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# Termite species identification and management using botanical pesticides in Arusha, Tanzania

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# TERMITE SPECIES IDENTIFICATION AND MANAGEMENT USING BOTANICAL PESTICIDES IN ARUSHA, TANZANIA

**Shaban James**

**A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Master's in Life Sciences of the Nelson Mandela African institution of Science and Technology**

**Arusha, Tanzania**

**April, 2019**

**ABSTRACT**

A study was conducted at Kikwe ward in Arumeru District of Arusha region to assess the effects of *Cupressus lusitanica*, *Tephrosia vogelii*, *Eucalpytus dalrympleana*, *Lantana camara* and *Azadirachta indica* in managing destructive termite species. Termite samples were collected from maize farms and trees within the ward and were identified at the Tropical Pesticides Research Institute. Different rates of powders weighing 5g, 10g and 20g of each botanical per 5 kg of termite infested soils were tested for their effects on termite mortality and repellency in the laboratory using a completely randomized design (CRD) with three replications. In field trials, a randomized complete block design (RCBD) with four replications was used in three different sites within the ward. Following laboratory studies, 20g of leaf powder from each treatment was applied around maize plants and monitored for every 14 days. The results showed that, there were five morphologically different termite species in the study area, two of which were identified as *Macrotermes* and *Odontotermes* and the rest were not identified based on the available capacity. The results also showed that, powders from *T. vogelii*, *C. lusitanica* and *E. dalrympleana* were effective in managing termites and significant different ($p<0.001$) from other plants. Such results highlight potentiality of developing bio-termiticides from *T. vogelii*, *C. lusitanica* and *E. dalrympleana* in the country. Further studies are recommended on characterizing termite species that were not identified in this study and on identification of chemical ingredients from the identified effective plants for formulation of bio-termiticides in Tanzania.

## DECLARATION

I, Shaban James do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

Mr. Shaban James
**Name and signature of candidate**

05/04/2019
**Date**

The above declaration is confirmed;

Dr. Ernest R. Mbega
**Name and signature of Principal supervisor**

05.04.2019
**Date**

Prof. Patrick A. Ndakidemi
**Name and signature of Co-supervisor**

5/4/2019
**Date**

# COPYRIGHT

# CERTIFICATION

This is to certify that, the dissertation titled "Termite Species Identification and Their Sustainable Management Using Botanical Pesticides in Arusha, Tanzania" submitted by Shaban James (M. 387/T.16) in partial fulfillment of the requirements for the award of Master's in Life Sciences of the Nelson Mandela African Institution of Science and Technology.

05.04.2019

Dr. Ernest R. Mbega — Date

Name and signature of Principal supervisor

5/04/2019

Prof. Patrick A. Ndakidemi — Date

Name and signature of Co-supervisor

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To be honest I would like to be clear that no one can walk alone in the journey of career development just like in this study.

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# DEDICATION

I dedicate this work from my heart felt and thank my beloved wife, Eutropia Mathias Kileo and my son Elia S. James for their love, support, encouragement, prayers and tolerance at the time when I was away for study purpose.

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## LIST OF ABBREVIATION AND SYMBOLS

| | |
|---|---|
| AfDB | African Development Bank |
| ANOVA | Analysis of Variance |
| C | Carbon |
| cm | Centimeter |
| CRD | Completely randomized design |
| g | gram |
| GenStat | General Statistics |
| K | Potassium |
| kg | kilogram |
| LSD | Least Significant Differences |
| m | Meter |
| $m^2$ | Meter square |
| N | Nitrogen |
| NM-AIST | Nelson Mandela African Institution of Science and Technology |
| P | Phosphorus |
| P | Probability |
| pH | Potential hydrogen |
| RCBD | Randomized complete block design |
| Temp | Temperature |
| TPRI | Tropical Pesticides Research Institute |
| USA | United States of America |
| WHO | World Health Organization |
| $ | Dollar sign |
| % | Percent |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background

Termites are insects which belongs to order Isoptera and are usually found in organized colonies in warm terrestrial environments (Inward *et al.*, 2007; Singha *et al.*, 2010). They contribute significantly to the ecosystems of the world through decomposing and recycling wooden components (Verma *et al.*, 2009; Jasmi and Ahmad, 2011). Their activities in the soil contribute to both improved aeration and soil nutrients by adding Nitrogen (N) and Carbon (C) through Nitrogen (N) fixation and Carbon (C) mineralization, respectively (Jasmi and Ahmad, 2011). Termites are known primarily for their ability to damage woody plant parts and crops (Midega *et al.*, 2016), attacking different structures of buildings and inhibit production of trees of economic importance globally (Sileshi *et al.*, 2009; Verma *et al.*, 2009; Maayiem *et al.*, 2012).

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) (Verma *et al.*, 2009; Maayiem *et al.*, 2012; Machar *et al.*, 2016). These species have been documented as among insect pests which destroy various crops around the world. For example, termite damage cases have been reported to cause a loss of about $ 40 billion in terms of buying synthetic pesticides purposely to manage termites and repair destroyed wooden properties globally (Maayiem *et al.*, 2012; Rust and Su, 2012). In some African countries such as Mozambique, Zambia, Uganda and Malawi, the termite effects on different crops such as maize have been reported (Sekamatte *et al.*, 2003; Sileshi *et al.*, 2007). In other African countries such as Nigeria, Burkina-Faso, Niger and Mali losses amounting to 30% in groundnuts have been reported (Umeh *et al.*, 1999). In Tanzania, damage by termites on coconuts has been reported especially during the dry seasons (Machar *et al.*, 2016). In Arusha, termites have been reported to attack maize, some trees in gardens, farmlands and public parks (Mwalongo *et al.*, 1999; Abate *et al.*, 2000).

Managing termites is possible with use of synthetic pesticides, however, the chemicals are hazardous to the environment and people (Weichenthal *et al.*, 2010). Thus, search for alternative affordable, eco-friendly and appropriate management strategies for termites such as use of bio-pesticidal plants is urgently needed. This research therefore, aims at understanding the effects of *Tephrosia vogelii, Eucalyptus dalrympleana, Azadirachta indica, Cupressus lusitanica* and *Lantana camara* leaf powders as sustainable alternative inputs to synthetic pesticides.

## 1.2 Problem Statement

Termite destruction on agricultural crops and wooden properties has brought a great economic loss worldwide (Verma *et al.*, 2009). Huge funds are being spent annually to buy synthetic pesticides for the purpose of controlling termites and repairing wooden structures in buildings. In some countries such as USA, around $ 3 billion is used to buy synthetic pesticides and repairing of buildings annually (Carr, 2006). In Malaysia, more than $ 11 million has been reported to be used in management of termites (Ngee *et al.*, 2004) while in Africa, a loss of 15-100% in crops due to termite damage has been reported (Janssen, 2006). Ghana for instance, has been reported to face a loss on groundnuts due to termite damage of up to 100% (Maayiem *et al.*, 2012), Ethiopia 45-50% loss in maize per year (Addisu *et al.*, 2014), and in Tanzania, a loss of about 20-100% has been documented as a loss due to termites in crops (Machar *et al.*, 2016). In Arusha region particularly Arumeru District there is high devastation of maize farms and trees of economic importance by termites and no information or management is available.

This research therefore, aimed at understanding the potential use of plants as bio-pesticides from selected botanicals that are locally available, cheap and eco-friendly to find solutions for the small scale farmers on crop loss and cost associated with termites.

## 1.3 Research Justification

Efforts have been made by farmers and householders on termite control using synthetic chemical pesticides to the farms and plantations. However, synthetic pesticides are very expensive, need skilled people and can cause health problems among workers (Maayiem *et al.*, 2012). Their residues can have long half-life in the environment (Chaudhary *et al.*, 2017), can affect non-targeted massive organisms / biodiversity (Chaudhary *et al.*, 2017). Dangerous diseases such as cancer to humans have been reported and most of them have been associated with exposure of synthetic pesticides (Weichenthal *et al.*, 2010). In a brighter alternative, insecticidal plant compounds have been cited to be good for termite management (Chaudhary *et al.*, 2017). The insecticidal plant occurs naturally, degrade easily when exposed to the sunlight and therefore have very short half-life of persistence to the environment and usually they have little negative effects to non-targeted insects, human health and environment (Dubey *et al.*, 2008; Mkindi *et al.*, 2015; Chaudhary *et al.*, 2017). In addition, plant pesticides degrade into harmless substances ranging from few seconds, hours and even a day (Dubey, 2011), they decompose and contribute to soil fertility (Stevenson *et al.*, 2012).

In this regard, the study aimed identifying common termites and assessing the efficacy of plant pesticides from *Tephrosia vogelii, Eucalyptus dalrympleana, Azadirachta indica, Cupressus lusitanica* and *Lantana camara* as alternative pesticides to synthetic pesticides in management of termites for small scale farmers so that to minimize health risks to humans, maintain biodiversity and protect crops as well as trees of economic value at low cost.

## 1.4 Research Objectives

### 1.4.1 Overall objective

The overall objective of this study was to identify termite species, test and evaluate the effectiveness of botanical pesticides for termite management in Arusha region, Tanzania.

### 1.4.2 Specific objectives

(i) To identify termite species that damage maize crops and trees of economic importance in Arumeru District

(ii) To screen the effective selected pesticidal plants for controlling termites under laboratory conditions

(iii) To assess the repellency ability of the selected pesticidal plants on termites under laboratory conditions

(iv) To assess the efficiency of selected pesticidal plants in termite management under field conditions in Arumeru District.

## 1.5 Research questions

(i) Which species of termites inflict most damage on maize farms and trees of economic values?

(ii) What are the effective pesticidal plants for controlling termites under laboratory conditions?

(iii) Which among selected botanicals have significant repellency against termites under laboratory conditions?

(iv) What are the best performing pesticidal plants under small scale farm conditions?

## 1.6 Study significance

The proposed study contributes to a better understanding of termite and the use of pesticidal plants for managing destructive termites. The study paves a way forward and recommends use of pesticidal plants as eco-friendly alternative for sustainable management of termites and sets a benchmark for future studies.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Termites classification, origin and distribution

Termites are insects which belong to order Isoptera (Inward *et al.*, 2007). Globally there are seven known termite families; Kalotermitidae, Hodotermitidae, Rhinotermitidae, Termitidae, Mastotermitidae, Termopsidae and Serritermitidae (Engel and Krishna, 2004). Four out of seven mentioned termite families, are richly found in Africa, especially Kalotermitidae, Hodotermitidae, Rhinotermitidae and Termitidae (Ahmed *et al.*, 2011). The species of family Rhinotermitidae and Kalotermitidae forage entirely on dried wooden materials (Ahmed *et al.*, 2011). Moreover, individual termites of Hodotermitidae are destructive species to grasses and timbers (Ahmed *et al.*, 2011). The Termitidae is the richest family which represents more than 601 living African species which cause a great destruction in crop plants, trees and wooden components (Eggleton, 2000).

