of *Tuta absoluta* in vegetable tomatoes compared with the fields without treatments[118]. Thereafter, it is worthy to use *A. indica* extracts as alternative to control insect pests and termites which are serious menace to plants.

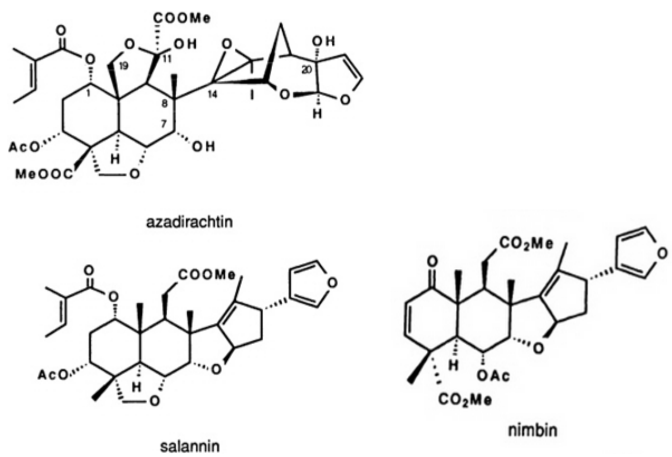

Figure-5: Some of chemical structures in *Azadirachta indica*[119].

Lantana camara: *Lantana camara* is a native plant of South America and it belongs to Verbenaceae[120]. Apart from South America, it is invasive plant to other areas[121]. Some scholars have recognized and presented that *Lantana camara* possesses diverse compounds including proteins, carbohydrates, lactones, furfural, flavonoids, triterpenoids, glycosides, flavonoids, and phenylethanoid glycosides[120,122]. Among these chemical compounds, triterpenoids such as ursolic acid stearoylglucoside is reported to be more active component than any other in this plant, as illustrated in (Figure-6)[123]. The presence of ursolic acid stearoylglucoside and others have enhanced many medicinal applications and few of them have been discussed here. Exposing rats or mice to *Lantana camara* affected their ability to move, caused congestion of heart and lung, nephrosis, dehydration and constipation with hepatosis as well as low reproduction performance according[123,124].

Lantana camara is also reported to have a fumigant effect against *Sitophilus granarius* adults in the stored grains[125]. Laboratory experiments of scholars have also indicated that *Lantana camara* possesses a repellency, antifeedant, insecticidal activity to stored food grains insect pests[126,127]. Besides, leaf extracts of *Lantana camara* have shown excellent repellent, moderate toxic and antifeedant activities on termites, *Reticulitermes flavipes* in the laboratory[91]. Also 5 % chloroform extracts of *Lantana camara* have exhibited excellent mortality in termite workers under laboratory conditions[122]. However, most of these reports are laboratory based, thus more field trials are needed. In addition, continuous use of *Lantana camara* would minimize invasion to other biodiversity. Also the toxic effects exhibited by *Lantana camara*, demands for further experiments so that to quantify the toxicity level on treated stored food grains before taken by consumers.

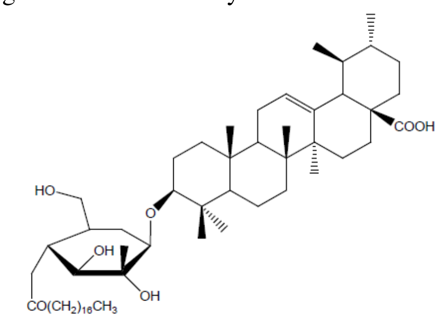

Figure-6: A chemical structure of ursolic acid stearoylglucoside[128].

Conclusion

This review has demonstrated that termite infestation is high to less developed countries although synthetic insecticides are primarily applied to control termites. However, the continuous use of synthetic insecticides is highly discouraged since they cause human health and environmental problems. Therefore, it is necessary to combine or integrate two or more pest control systems which are environmentally friendly in order to minimize the negative effects caused by synthetic chemicals. In addition, more research is needed regarding the active botanical ingredients, preparation requirements, application rates and residue effects to the environment and health risks to the farmers and other users. Apart from insecticidal plants, on-farm research is required in biological and cultural control for feasible management of termites at farmer level.