Under Termitidae there are four subfamilies such as Termitinae, Nasutitermitinae, Macrotermitinae and Apicotermitinae (Eggleton, 2000). A total number of 272 species in Termitinae are known primarily as African termites (Eggleton *et al.*, 2002). About 70 African different species have been documented in the Apicotermitinae (Cowie *et al.*, 1990; Eggleton, 2000). Approximate of 56 species of Nasutitermitinae forage on litter of leaves and grass (Ahmed *et al.*, 2011). Also Macrotermitinae consists of unknown bigger figure than 165 African termite species which have been reported as insect pests in agricultural crops and various trees of economic values (Eggleton *et al.*, 1999). The most key genera of Macrotermitinae which cause great damage in agriculture and the natural environments are *Odontotermes*, *Microtermes* and *Macrotermes* (Kumar and Pardeshi, 2011; Debelo and Degaga, 2014; Machar *et al.*, 2016). High abundance and distribution of termites in Africa is supported with favourable conditions (Eggleton, 2000; Maayiem *et al.*, 2012). For instance, Africa alone has a high abundance of termites with more than 664 termite species diversity (Eggleton, 2000; Sileshi *et al.*, 2009). High abundance of termite animals has been documented from southern, western and eastern Africa, with few species recorded in Northern Africa (Sileshi *et al.*, 2010; Ahmed *et al.*, 2011). For example, a total number of 143 termite species has been reported in Eastern African countries such as Djibouti, Sudan, Somalia, Ethiopia and Eritrea (Sileshi *et al.*, 2010). Furthermore, from Southern Africa particularly Zimbabwe, Lesotho, South Africa, Botswana, Mozambique, Namibia, Malawi and Swaziland more than 160 species have been recorded (Ahmed *et al.*, 2011). Also documented information showed that over 75 different termite species are found in Western Africa (Eggleton *et al.*, 2002).

In light of the above it indicates that Africa is highly rich in variety of termites. Despites of the efforts that have been done, several species are not yet known due to inadequate of termite taxonomists, under developed infrastructures as well as facilitating equipment (Nkunika, 1994; Eggleton *et al.*, 2002; Darlington *et al.*, 2008). Therefore, there is a need to conduct experiments to identify all termite species around farmlands pointing to their role both negative and positive and on how a balance can be created at which economical injury level to crops are avoided while maintaining biodiversity health

### 2.2 Overview on chemical applications against termites

Synthetic pesticides are artificial made compounds which have long half-life in the environment (Chaudhary *et al.*, 2017). They are effective in managing termites though they cause serious human health and environmental problems (Kamble *et al.*, 1992; Forschler and Townsend, 1996; Mulrooney *et al.*, 2006). For instance, when methyl bromide is sprayed, it penetrates quickly inside the wooden structures and kills either dry wood termites or arboreal species (Verma *et al.*, 2009). Although methyl bromide control termites successfully, it is believed to cause atmospheric ozone layer depletion (Verma *et al.*, 2009; Himmi *et al.*, 2013). The ozone layer depletion can in turn expose people to direct radiations which may lead to skin cancers in humans (Slaper *et al.*, 1996).

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 (Su *et al.*, 1999; Parman and Vargo, 2010; Himmi *et al.*, 2013; Rakshiya *et al.*, 2016). Residues of these chemicals are usually carried away from their sources by air and water to aquatic and terrestrial systems and affect other organisms. For example, decrease by 80% in fishes has been reported in different farming seasons of paddy cropping in Malaysia (Watson, 2014). Synthetic pesticides have caused insect population reduction in USA and bird population decline in India (Johnson *et al.*, 2010; Mitra *et al.*, 2011). Furthermore, synthetic pesticides have been reported to have negative effects to human health and other non-target animals (Weichenthal *et al.*, 2010). Also they cause hardness in breathing, skin pill off, vomiting, stomach ache and disrupt hormonal balance system in humans and wildlife (Mnif *et al.*, 2011;

Mkindi *et al.*, 2015). Although one may apply synthetic chemicals on farms and protect crops from insect pests and diseases but on the other hand they affect biodiversity (Chaudhary *et al.*, 2017).

Considering the effects of synthetic pesticides on human, environment, increased insect pest resistance 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 insecticidal plants to control termites since this method has less negative effects to non-targeted organisms, environment and human health as well.

### 2.3 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 (Dubey *et al.*, 2008; Chaudhary *et al.*, 2017). Generally, plant pesticides are known to control insect pests in eco-friendly way because they have less negative effects on non-targeted insects, human health, environment and crops. Studies show that compounds derived from plants usually degrade into harmless substances ranging from few seconds, hours and even a day (Dubey, 2011; Mkindi *et al.*, 2015).

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 (Koona and Dorn, 2005; Dubey *et al.*, 2008; Mugisha-Kamatenesi *et al.*, 2008). For instance, candidate pesticidal plants that are applied by Ugandan farmers in control of insect pests on basin of the Lake Victori 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* (Mugisha-Kamatenesi *et al.*, 2008; Kamatenesi-Mugisha *et al.*, 2013). 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 (Mihale *et al.*, 2009). 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 (Amoabeng *et al.*, 2014). A boiled combination of detergent soap and parts of pesticidal plants has demonstrated positive results in control of insect pests (Belmain and Stevenson, 2001).

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 disease in both field and greenhouse conditions (Mekonnen *et al.*, 2014). All mentioned techniques show efficacious results in controlling some insect pests. This calls for diverse research approaches to assess the effective application method. For example, what happens when plant parts are boiled or soaked in soap solution and organic solvents with the aim of wider scale application on the termites and insect pests control.

### 2.3.1 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* have been selected and reviewed 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 on field crops, stored food cereal and legume grains as well as wooden properties (Sekamatte *et al.*, 2003; Yuan and Hu, 2012; Mkenda *et al.*, 2014). In developing countries especially in villages, these botanicals are used to control insect pests and termites in agricultural crops, stored grains and wooden materials (Raina *et al.*, 2007; Mugisha-Kamatenesi *et al.*, 2008; Sileshi *et al.*, 2008; Sileshi *et al.*, 2009; Alavijeh *et al.*, 2014). Therefore, it is of paramount importance to conduct researches that serve to raise awareness of people especially farmers and households on how to use the locally available pesticidal plants in control of insect pests.

#### (i) *Cupressus lusitanica*

*Cupressus lusitanica* (mexican cypress) belongs to the family cupressaceae (Plate 1) and possesses aromatic compounds and essential oils such as β-cedrene, bornyl acetate, α-cedrene, epimanool, cedrol and agathadiol as depicted in (Fig. 1) (Mohareb *et al.*, 2010; Bett *et al.*, 2016). Essential oils possess antimicrobial, antifungal and insecticidal properties (Jeong *et al.*, 2007; Kordali *et al.*, 2008). Growth inhibition has been observed in *Aspergillus niger* and *Bacillus cereus* after exposing to volatile essential oils (Hassanzadeh *et al.*, 2010). Other studies, found that essential oils have a fumigant and repellency effects against insect pests in stored food grains (Bett *et al.*, 2013; Bett *et al.*, 2016). In addition, leaf powders are used to protect crops from storage insect pests and termites (Kamatenesi-Mugisha *et al.*, 2013; Tsegay *et al.*, 2018). This body of knowledge might be useful for insect pests and termites control in field crops and trees of economic importance. Therefore, many more studies are needed to be conducted in assessing the efficacy of leaf powders of *C. lusitanica* in management of insect pests including destructive termites.

**Plate 1**: *Cupressus lusitanica* (Confirmed by Mr. Emmanuel Mboya at Tropical Pesticides Research Institute)

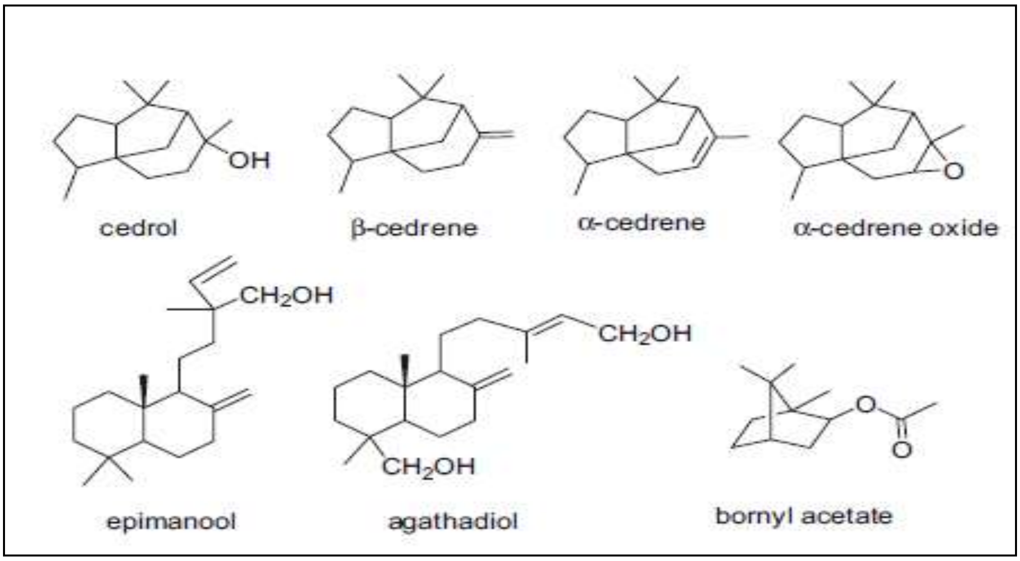



**Figure 1**: Some terpenic compounds in *Cupressus lusitanica* (Mohareb *et al.*, 2010).

### (ii) *Eucalpytus dalrympleana*

There are many varieties of *Eucalyptus* species which belong to the family myrtaceae (Plate 2) (Ebadollahi, 2013; Bett *et al.*, 2016). *Eucalpytus 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, ү-terpinene and citronellal (Batish *et al.*, 2008; Ebadollahi, 2013). Among these components, the 1, 8-cineole has been reported severally as the most active monoterpene (Toloza *et al.*, 2006). Many studies have reported similar results on 1, 8-cineole as shown in Fig. 2. For example, 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 (Sfara *et al.*, 2009).

Moreover, the extracts of 1,8-cineole from *E. dalrympleana* is effective for the reduction of *Haematobia irritans* (Horn fly) incidence in cattle (Juan *et al.*, 2011). Other scholars have quantified that essential oils from *E. dalrympleana* have insecticidal and repellent activity against stored food grains insect pests (Batish *et al.*, 2008). Similarly, essential oils of *E. dalrympleana* have shown antifeedant, repellency and insecticidal properties on termite workers of the *Odontotermes obesus* (Ebadollahi, 2013). Based on these findings, essential oils could be useful in 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 (Van Andel *et al.*, 2015). Any study to investigate the effects of leaf powders instead of essential oils of *E. dalrympleana* for insect pests control.

**Plate 2**: *Eucalyptus dalrympleana* (Confirmed by Mr. Emmanuel Mboya at Tropical Pesticides Research Institute)

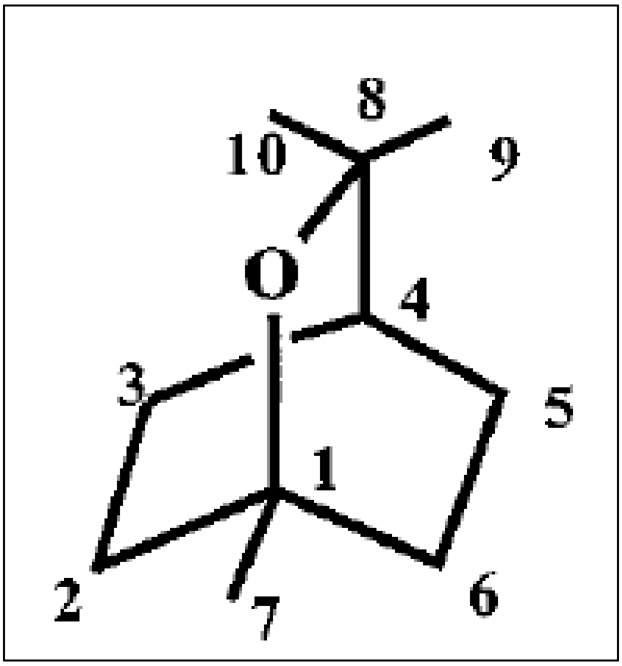



**Figure 2**: Chemical structure of 1,8-cineole (Southwell *et al.,* 2003).

### (iii) *Tephrosia vogelii*

*Tephrosia vogelii* is a legume which belongs to the family Fabaceae (Plate 3) (Ibrahim *et al.*, 2000; Stevenson *et al.*, 2012). *T. vogelii* is the most effective insecticidal plant which is used in management of insect pests in both field crops and stored products (Stevenson *et al.*, 2012). It is also used to increase soil fertility through biological nitrogen fixation (Stevenson *et al.*, 2012). The effectiveness of *T. vogelii* is due to bioactive compounds such as chemotype 2 (C2) and chemotype 1 (C1) (Fig. 3) (Belmain *et al.*, 2012). C1 has been reported to be the most effective compound in *T. vogelii* resulting to the repellency of insect pests (Belmain *et al.*, 2012; Kalume *et al.*, 2012; Mkindi *et al.*, 2015). For these reasons, the pesticides from *T. vogelii* possess insecticidal effects. For example, the pesticides from *T. vogelii* have been commonly used in remote areas of Africa for illegal fishing (Neuwinger, 2004; Wang *et al.*, 2011). The pesticides from *T. vogelii* have been confirmed to exhibit antifeedant, repellent and insecticidal properties towards golden flea beetle (Igogo *et al.*, 2011).

In Malawi, Mozambique and Zambia, farmers who used extracts from crushed leaves of *T. vogelii* managed to protect field crops from termites (Sileshi *et al.*, 2008). However, there are inadequate scientific studies which show the potentiality of using leaf powders of *T. vogelii* in controlling field insect pests including termites (Sileshi *et al.*, 2009). Therefore, there is an urgent need to test leaf powders of *T. vogelii* for security of crop plants and trees of economic importance.

**Plate 3**: *Tephrosia vogelii* (Confirmed by Mr. Emmanuel Mboya at Tropical Pesticides Research Institute).

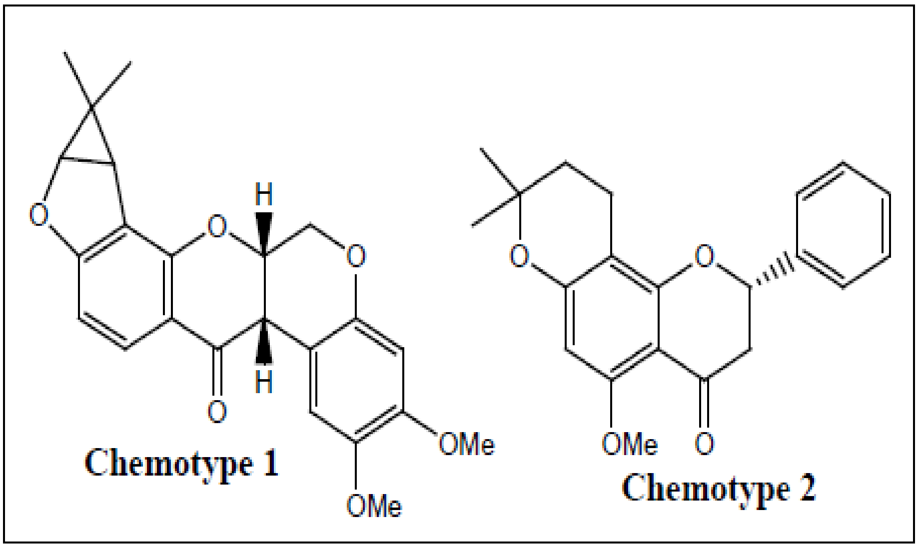



**Figure 3**: Chemotype 1 (C1) and Chemotype 2 (C2) (Stevenson *et al.,* 2012).

### (iv) *Azadirachta indica*

*Azadirachta indica* is a native plant in India (Plate 4) (Khater, 2012). It belongs to Meliaceae family with more than 200 compounds (Chaudhary *et al.*, 2017). Among these compounds, Azadirachtin is the most active constituent in *A. indica* compared with salannin and nimbin (Fig. 4). 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 oviposition in female and interrupt mature sperm production in male insects (Chaudhary *et al.*, 2017). Various studies 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* (Ishida *et al.*, 1992). 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 (Akhtar *et al.*, 2008). The *A. indica* oil extracts minimized significantly the number of *Tuta absoluta* in vegetable tomatoes compared with fields without treatments (El-Samahy *et al.*, 2014). Hence, it is worthy to use *A. indica* extracts as alternative to control insect pests and termites which are serious menace to plants.

**Plate 4**: *Azadirachta indica* (Confirmed by Mr. Emmanuel Mboya at Tropical Pesticides Research Institute)

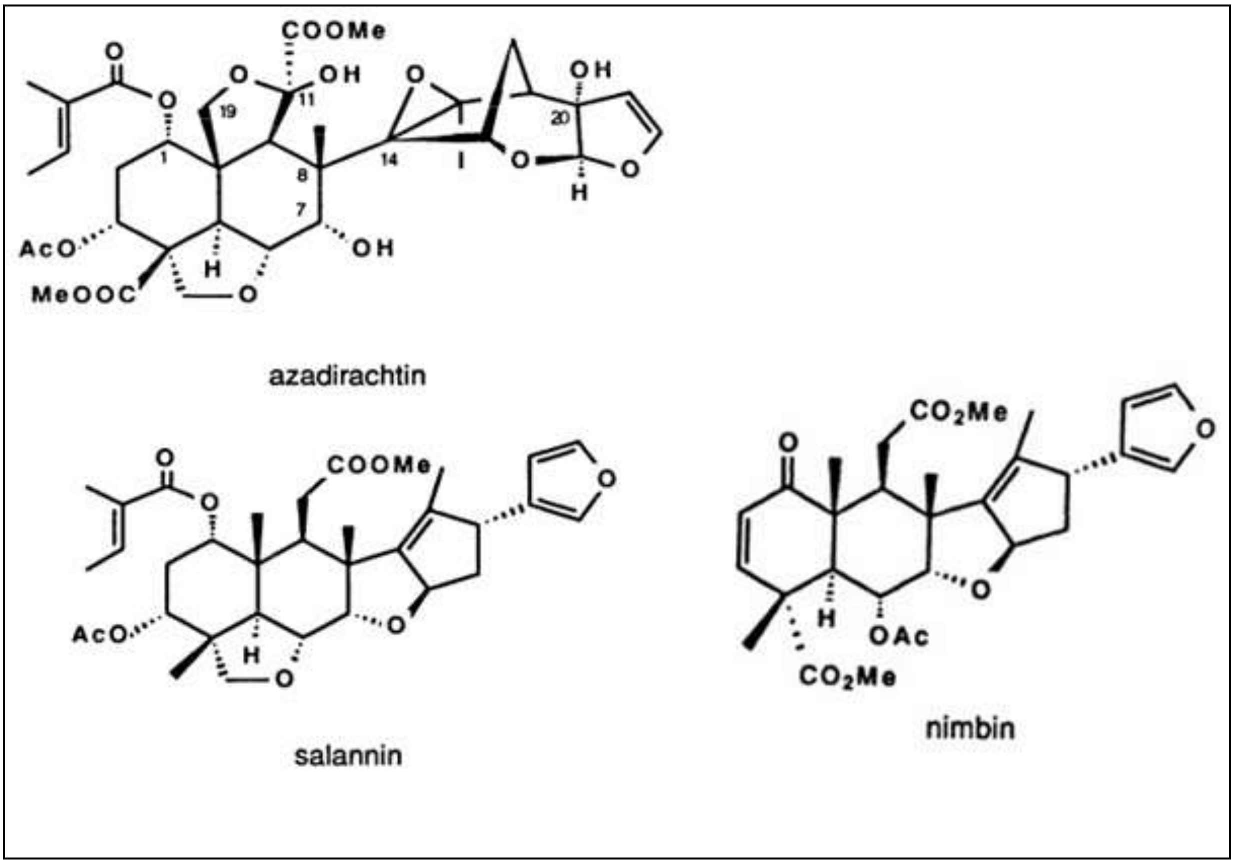



**Figure 4**: Some of chemical structures in *Azadirachta indica* (Govindachari *et al.,* 1996).

**(v) *Lantana camara***

*Lantana camara* is a native plant of South America which belongs to Verbenaceae (Plate 5) (Ghisalberti, 2000). Apart from South America, it is invasive plant to other areas (Baars and Neser, 1999). Some scholars have recognized and presented that *L. camara* possesses diverse compounds including proteins, carbohydrates, lactones, furfural, flavonoids, triterpenoids, glycosides, flavonoids, and phenylethanoid glycosides (Ghisalberti, 2000; Verma and Verma, 2006). Among these chemical compounds, triterpenoids such as ursolic acid stearoylglucoside have been reported to be more active component than any other in this plant, as illustrated in (Fig. 5) (Bevilacqua *et al.,* 2011). 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 *L. 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 to (Mello *et al.,* 2005; Bevilacqua *et al.,* 2011).