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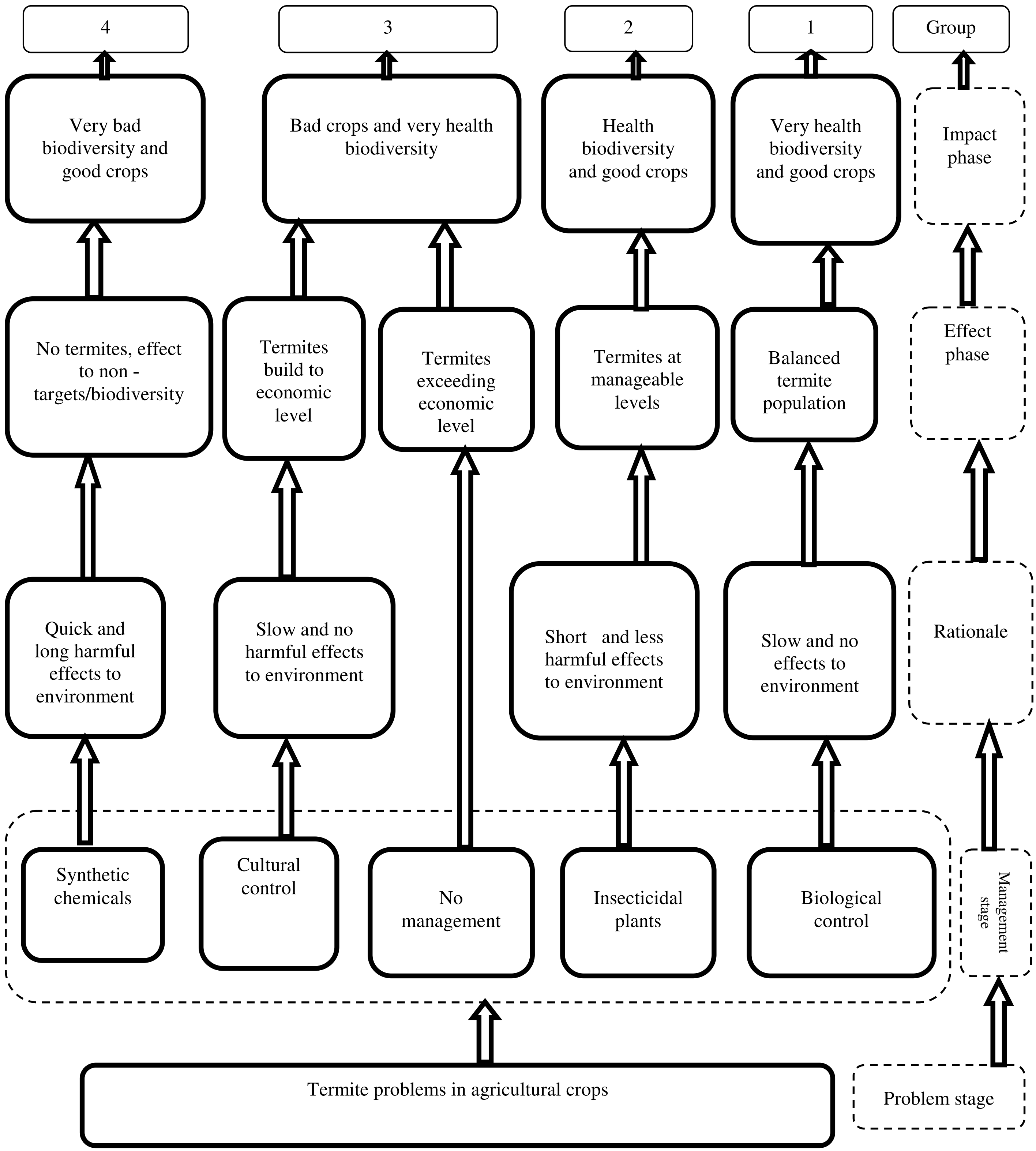

Figure-7: Termite management practice model and its effect on crop and biodiversity. In this model, four methods with regard to management have been described. In group 1, the termite management option leads to very health biodiversity and good crops; group 2, termite management option leads to health biodiversity and good crops; in group 3, termite management strategy results to bad crops and very health biodiversity while in group 4, termite control option causes very bad biodiversity and good crops.

References

1. Singha D.I.P.E.N.D.R.A., Singha B.A.B.Y. and Dutta B.K. (2010). In vitro pathogenicity of Bacillus thuringiensis against tea termites. *J. Biol. Control*, 24, 279-281.

2. Jasmi A.H. and Ahmad A.H. (2011). Termite incidence on an Araucaria plantation forest in Teluk Bahang, Penang. *Insects*, 2(4), 469-474.

3. Midega C.A.O., Murage A.W., Pittchar J.O. and Khan Z.R. (2016). Managing storage pests of maize : Farmers' knowledge, perceptions and practices in Western Kenya. *Crop Prot.*, 90, 142-149.

4. Sileshi G.W., Nyeko P., Nkunika P.O., Sekematte B.M., Akinnifesi F.K. and Ayaji O.C. (2009). Integrating ethno-ecological and scientific knowledge of termites for sustainable termite management and human welfare in Africa. *Ecol. Sociol.*, 14(1), 48.

5. Maayiem D., Bernard B.N. and Irunuoh A.O. (2012). Indigenous knowledge of termite control: A case study of five farming communities in Gushegu District of Northern Ghana. *J. Entomol. Nematol.*, 4(6), 58-64.

6. Verma M., Sharma S. and Prasad R. (2009). Biological alternatives for termite control: a review. *International Biodeterior. Biodegrad*., 63(8), 959-972.