*Lantana camara* is also reported to have a fumigant effect against *Sitophilus granarius* adults in stored grains (Zoubiri and Baaliouamer, 2012). Laboratory experiments of scholars have also indicated that *Lantana camara* possesses a repellency, antifeedant, insecticidal activity to stored food grains insect pests (Rajashekar *et al.*, 2013; Rajashekar *et al.*, 2014). Besides, leaf extracts of *Lantana camara* have shown excellent repellent, moderate toxic and antifeedant activities on termites, *Reticulitermes flavipes* in the laboratory (Yuan and Hu, 2012). Also 5% chloroform extracts of *Lantana camara* have exhibited excellent mortality in termite workers under laboratory conditions (Verma and Verma, 2006). However, most of these reports are laboratory based, thus more field trials are needed with application of leaf powders of *L. camara*.

**Plate 5**: *Lantana camara* (Confirmed by Mr. Emmanuel Mboya at Tropical Pesticides Research Institute).

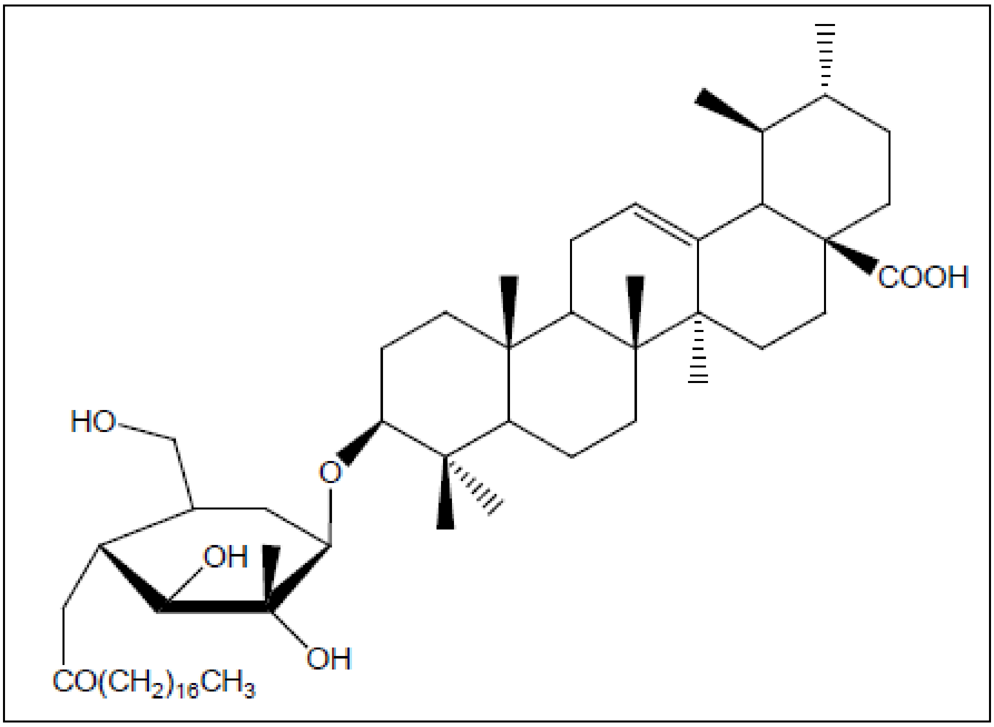



**Figure 5**: A chemical structure of ursolic acid stearoylglucoside (Kazmi et al., 2013).

### 2.4 Conceptual frame work

Termite management has been attributed by various methods including synthetic pesticides and botanicals. However, synthetic pesticides have been infective due to environmental problems, health hazardous/problems, high dosage, increased insect pest resistance and unaffordable cost/expensive. Application of botanicals has been effective in controlling termites/insect pests due to their affordable cost, eco-friendly, low dosage, health safety and less insect pest resistance (Fig. 6).

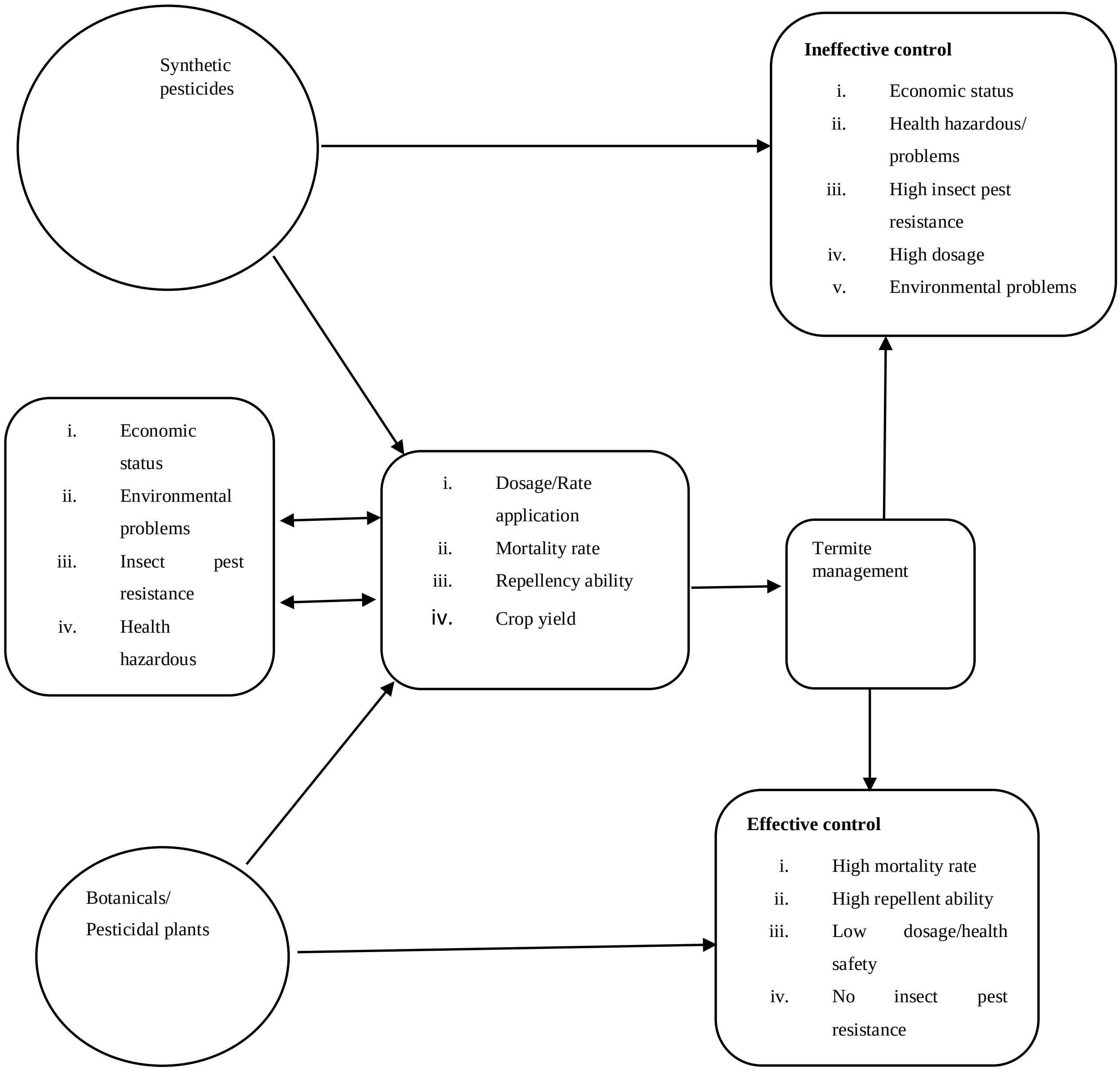



**Figure 6**: Conceptual frame work

## CHAPTER THREE

## MATERIALS AND METHODS

### 3.1 Study area description

The study was conducted at Kikwe Ward in Arumeru District of Arusha region (Fig. 7). The area receives an average monthly rainfall of about 5.2 mm to 180.6 mm and temperatures of about 13.6$^0$C to 33$^0$C (Appendix 1). The area harbours a high population of termite that affect maize crops and trees of economic importance. The field experiments were conducted at Nambala village at Gomba's farm (location in a cycle with black colour) and laboratory experiments were conducted at the Nelson Mandela African Institution of Science and Technology (NM-AIST) laboratory.

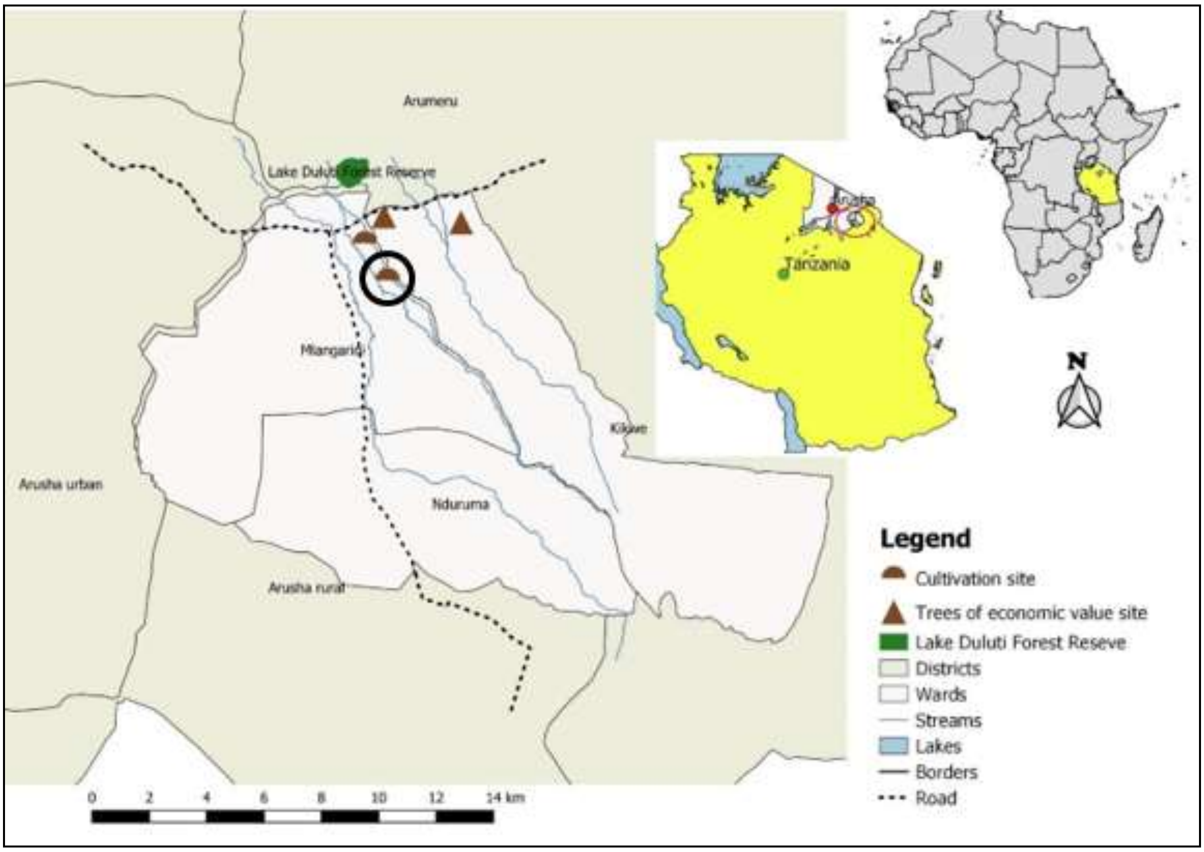



**Figure 7**: Study area

### 3.2 Source of insecticidal plants used in this study

Leaves of *Cupressus lusitanica*, *Tephrosia vogelii*, *Eucalpytus dalrympleana*, *Lantana camara* and *Azadirachta indica* were collected from their natural environments at Nambala village in Kikwe Ward. The leaves collected were air dried under shade in the NM-AIST laboratory for 30 days. All dried leaves were crushed separately into powders, packed, labeled and stored in dark room prior to use. Also leaf powders of maize plant and Bakiller dust (Carbaryl 5% w/w + Lambdacyhalothrin 0.1% w/w) were included as negative and positive controls, respectively. During collection, a soft camel hair brush was used to sweep termites into polyethylene plastic boxes in order to avoid possible injuries (Addisu *et al.*, 2014).

### 3.3 Experimental design

#### 3.3.1 Termite collection

Four farms (two with maize and two with trees) were purposively selected at Kikwe ward based on history of presence of termites and in each farm; quadrats of (5 m x 2 m in maize and 10 m x 10 m in trees) were established in 160 different points (maize farms and trees) based on Coulibaly *et al.* (2013) protocol with modifications. On maize, the quadrats were established within two parallel transect of 200 m separated by a 10 m distance between each on maize fields or on trees. Termite collection was done from 20-30 cm holes made as illustrated in Plate 6.  A total of 40 quadrats per farm were established. In each quadrat on maize farm, three lines were created at 40 cm apart. From each quadrat, 20 termites were collected and put into small bottles (diameter 3 cm, height 5 cm) containing 70% alcohol.

On trees, two transects of 400 m long separated by a 10 m distance were established. The quadrats of 10 m x 10 m (Plate 7) were established in twenty different points along the transect making 40 different points per farm and twenty termites per quadrat were collected and also preserved in alcohol as previously described. Termite collection on trees along established points were randomly established using small papers labeled with numerals equivalent to the number of trees in a quadrat. As each tree was as also labeled, random picking of five papers which matched corresponding to labels as on trees were used on which trees to select for termite sampling.  Furthermore, tree leaf and flower samples (from five trees) which were covered within the quadrat were collected and kept in paper bags and transported together with collected termite samples to the Tropical Pesticides Research Institute (TPRI) for identification.

#### 3.3.2 Termite identification

A Stereo-microscope was used for  morphological identification at the TPRI based on Sands (1959), Bouilon and Mathot (1965), Pearce *et al.* (1992) and Sands (1998).

### 3.3.3 Testing the efficacy of pesticidal plants on termite mortality and repellency

A completely randomized design (CRD) was used using seven treatments on pot experiments in triplicates for the mortality test (Appendix 3). The pots (28.8 cm in height and 25 cm diameter) were filled with termite mound soil of 5 kg and in each bucket, 2 liters of tap water was added and left to drain for one hour. Then on each bucket, about 20 termites (identified as *Macrotermes*) were added followed by addition of powder of the treatment. Bakiller dust (Carbaryl 5% w/w + Lambdacyhalothrin 0.1% w/w) was used as positive control based on manufacture's recommendation and leaf powder (5 g) of maize plant was used as negative control. Thereafter, all buckets were covered with ventilated wire mesh covers to prevent termites from escaping. Three different rates (5 g, 10 g and 20 g powder per 5 kg soil) of *C. lusitanica*, *T. vogelii*, *E. dalrympleana*, *L. camara* and *A. indica*. The mortality rates were recorded after 6, 12, 18 and 24 hours followed by spraying 6 millilitres of tap water on surviving termites to avoid dehydration.

To test the ability of the plants to repel the termites, the experiments were set as per the previously described mortality experiments with an exception that, the powder of the test plants (*C. lusitanica*, *T. vogelii*, *E. dalrympleana*, *L. camara* and *A. indica*) at similar concentrations was poured on top of soil in the bucket to half the diameter (Plate 8) and twenty termites were placed on the centre of the bucket and were visually observed whether or not they can move away or towards the plant powder under the test. As of the previous description, this experiment was arranged in a completely randomized design (CRD) with three replications (Appendix 4). The repellency ability of the treatment was recorded only after one hour.

### 3.3.4 Testing the efficacy of the pesticidal plants in the field.

For field experiments**,** three sites were set for trials in Gomba's maize farms during maize crops growing season from March to July in 2018 and the distance from one site to another was 500 meters (Fig. 8). In each site, 28 plots (Appendix 2) of 150 cm long and 90 cm wide each were set and the distance separation from plot to plot was 50 cm. In each plot there were two rows planted with four maize plants (PAN 691) each at spacing of 30 cm by 75 cm. After two weeks of germination, Basal fertilizers containing Nitrogen Phosphorus Potassium (NPK) and Urea were applied to enhance maize growth. Thereafter, five treatments of leaf powders prepared from *C. lusitanica*, *T. vogelii*, *E. dalrympleana*, *L. camara* and *A. indica* at the rate of 20 g plus positive control [Bakiller dust (Carbaryl 5% w/w + Lambdacyhalothrin

0.1% w/w)] at 2 g and no treatment as negative control were applied following randomized complete block design (RCBD) in four replications. Botanical leaf powders and Bakiller dust were applied directly to the maize stems after 30 days of germination. The application of botanical leaf powders and the controls were re-applied and monitored on treated plants every after 14 days until harvest.