7. Machar Y., Benjamin M.J., Deng C. and Tahir E. (2016). Coconut seedling (*Cocos nucifera*) losses due to termite pest species and possible control measures. *African J. Agric.*, 3(3), 148-153.

8. Rust M.K. and Su N.Y. (2012). Managing social insects of urban importance. *Annu. Rev. Entomol.*, 57(1), 355-375.

9. Umeh V.C., Waliyar F., Traore S. and Egwurube E. (1999). Soil pests of groundnut in West Africa- species diversity, damage and estimation of yield losses. *Insect Sci. Appl.*, 19(2), 131-140.

10. Sekamatte B.M., Ogenga-latigo M. and Russell-smith A. (2003). Effects of maize - legume intercrops on termite damage to maize, activity of predatory ants and maize yields in Uganda. *Crop Prot.*, 22(1), 87-93.

11. Sileshi G.W., Kuntashula E., Matakala P. and Nkunika P. O. (2008). Farmers' perceptions of tree mortality, pests and pest management practices in agroforestry in Malawi, Mozambique and Zambia. *Agroforest Syst.*, 72(2), 87-101.

12. Eggleton P. (2000). Global patterns of termite diversity. *Termites: Evolution, Sociality, Symbioses and Ecology*, Kluwer, Academic publishers, Dordrecht, Netherlands, 25-51.

13. Davies A.B., Baldeck C.A. and Asner G.P. (2016). Termite mounds alter the spatial distribution of African savanna tree species. *J. Biogeogr.*, 43(2), 301-313.

14. Sileshi G.W., Arshad M.A., Konaté S. and Nkunika P.O. (2010). Termite-induced heterogeneity in African savanna vegetation: mechanisms and patterns. *Journal of vegetation science*, 21(5), 923-937.

15. Shiday B.M., Nkunika P.O.Y., Sileshi G.W., French J.R., Nyeko P. and Jain S. (2011). Potential impact of climate change on termite distribution in Africa. *Br. J. Environ. Clim. Chang.*, 1(4), 172-189.

16. Nalepa C.A. (2011). Body size and termite evolution. *Evol. Biol.*, 38(3), 243-257.

17. Popoola K.O. and Opayele A.V. (2012). Morphometrics of *Macrotermes bellicosus* (African mound termite) (Blattodea:Termitidae) and the impact of its saliva amylase on the strength of termitarium soil. *New York Sci. J.,* 5(12), 207-216.

18. Loko L.E., Orobiyi A., Agre P., Dansi A., Tamò M. and Roisin Y. (2017). Farmers' perception of termites in agriculture production and their indigenous utilization in Northwest Benin. *J. Ethnobiol. Ethnomed.*, 13(1), 64.

19. Hager F.A. and Kirchner W.H. (2013). Vibrational long-distance communication in the termites *Macrotermes natalensis* and *Odontotermes* sp. *J. Exp. Biol.*, 216(17), 3249-3256.

20. Cowie R.H., Wooo T.G., Barnett E.A., Sands W.A. and Black H.I. (1990). A checklist of the termites of Ethiopia with a review of their biology, distribution and pest status. *Afr. J. Ecol.*, 28(1), 21-33.

21. Zeidler J., Hanrahan S. and Scholes M. (2004). Determining termite diversity in arid Namibian rangelands - a comparison of sampling methods. *African Zool.*, 39(2), 285-292.

22. Attignon S.E., Lachat T., Sinsin B., Nagel P. and Peveling R. (2005). Termite assemblages in a West-African semi-deciduous forest and teak plantations. *Agriculture, Ecosyst. Environ.*, 110, 318-326.

23. Sane H., Samb T., Ndiaye A.B. and Tidiane Ba C. (2016). Etude de la diversite des termites (Isoptera) dans quelques localites de la region de Kolda (Haute Casamance, Senegal). *Eur. Sci. J.,* 12(33).

24. Krasulová J., Hanus R., Kutalová K., Šobotník J., Sillam-Dussès D., Tichý M. and Valterová I. (2012). Chemistry and anatomy of the frontal gland in soldiers of the sand termite Psammotermes hybostoma. *J. Chem. Ecol.*, 38(5), 557-565.

25. Turner S., Marais E., Vinte M., Mudengi A. and Park W. (2006). Termites, water and soils. *Agric.*, 16, 40-45.

26. Kambhampati S. and Eggleton P. (2000). Phylogeny and Taxonomy. Termites: Evolution, Sociality Symbioses and Ecology. Kluwer, Academic Publishers, Dordrecht, Netherlands. 1-24.

27. Geerts S., van der Linden J. and van der Linden E. (2016). The ecology and foraging behaviour of the harvester termite, *Baucaliotermes hainesi* in semi-arid grasslands in the northwestern interior of South Africa. *Insec. Soc.,* 63(3), 457-465.

28. Jmhasly P.and Leuthold R.H. (1999). Intraspecific colony recognition in the termites *Macrotermes subhyalinus* and *Macrotermes bellicosus* (Isoptera, Termitidae). *Insec. Soc.*, 46(2), 164-170.