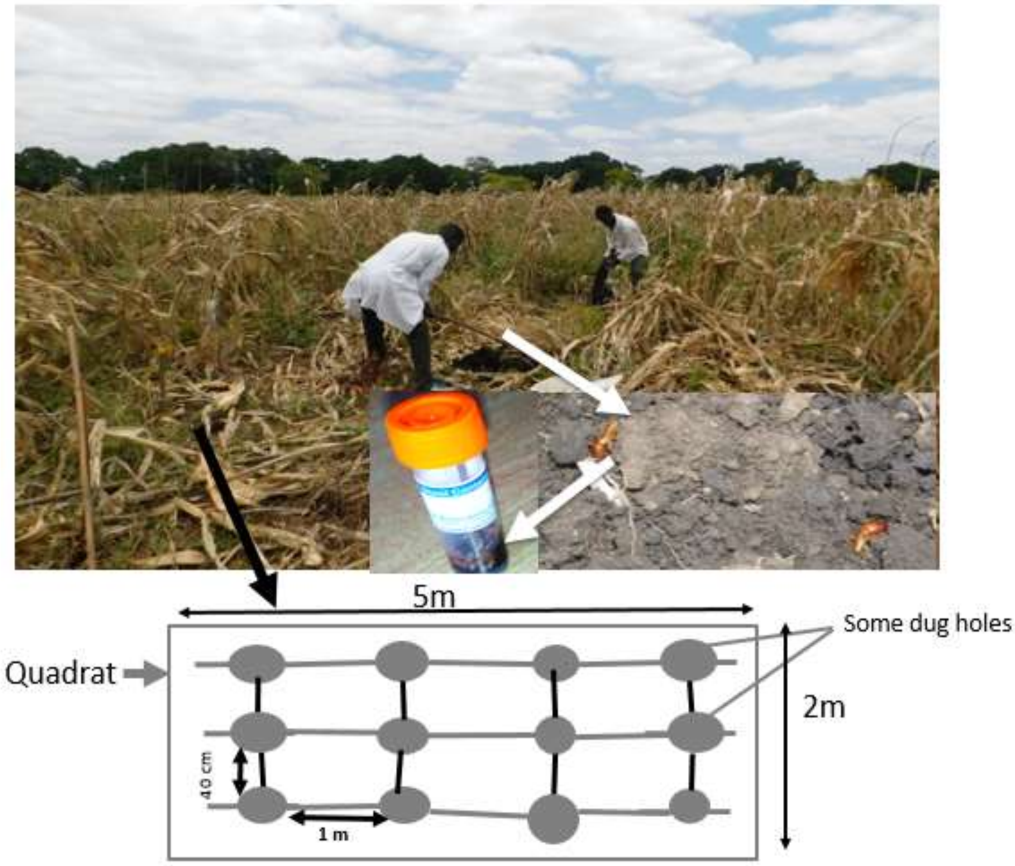



**Plate 6:** Termite sampling in maize fields

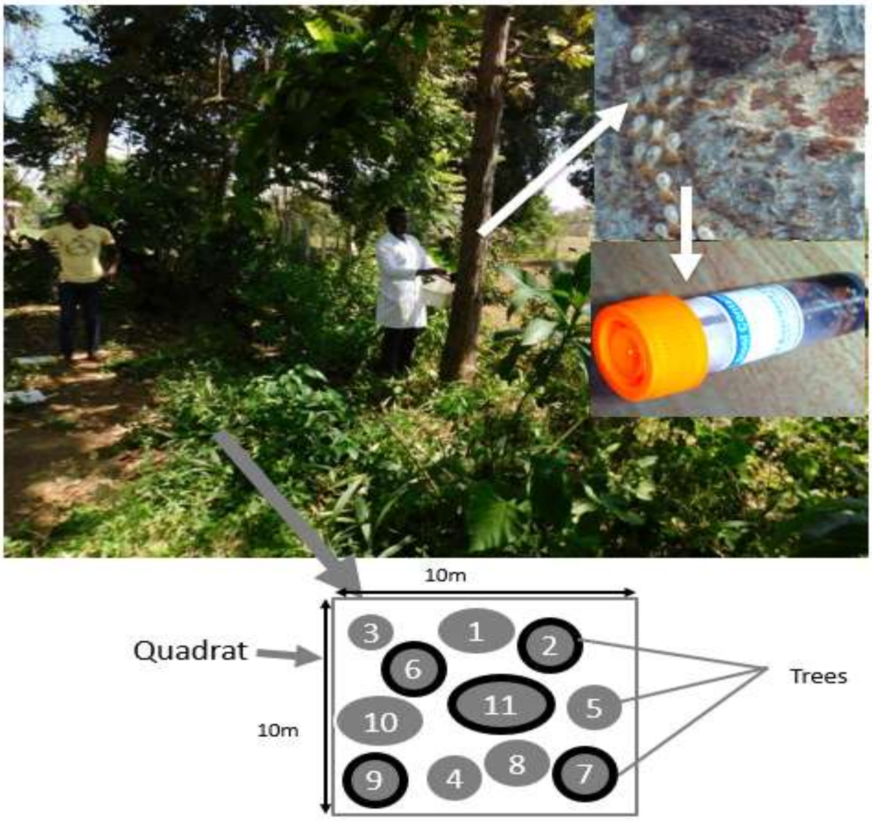



**Plate 7**: Termite sampling in the trees of economic importance


**Plate 8**: Repelled termites

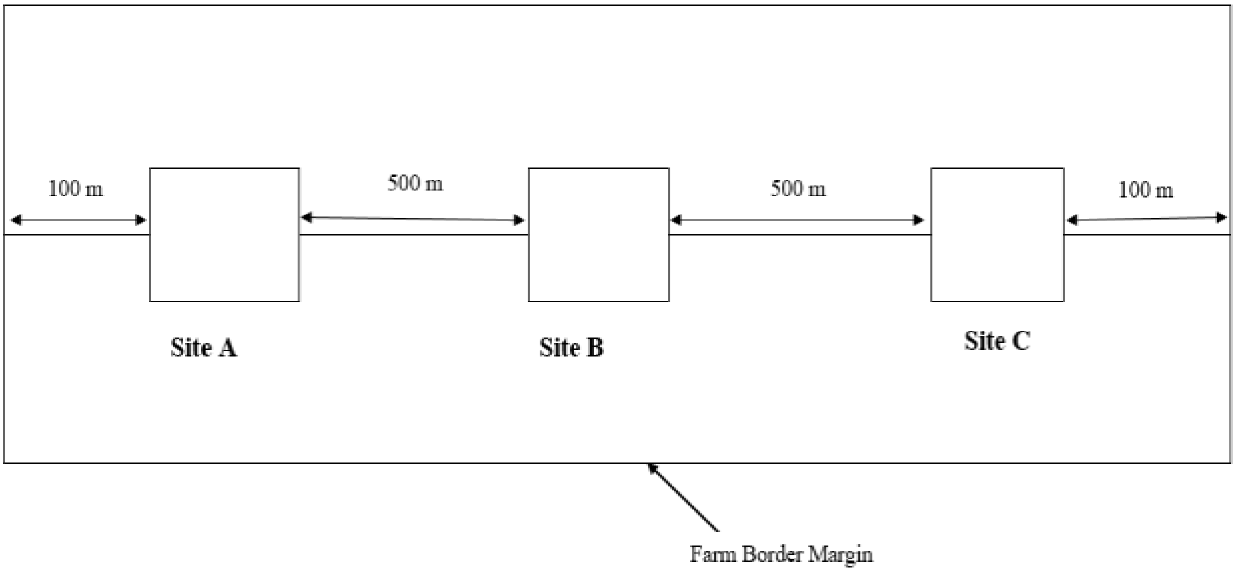



**Figure 8**: Three sites for trials within Gomba's maize farms

### 3.4 Data collection

The names of identified termites and trees of economic importance were recorded. Number of died termites were recorded while repelled termites were counted and recorded from both treated and untreated samples. The termite mortality (%) and repellency rate (%) were calculated using Equation (a) and Equation (b) as described by Bett *et al.* (2016), and Addisu *et al.* (2014), respectively. In the field experiment, maize yield was determined from eight plants per treatment.

$$PM = \frac{(MTT - MTC)}{(100 - MTC)} X100 \quad \text{.........................} \text{ Equation (a)}$$

PM = Percent Mortality

MTT = Mortality of Termites in Treatment

MTC = Natural Mortality of Termites in Control

$$PR = \frac{(T - C)}{(T)} X100 \quad \text{.............................} \text{ Equation (b)}$$

PR = Percent repellency

T = All termites counted from the part without treatment

C = All termites counted from the part with treatment

### 3.5 Data analysis

The collected data on termite mortality, repellency, maize grain yields (kg) and data on maize damage were subjected to analysis of variance (ANOVA) for the determination of significant differences. Differences among treatment means were determined using Duncan's multiple range test at p = 0.05 using GenStat 15 edition statistical package.

## RESULTS AND DISCUSSION

### 4.1 Results

### 4.1.1 Termite associated with maize and selected trees at Kikwe ward

The results in Table 1 show that 800 out of 1600 termite samples were identified as *Odontotermes* (Plate 9 (a)), 750 termites were *Macrotermes* (Plate 9 (b)) and 50 termites were not identified with available capacity at the Tropical Pesticides Research Institute. Also 242 leaves / flowers out of 400 were identified as *Gravillea robusta* (60.5%) followed by 97 leaves / flowers of *Acrocarpus fraxinifolius* (24.5%), 39 leaves / flowers of *Jacaranda mimosifolia* (4.7%), 12 leaves / flowers of *Terminalia mantale* (2.9%) as well as 10 leaves / flowers of *Moringa oleifera* (2.4%) (Fig. 9)

**Table 1**: Termite species identified in this study

| Area | Latitudes | Longitudes | Altitudes (m) | Plant host | Termite number collected | Termites identified as *Macrotermes* | Termites identified as *Odontotermes* | Unknown termite species |
|---|---|---|---|---|---|---|---|---|
| Kikwe | 3.40887 | 36.79201 | 1175.672 | Maize | 400 | 360 | 30 | 10 |
| Kikwe | 3.42046 | 36.7992 | 1148.135 | Maize | 400 | 390 | 10 | 0 |
| Kikwe | 3.40038 | 36.79797 | 1193.815 | *G. robusta*, *A. fraxinifolius*, *T. mantale*, *M. oleifera* and *J. mimosifolia* | 400 | 0 | 380 | 20 |
| Kikwe | 3.40236 | 36.8222 | 1147.734 | *G. robusta*, *A. fraxinifolius*, *T. mantale*, *M. oleifera* | 400 | 0 | 380 | 20 |

(a) (b)