29. Maniania N.K., Ekesi S. and Songa J.M. (2001). Managing termites in maize with the entomopathogenic fungus metarhizium. *Insec. Sci. Appl.*, 22(1), 41-46.

30. Riekert H.F. and Van Den Berg J. (2003). Evaluation of chemical control measures for termites in maize. *South African J. Plant Soil.,* 20(1), 1-5.

31. Paul B.K., Vanlauwe B., Hoogmoed M., Hurisso T.T., Ndabamenye T., Terano Y. and Pulleman M.M. (2015). Exclusion of soil macrofauna did not affect soil quality but increased crop yields in a sub-humid tropical maize-based system. *Agric. Ecosyst. Environ.,* 208, 75-85.

32. Orikiriza B., Nyeko P. and Sekamatte B.M. (2012). Farmers' knowledge, perceptions and control of pestiferous termites in Nakasongola district, Uganda. *Uganda J. Agric. Sci.*, 13(1), 71-83.

33. Nwilene F.E., Agunbiade T.A., Togola M.A., Youm O., Ajayi O., Oikeh S.O. and Falola O.O. (2008). Efficacy of traditional practices and botanicals for the control of termites on rice at Ikenne , southwest Nigeria. *Int. J. Trop. Insect Sci.*, 28(1), 37-44.

34. Ibrahim B.U. and Adebote D.A. (2012). Appraisal of the economic activities of termites: A review. *Bayero Int. J. Pure App. Biosci.*, 5(1), 84-89.

35. Sekamatte B.M. (2001). Options for integrated management of termites (Isoptera: Termitidae) in smallholder maize-based cropping systems in Uganda. PhD Thesis. Makerere University, Kampala, uganda, 1-289.

36. Nyeko P. and Olubayo F. (2005). Participatory assessment of farmers' experiences of termite problems in agroforestry in Todoro district, Uganda. *Agric. Res. Ext. Netw.*, 143, 1-15.

37. Addisu S., Mohamed D. and Woktole S. (2013). Efficacy of botanicals extracts against termites *Macrotermes* spp., under laboratory conditions. *Int. J. Agric. Res.*, 9, 60-73.

38. Ghaly A. and Edwards S. (2011). Termite damage to buildings : nature of attacks and preventive construction methods. *Am. J. Eng. Appl. Sci.*, 4(2), 187-200.

39. Chaudhary S., Kanwar R.K., Sehgal A. and Cahill D.M. (2017). Progress on *Azadirachta indica*based biopesticides in replacing synthetic toxic pesticides. *J. Front. plant Sci.*, 8(610), 1-13.

40. Kamble S.T., Ogg C.L., Gold R.E. and Vance A.D. (1992). Exposure of applicators and residents to Chlordane and Heptachlor when used for subterranean termite control. *Arch. Biol. Sci.*, 22, 253-259.

41. Forschler B.T. and Townsend A.L. (1996). Mortality of eastern subterranean termites(Isoptera : Rhinotermitidae) exposed to four soils treated with termiticides. *J. Econ. Entomol.*, 89(3), 678-681.

42. Mulrooney J.E., Davis M.K. and Wagner T.L. (2006). Persistence and efficacy of termiticides used in preconstruction treatments to soil in Mississippi. *J. Econ. Entomol.*, 99(2), 469-475.

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

44. Slaper H., Velders G.J., Daniel J.S., de Gruijl F.R. and van der Leun J.C. (1996). Estimates of ozone depletion and skin cancer incidence to examine the Vienna Convention achievements. *Lett. to Nat.*, 384, 256-258.

45. Su N-Y., Ban P.M. and Scheffrahn R. (1999). Longevity and efficacy of pyrethroid and organophosphate termiticides in field degradation studies using miniature slabs. *J. Econ. Entomol.*, 92(4), 890-898.

46. Parman V. and Vargo E.L. (2010). Colony-level effects of imidacloprid in subterranean termites (Isoptera : Rhinotermitidae). *J. Econ. Entomol.*, 103(3), 791-798.

47. Rakshiya Y.S., Verma M.K. and Sindhu S.S. (2016). Efficacy of antagonistic soil bacteria in management of subterranean termites (Isoptera). *Res. Environ. Life Sci.*, 9(8), 949-955.

48. Watson S. (2014). Assessing the impacts of unrestricted pesticide use in small-scale agriculture on water quality and associated human health and ecological implications in an indigenous village in rural Panam [aacute]. Master's thesis,University of South Florida.

49. Johnson R.M., Ellis M.J., Mullin C.A. and Frazier M. (2010). Review article pesticides and honey bee toxicity - USA. *Apidol.*, 41(3), 312-331.

50. Mitra A., Chatterjee C. and Mandal F.B. (2011). Synthetic chemical pesticides and their effects on birds. *Res. J. Environ. Toxicol.*, 5(2), 81-96.

51. Weichenthal S., Moase C.and Chan P. (2010). A review of pesticide exposure and cancer incidence in the agricultural health study cohort. *Environ. Health Perspect.*, 118(8), 1117-1125.

52. Saxena P. (2014). Comparative prediction of binding site of organophosphorus, carbamate and synthetic pyrethroid pesticides on human cyclin-dependent protein kinases. *J. Entomol. Zool. Stud.*, 2(2), 106-110.

53. Mnif W., Hassine A., Bouaziz A., Bartegi A., Thomas O. and Roig B. (2011). Effect of endocrine disruptor pesticides: A review. *Int. J. Environ. Res. Public Health.*, 8(6), 2265-2303.

54. Mkindi A.G., Mtei K.M., Njau K.N. and Ndakidemi P.A. (2015). The potential of using indigenous pesticidal plants for insect pest control to small scale farmers in Africa. *Am. J. Plant Sci.*, 6(19), 3164-3174.

55. Lodhi S. and Mikulecky P. (2010). Management of indigenous knowledge for developing countries. *International Conference on Communication and Management in Technological Innovation and Academic Globalization*., 94-98. ISBN: 978-960-474-254-7.

56. Sukula S.K. (2006). Developing indigenous knowledge databases in India. *Electron. Libr.*, 24(1), 83-93.

57. Logan J., Cowie R. and Wood T. (1990). Termite (Isoptera) control in agriculture and forestry by non-chemical methods: A review. *Bullet. Entomol. Res.*, 80(3), 309-330.

58. Banjo A.D., Lawal O.A., Fapojuwo O.E. and Songonuga E. A. (2003). Farmers' knowledge and perception of horticultural insect pest problems in southwestern Nigeria. *African J. Biotechnol.*, 2(11), 434-437.

59. Malaret L. and Ngoru F. (1989). Ethno-ecology: a tool for community based pest management farmer knowledge of termites in Machakos district, Kenya. *Sociobiol.*, 15(2), 197-211.

60. Mihale M.J., Deng A.L., Selemani H.O., Mugisha-Kamatenesi M., Kidukuli A.W. and Ogendo J.O. (2009). Use of indigenous knowledge in the management of field and storage pests around Lake Victoria basin in Tanzania. *African J. Environ. Sci. Technol.*, 3(9), 251-259.

61. Sileshi G., Mafongoya P., Kwesiga F. and Nkunika P. (2005). Termite damage to maize grown in agroforestry systems, traditional fallows and monoculture on nitrogen-limited soils in Eastern Zambia. *Agric. For. Entomol.*, 7(1), 61-69.

62. Eilenberg J., Hajek A. and Lomer C. (2001). Suggestions for unifying the terminology in biological control. *BioCont.*, 46(4), 387-400.

63. Maredia K.M., Dakouo D. and Mota-Sanchez D. (2003). Integrated pest management in the global Arena. CAB International, Wallingford, UK.ISBN: 0-85199-652-3.

64. Sindhu S.S., Rakshiya Y.S. and Verma M.K. (2011). Biological control of termites by antagonistic soil microorganisms. *Bioa. Bios. Biocont.*, 108, 261-309.

65. Shahid A.A., Rao A.Q., Bakhsh A. and Husnain T. (2012). Entomopathogenic fungi as biological controllers: new insights into their virulence and pathogenicity. *Arch. Biol. Sci.*, 64(1), 21-42.

66. Sajap A.S., Rozihawati Z., Omar D. and Lau W.H. (2014). *Isaria fumosorosea*and *Metarhizium anisopliae*for controlling*Atteva sciodoxa* (Lepidoptera : Yponomeutidae), a pest of *Eurycoma longifolia*. *J. Trop. For. Sci.*, 26(1), 84-91.

67. Wright M.S. and Cornelius M.L. (2012). Mortality and repellent effects of microbial pathogens on *Coptotermes formosanus* (Isoptera : Rhinotermitidae). *BMC Microbiol.*, 12.

68. Azmi W.A., Sulaiman Z.A., Ishak I., Kin P.K., Lin G. L. and Addis S.N. (2016). Virulence evaluation of entomopathogenic fungi to subterranean termites, Globitermes sulphureus (Insecta: Isoptera). *Malays. J. Microbiol.*, 12(6), 492-497.

69. Singha D., Singha B. and Dutta B.K. (2011). Potential of *Metarhizium anisopliae* and *Beauveria bassiana* in the control of tea termite *Microtermes obesi* Holmgren in vitro and under field conditions. *J. Pest Sci.*, 84(1), 69-75.

70. Staples J. and Milner R. (2000). A laboratory evaluation of the repellency of *Metarhizium anisopliae* conidia to *Coptotermes lacteus* (Isoptera: Rhinotermitidae). *Sociobiol.*, 36(1), 133-148.

71. Myles T.G. (2002). Alarm, aggregation, and defense by *Reticulitermes flavipes* in response to a naturally occurring isolation of*Metarhizium anisopliae*. *Sociobiol.*, 40(2), 243-255.