**Plate 9**: Termite species (a*) Odontotermes* (b) *Macrotermes* as identified at the TPRI during this study

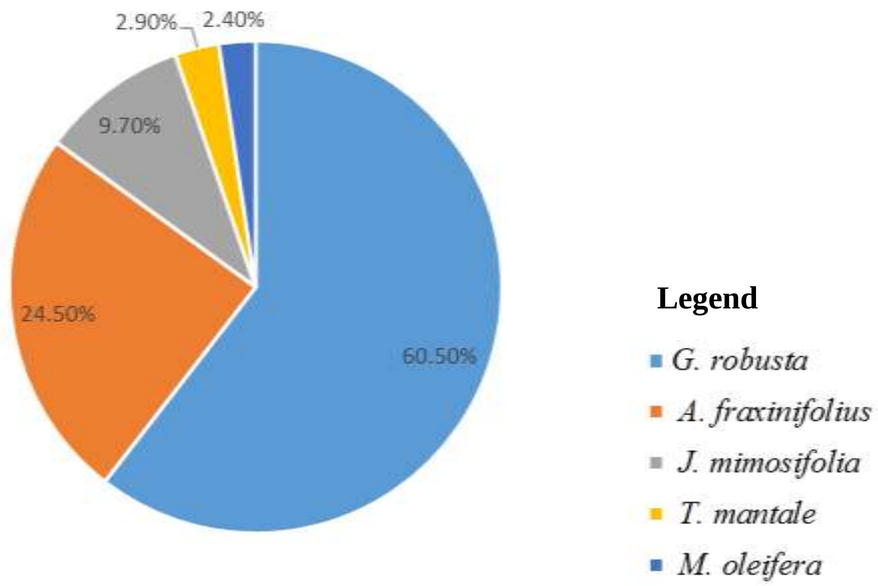



**Figure 9**: Percentage damage level by termites among trees of economic importance

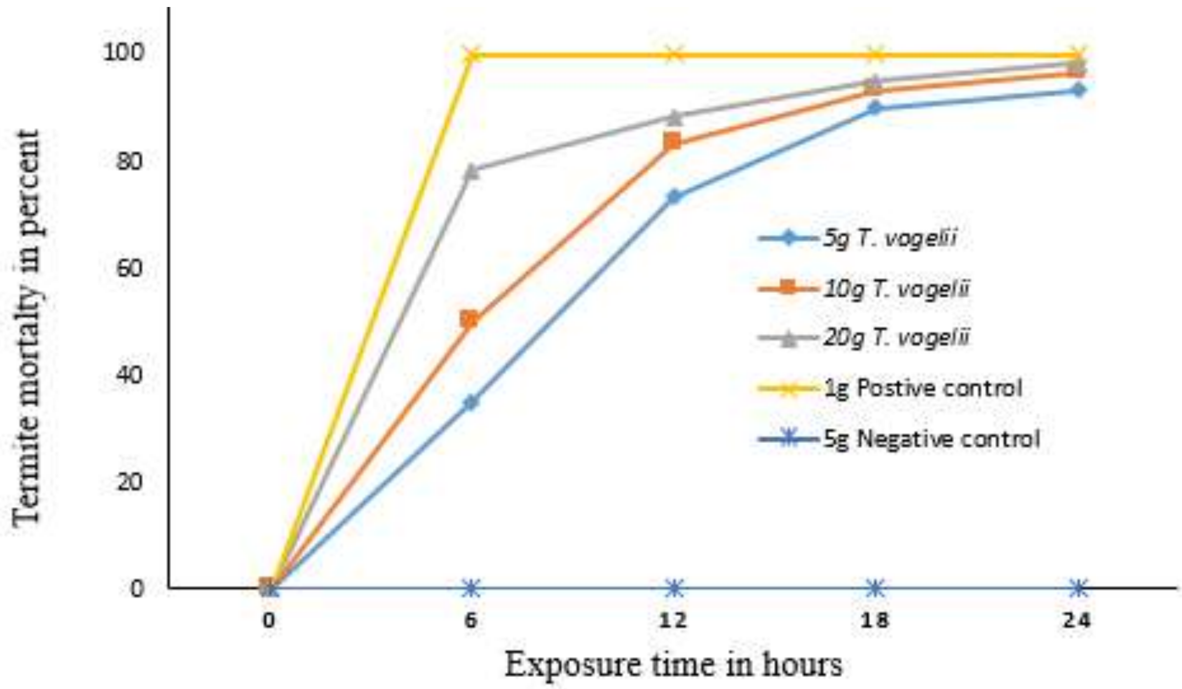
### 4.1.2 Mortality of *Macrotermes*

The results in Table 2 show that there is a significant difference ($p<0.001$) between effect of different insecticidal plants *C. lusitanica*, *T. vogelii*, *E. dalrympleana*, *L. camara* and *A. indica* against *Macrotermes* compared with negative control. *Tephrosia vogelii* and *E. dalrympleana* were the most effective plants that caused the highest mortality of *Macrotermes* at 6, 12, 18 and 24 hours. Plant powder rates at 5 g / 5 kg soil, 10 g / 5 kg soil and 20 g / 5 kg soil of *T. vogelii* together with 20 g / 5 kg soil of *E. dalrympleana* had similar significant effects as positive control [Bakiller dust (Carbaryl 5% w/w + Lambdacyhalothrin 0.1% w/w)] after post treatment of 24 hours [Table 2 and Fig. 10 (a) and (b)]. The *C. lusitanica*, *A. indica* and *L. camara* caused very low mortality of *Macrotermes* with figures of 23.33%, 30% and 33.33% mortality at 20 g / 5 kg soil [Table 2 and Fig. 10 (c), (d) and (e)].

**Table 2:** Effect of different insecticidal plants on termite (mortality)

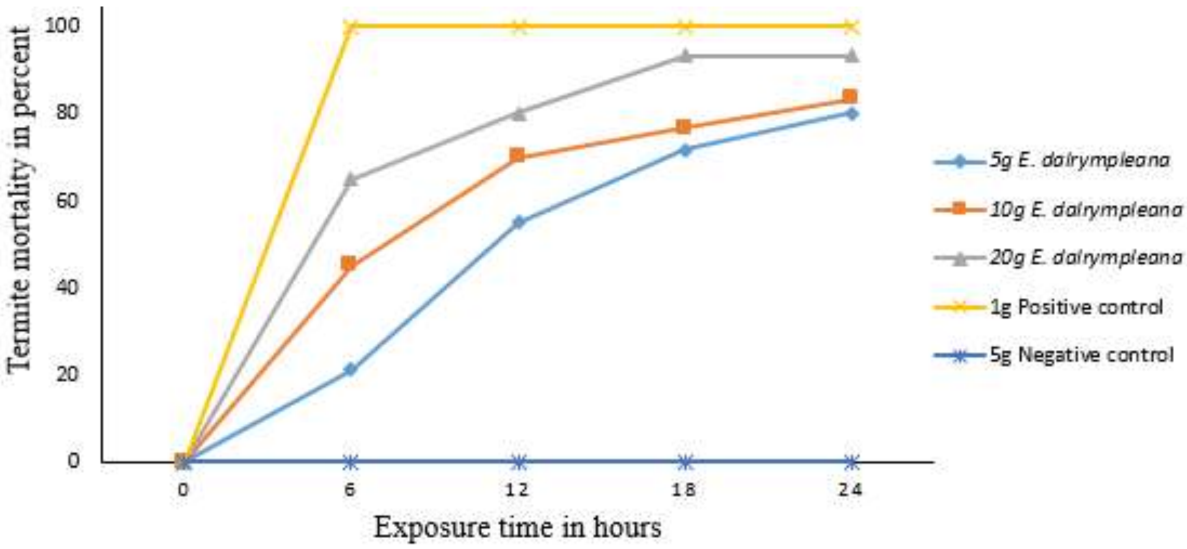
| Treatments | Rate in g / 5 kg soil | Mortality mean in percent (%) per time (hours) | | | |
|---|---|---|---|---|---|
| | | 6 | 12 | 18 | 24 |
| *T.vogelii* | 5 | 35.00d | 73.33hi | 90.00f | 93.33i |
| *T.vogelii* | 10 | 50.00e | 83.33j | 93.33fg | 96.67i |
| *T.vogelii* | 20 | 78.33g | 88.33j | 95.00fg | 98.33i |
| *L.camara* | 5 | 5.00ab | 10.00abcde | 11.67bc | 23.33cdef |
| *L.camara* | 10 | 5.00ab | 11.67bcdef | 13.33bc | 16.67bc |
| *L.camara* | 20 | 10.00ab | 18.33cdef | 20.00cd | 33.33g |
| *C.lusitanica* | 5 | 1.67a | 10.00abcd | 11.67bc | 20.00bcde |
| *C.lusitanica* | 10 | 5.00ab | 10.00bcd | 11.67bc | 20.00bcd |
| *C.lusitanica* | 20 | 3.33a | 10.00abcd | 20.00cd | 23.33cdef |
| *A.indica* | 5 | 8.33ab | 8.33abc | 11.67bc | 16.67bc |
| *A.indica* | 10 | 0.00a | 5.00 ab | 6.67ab | 11.67b |
| *A.indica* | 20 | 15.00bc | 20.00df | 23.33d | 30.00dfg |
| *E.dalrympleana* | 5 | 21.67c | 55.00g | 71.67e | 80.00h |
| *E.dalrympleana* | 10 | 45.00de | 70.00h | 76.67e | 83.33h |
| *E.dalrympleana* | 20 | 65.00f | 80.00ij | 93.33fg | 93.33i |
| Positive control | 1 | 100.00h | 100.00k | 100.00g | 100.00i |
| Negative control | 5 | 0.00a | 0.00a | 0.00a | 0.00a |
| LSD | | 10.147 | 9.057 | 8.057 | 9.127 |
| p value | | 0.001 | 0.001 | 0.001 | 0.001 |

*Means followed by the same letter (s) at the same column are not significant different at p = 0.05 using Duncan's Multiple Range Test.*



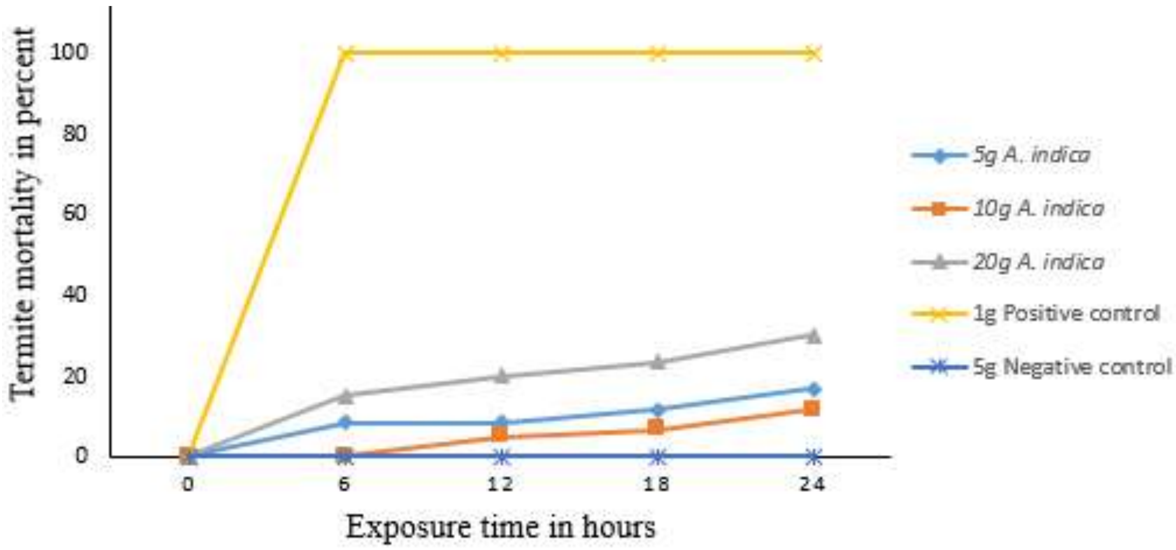
100
80
60
40
20
0
0
6
12
18
24
Termite mortalty in percent
Exposure time in hours
5g T. vogelii
10g T. vogelii
20g T. vogelii
1g Postive control
5g Negative control


(a)



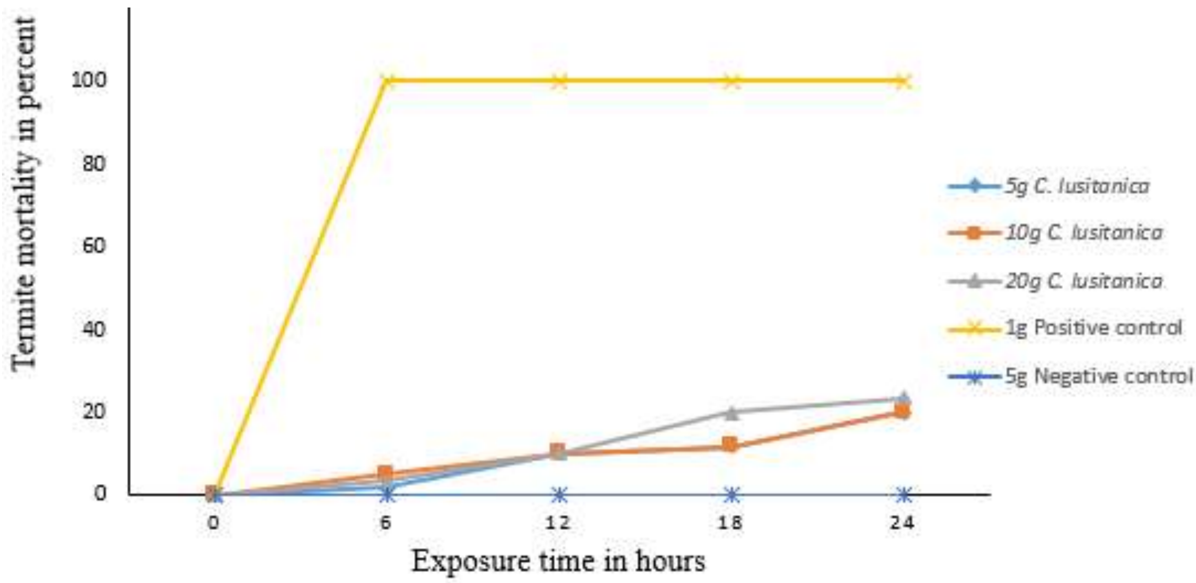
100
80
60
40
20
0
0
6
12
18
24
Termite mortality in percent
Exposure time in hours
5g E. dalrympleana
10g E. dalrympleana
20g E. dalrympleana
1g Positive control
5g Negative control