72. Zadji L., Baimey H., Afouda L., Moens M. and Decraemer W. (2014). Effectiveness of different Heterorhabditis isolates from Southern Benin for biocontrol of the subterranean termite, *Macrotermes bellicosus* (Isoptera : Macrotermitinae), in laboratory trials. *Nematol.*, 16(1), 109-120.

73. Burnell A.M. and Stock S.P. (2000). Heterorhabditis, Steinernema and their bacterial symbionts - lethal pathogens of insects. *Nematol.*, 2(1), 31-42.

74. Bai C., Shapiro-ilan D.I., Gaugler R. and Hopper K.R. (2005). Stabilization of beneficial traits in *Heterorhabditis bacteriophora* through creation of inbreed lines. *Biol. Contr.*, 32(2), 220-227.

75. Kaya H.K. and Gaugler R. (1993). Entomopathogenic nematodes. *Annu. Rev. Res. Biol.*, 38(1), 181-206.

76. Campbell J.F. and Lewis E.E. (2002). Entomopathogenic nematode host search strategies. Wallingford, UK, CAB International, 13-38. ISBN: 0851996159.

77. Poinar G.O. (1990). Biology and taxonomy of Steinernematidae and Heterorhabditidae. Boca Raton, FL, USA, CRC Press, 23-62.

78. Trudeau D. (1989). Selection of entomophilic nematodes for control of the eastern subterranean termite, *Reticulitermes flavipes (Kollar)* (Isoptera: Rhinotermitidae). Master's Thesis, University of Toronto,Ontario, Canada, 1-93.

79. Yu H., Gouge D.H. and Baker P. (2006). Parasitism of subterranean termites (Isoptera: Rhinotermitidae:Termitidae) by entomopathogenic nematodes (Rhabditida: Steinernematidae; Heterorhabditidae). *J. Econ. Entomol.*, 99(4), 1112-1119.

80. Epsky N.D. and Capinera A.L. (1988). Efficacy of the entomogenous nematode, *Steinernema feltiae* against a subterranean termite, *Reticulitermes tibialis* (Isoptera : Rhinotermitidae). *J. Econ. Entomol.*, 81(5), 1313-1317.

81. Rathour K.S., Ganguly S., Anupama Das T.K., Singh P., Kumar A. and Somvanshi V.S. (2014). Biological management of subterranean termites (*Odontotermes obesus*) infesting wheat and pearl millet crops by entomopathogenic nematodes. *Indian J. Nematol.*, 44(1), 97-100.

82. Darby C., Cosma C.L., Thomas J.H. and Manoil C. (1999). Lethal paralysis of *Caenorhabditis elegans* by *Pseudomonas aeruginosa*. *Proc. Natl. Acad. Sci.*, 96(26), 15202-15207.

83. Gallagher L.A. and Manoil C. (2001). *Pseudomonas aeruginosa PAO1 kills Caenorhabditis elegans* by cyanide poisoning. *J. Bacteriol.*, 183(21), 6207-6214.

84. Devi K.K., Seth N., Kothamasi S. and Kothamasi D. (2007). Hydrogen Cyanide-Producing Rhizobacteria Kill Subterranean Termite *Odontotermes obesus* (Rambur) by Cyanide Poisoning Under In Vitro Conditions. *Curr. Microbiol.*, 54(1), 74-78.

85. Dubey N.K., Srivastava B. and Kumar A. (2008). Current status of plant products as botanical pesticides in storage pest management. *J. Biopestic.*, 1(2), 182-186.

86. Dubey N.K. (2011). Natural products in plant pest management. CABI publishing, UK. ISBN:978-84593-671-6.

87. Mugisha-Kamatenesi M., Deng A.L., Ogendo J.O., Omolo E.O., Mihale M.J., Otim M. and Bett P. (2008). Indigenous knowledge of field insect pests and their management around lake Victoria basin in Uganda. *African J. Appl. Agric. Sci. Technol.*, 2(10), 342-348.

88. Amoabeng B.W., Gurr G.M., Gitau C.W. and Stevenson P. C. (2014). Cost benefit analysis of botanical insecticide use in cabbage : Implications for smallholder farmers in developing countries. *Crop Prot.*, 57, 71-76.

89. Belmain S. and Stevenson P. (2001). Ethnobotanicals in Ghana: reviving and modernising age-old farmer practice. *Pesticide outlook*, 12(6), 233-238.

90. Mekonnen M., Manhile B. and Mengesha B. (2014). Screening of botanical extracts for the control of spearmint leaf rust in greenhouse and field conditions. *World J. Agric. Sci.*, 10(2), 42-47.

91. Yuan Z. and Hu X.P. (2012). Repellent, antifeedant, and toxic activities of *Lantana camara* leaf extract against*Reticulitermes flavipes* (Isoptera : Rhinotermitidae). *J. Econ. Entomol.*, 105(6), 2115-2121.

92. Mohareb A., Sirmah P., Desharnais L., Dumarcay S., Pétrissans M. and Gérardin P. (2010). Effect of extractives on conferred and natural durability of *Cupressus lusitanica* heartwood. *Ann. For. Sci.*, 67(5), 504-504.

93. Bett P.K., Deng A.L., Ogendo J.O., Kariuki S.T., Kamatenesi-mugisha M., Mihale J.M. and Torto B. (2016). Chemical composition of *Cupressus lusitanica* and *Eucalyptus saligna* leaf essential oils and bioactivity against major insect pests of stored food grains. *Ind. Crop. Prod.*, 82, 51-62.

94. Jeong S., Lim J.P. and Jeon H. (2007). Chemical composition and antibacterial activities of the essential oil from *Abies koreana*. *Phyther. Res.*, 21, 1246-1250.

95. Kordali S., Cakir A., Ozer H., Cakmakci R., Kesdek M. and Mete E. (2008). Antifungal, phytotoxic and insecticidal properties of essential oil isolated from Turkish Origanum acutidens and its three components, carvacrol, thymol and p-cymene. *Bioresource Technology*, 99(18), 8788-8795.

96. Hassanzadeh S., Tuten J., Vogler B. and Setzer W. (2010). The chemical composition and antimicrobial activity of the leaf oil of *Cupressus lusitanica* from Monteverde, Costa Rica. *Pharmacognosy Res.*, 2(1), 19-21.

97. Bett P.K., Deng A.L., Ogendo J.O., Kamatenesi-Mughisha M. and Mihale J.M. (2013). Toxic and repellent properties of Cupressus lusitanica and Eucalyptus saligna essential oils against Callosbrochus chinesis and Sitophilus zeamais. Proceedings of the First International Conference on Pesticidal Plant*s*. Egerton University, 121-123.

98. Kamatenesi-Mugisha M., Buyungo J.P., Ogwal P., Kasibante A., Deng A.L., Ogendo J.O. and Mihale M.J. (2013). Oral acute toxicity study of selected botanical pesticide plants used by subsistence farmers around the Lake Victoria Basin. *African J. Sci. Technol.,* 7(3), 93-101.

99. Tsegay B.A., Weldeyes A.T. and Cardelús C.L. (2018). Traditional use of botanicals in reducing post harvest loss at crop stacking stage in Ethiopia : A case of Farta district. 17, 534-541.

100. Ebadollahi A. (2013). Essential oils isolated from myrtaceae family as natural insecticides. *Annu. Rev. Res. Biol.*, 3(3), 148-175.

101. Batish D.R., Singh H.P., Kohli R.K. and Kaur S. (2008). Forest ecology and management eucalyptus essential oil as a natural pesticide. *For. Ecol. Manage.*, 256(12), 2166-2174.

102. Toloza A.C., Zygadlo J., Mougabure Cueto G., Biurrun F., Zerba E. and Picollo M.I. (2006). Fumigant and repellent properties of essential oils and component compounds against permethrin-resistant *Pediculushumanus capitis* (Anoplura: Pediculidae) from Argentina. *J. Med. Entomol.*, 43(5), 889-895.

103. Tarelli G., Zerba E.N. and Alzogaray R.A. (2009). Toxicity to vapor exposure and topical application of essential oils and monoterpenes on *Musca domestica* Diptera: Muscidae). *J. Econ. Entomol.*, 102(3), 1383-1388.

104. Sfara V., Zerba E.N. and Alzogaray R.A. (2009). Fumigant insecticidal activity and repellent effect of five essential oils and seven monoterpenes on first-instar nymphs of *Rhodnius prolixus*. *J. Med. Entomol.*, 46(3), 511-515.

105. Juan L.W., Lucia A., Zerba E.N., Harrand L., Marco M. and Masuh H. (2011). Chemical composition and fumigant toxicity of the essential oils from 16 species of eucalyptus against *Haematobia irritans* (Diptera : Muscidae) adults. *J. Econ. Entomol.*, 104(3), 1087-1092.

106. van Andel T.R., Croft S., van Loon E.E., Quiroz D., Towns A.M. and Raes N. (2015). Prioritizing West African medicinal plants for conservation and sustainable extraction studies based on market surveys and species distribution models. *Biol. Conserv.*, 181, 173-181.

107. Southwell I.A., Russell M.F., Maddox C.D.A. and Wheeler G.S. (2003). Differential metabolism of 1,8-cineole in insects. *J. Chem. Ecol.*, 29(1), 83-94.

108. Ibrahim B., Mounzeo H. and Bourobou H.P. (2000). Effect of *Tephrosia Togelii* and *Justicia extensa* on *Tilapia nilotica* i*n vivo*. *J. Ethnopharmacol.*, 69(2), 99-104.

109. Stevenson P.C., Kite G.C., Lewis G.P., Forest F., Nyirenda S.P., Belmain S.R. and Veitch N.C. (2012). Distinct chemotypes of *Tephrosia vogelii* and implications for their use in pest control and soil enrichment. *Phytochem.*, 78, 135-146.

110. Belmain S.R., Amoah B.A., Nyirenda S.P., Kamanula J. F. and Stevenson P.C. (2012). Highly variable insect control efficacy of *Tephrosia vogelii*chemotypes. *J. Agric. Food Chem.*, 60(40), 10055-10063.

111. Kalume M.K., Losson B., Angenot L., Tits M., Wauters J. N. and Frédérich M. (2012). Veterinary parasitology rotenoid content and in vitro acaricidal activity of *Tephrosia vogelii* leaf extract on the tick *Rhipicephalus appendiculatus*. *Vet. Parasitol.*, 190, 204-209.

112. Neuwinger H.D. (2004). Plants used for poison fishing in tropical Africa. *Toxicon.*, 44(4), 417-430.

113. Wang R., Yang X., Song Y., Zhang M., hu L., Su Y. and Zeng R. (2011). Allelopathic potential *of Tephrosia vogelii* Hook, Laboratory and field evaluation. *Allelopath. J.,* 28(1), 53-61.

114. Igogo J.M., Ogendo J.O., Kariuki S.T. and Otaye D.O. (2011). Insecticidal, antifeedant and repellent effects of *Tephrosia vogelii* Hook, and *Lantana camara* L. aqueous crude extracts against golden flea beetle, *Aphthona whitfieldi* Bryant in Jatropha. *Jatropha curcas* L. *Biopestic. Int.*, 7(2), 93-103.

115. Khater H.F. (2012). Prospects of botanical biopesticides in insect pest management. *Pharmacologia*, 3(12), 641-656.

116. Ishida M., Serit M., Nakata K., Juneja L.R., Kim M. and Takahashi S. (1992). Several antifeedant from neem oil, *Azadirachta indica*against *Reticulitermes speratus* Kolbe (Isoptera:Rhinotermitidae). *Biosci. Biotechnol. Biochem.*, 56(11), 1835-1838.

117. Akhtar Y., Yeoung Y.R. and Isman M.B. (2008). Comparative bioactivity of selected extracts from Meliaceae and some commercial botanical insecticides against two noctuid caterpillars. *Trichoplusia ni* and *Pseudaletia unipuncta*. *Phytochem. Rev.*, 7, 77-88.

118. El-Samahy M.F., El- Ghobary A.M. and Khafagy I.F. (2014). Using silica nanoparticles and neemoil extract as new approaches to control*Tuta absoluta* (Meyrick) in tomato under field conditions. *Int. J. Plant Soil Sci.*, 3(10), 1355-1365.

119. Govindachari T.R., Narasimhan N.S., Suresh G., Partho P. D. and Gopalakrishnan G. (1996). Insect antifeedant and growth-regulating activities of salannin and other C-Seco limonoidsfrom neem oil in relation to azadirachtin. *J. Chem. Ecol.*, 22(8), 1453-1461.

120. Ghisalberti E.L. (2000). Lantana camara L. (Verbenaceae). *Fitoterapia.*, 71, 467-486.

121. Baars J. and Neser S. (1999). Past and present initiatives on the biological control of *Lantana camara* (Verbenaceae) in South Africa. *African Entomol. Mem.*, 1, 21-33.

122. Verma R.K. and Verma S.K. (2006). Phytochemical and termiticidal study of *Lantana camara* var. aculeata leaves. *Fitoterapia.*, 77, 466-468.

123. Bevilacqua A.H.V., Suffredini I.B., Romoff P., Lago J.H. G. and Bernardi M.M. (2011). Research in veterinary science toxicity of apolar and polar *Lantana camara* L. crude extracts in mice. *Res. Vet. Sci.*, 90(1), 106-115.

124. Mello F.B., Jacobus D., Carvalho K. and Mello J.R.B. (2005). Effects of *Lantana camara* (Verbenaceae) on general reproductive performance and teratology in rats. *Toxicon.*, 45(4), 459-466.

125. Zoubiri S. and Baaliouamer A. (2012). GC and GC / MS analyses of the Algerian *Lantana camara* leaf essential oil: effect against *Sitophilus granarius* adults. *J. Saudi Chem. Soc.*, 16(3), 291-297.

126. Rajashekar Y., Vijay H., Ravindra K.V. and Bakthavatsalam N. (2013). Isolation and characterization of biofumigant from leaves of *Lantana camara* for control of stored grain insect pests. *Ind. Crop. Prod.,* 51, 224-228.

127. Rajashekar Y., Raghavendra A. and Bakthavatsalam N. (2014). Acetylcholinesterase inhibition by biofumigant (Coumaran) from leaves of *Lantana camara* in stored grain and household insect pests. *Biomed Res. Int.,* Article ID: 187019.

128. Kazmi I., Afzal M., Ali B., Damanhouri Z.A. and Ahmaol A. (2013). Anxiolytic potential of ursolic acid derivative-a stearoyl glucoside isolated from *Lantana camara* L. (verbanaceae). *Asian Pac. J. Trop. Med.*, 6(6), 433-437.