(b)



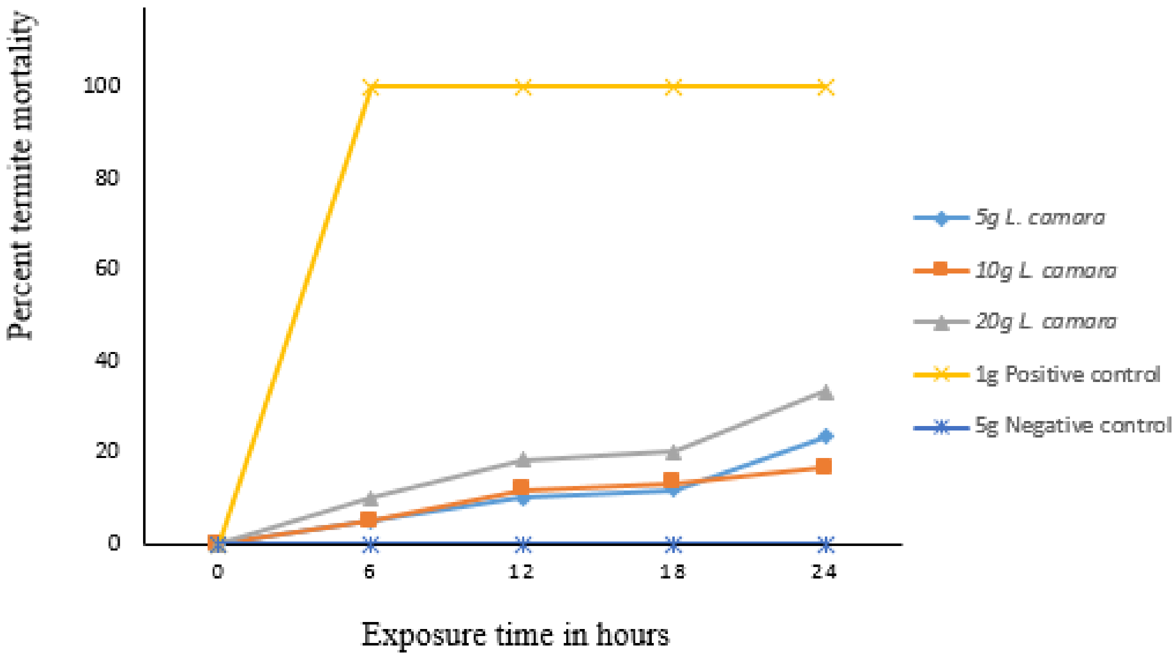
Termite mortality in percent
100
80
60
40
20
0
0
6
12
18
24
Exposure time in hours
5g A. indica
10g A. indica
20g A. indica
1g Positive control
5g Negative control


(c)



Termite mortality in percent
100
80
60
40
20
0
0
6
12
18
24
Exposure time in hours
5g C. lusitanica
10g C. lusitanica
20g C. lusitanica
1g Positive control
5g Negative control


(d)




**(e)**

**Figure 10**: **(**a) *T. vogelii* (b) *E. dalrympleana* (c) *A. indica* (d) *C. lusitanica* (e) *L. cámara*

### 4.1.3 Repellency of *Macrotermes*

The results show significant difference in termite repellency (p<0.001) compared with negative control (Table 3). The percentage repellency values ranged from 77 to 97%. Powder from *T. vogelii E. dalrympleana* and *C. lusitanica* demonstrated the highest repellency power on *Macrotermes* (95%, 95% and 97%, respectively) whereby *T. vogelii* at 10 g / 5 kg soil and 20 g / 5 kg soil and *C. lusitanica* at 5 g / 5 kg soil, 10 g / 5 kg soil and 20 g / 5 kg soil as well as 10 g / 5 kg soil and 20 g / 5 kg soil rates of *E. dalrympleana* had no significant differences in their recorded percentage repellency values. Additionally, positive results were recorded from *A. indica* and *L. camara* of which their percent repellency values were found to be 77 to 87%.

**Table 3**: Repellency (%) ability of different insecticidal plants on termites

| Treatments | Rate in g / 5 kg soil | Average percent repellency |
|---|---|---|
| *T.vogelii* | 5 | 88.33bc |
| *T.vogelii* | 10 | 95.00c |
| *T.vogelii* | 20 | 95.00c |
| *L.camara* | 5 | 76.67b |
| *L.camara* | 10 | 76.67b |
| *L.camara* | 20 | 77.67b |
| *C.lusitanica* | 5 | 95.00c |
| *C.lusitanica* | 10 | 95.00c |
| *C.lusitanica* | 20 | 96.67c |
| *A.indica* | 5 | 76.67b |
| *A.indica* | 10 | 83.33bc |
| *A.indica* | 20 | 83.33bc |
| *E.dalrympleana* | 5 | 86.67bc |
| *E.dalrympleana* | 10 | 93.33c |
| *E.dalrympleana* | 20 | 95.00c |
| Negative control | 5 | 0.00a |
| LSD | | 13.320 |
| p value | | 0.001 |

Means followed by the same letter (s) at the same column are not significant different at p = 0.05 using Duncan's Multiple Range Test

#### 4.1.4 Effect of pesticidal plants powder on field maize at Kikwe ward

The results in Fig. 11, show that there was a significant reduction ($p<0.001$) of maize crops damage by termites in treated plots compared with untreated plots. Number of standing maize crops per site was 4, 4 and 6 in treatments with *E. dalrympleana*, *C. lusitanica* and *T. vogelii,* respectively. High average of maize grain yields were obtained from plots with treatments of *T. vogelii* (3.4 kg) followed by *E. dalrympleana* (2.93 kg) and *C. lusitanica* (2.58 kg) as depicted in Fig. 12.

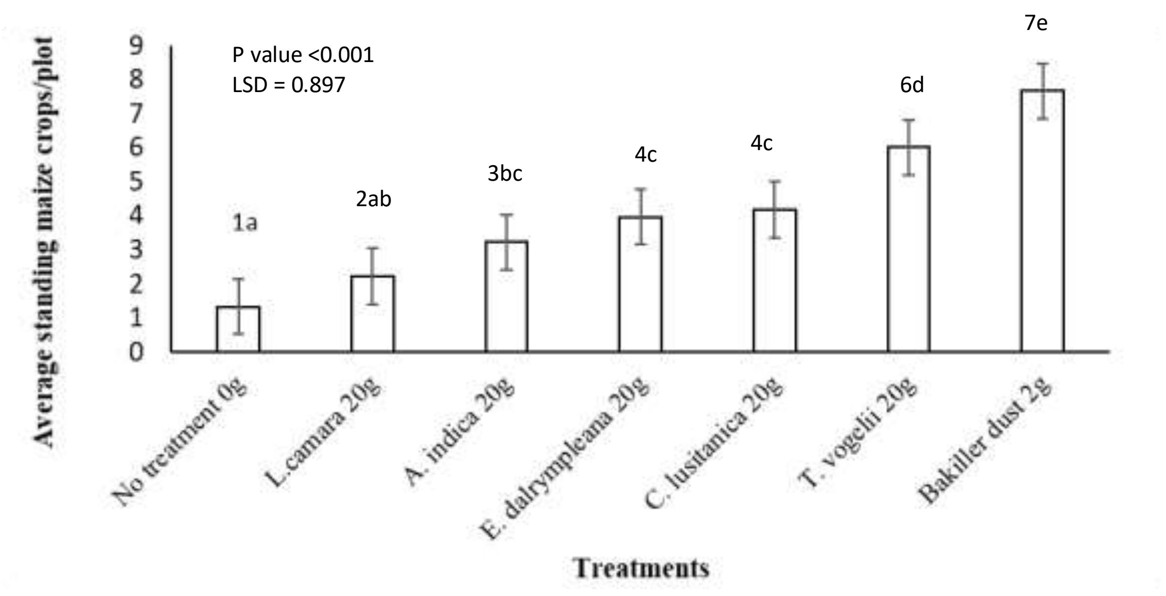



**Figure 11**: Number of standing maize plants treated with different pesticidal plants and control (A, B and C).

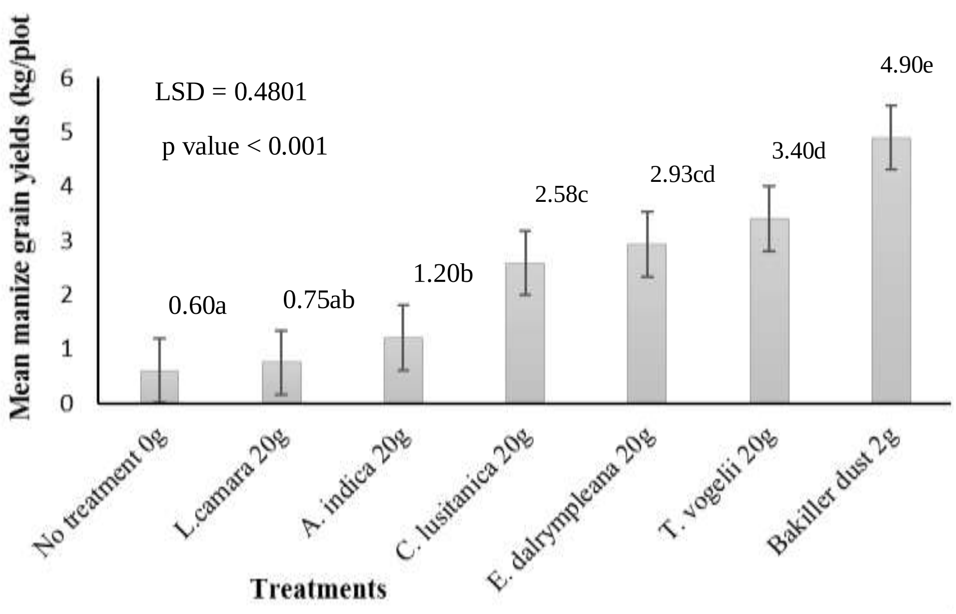



**Figure 12**: Maize grain yields in different treatments

### 4.2 Discussion

This study has identified two termite genera namely *Macrotermes* and *Odontotermes* which are associated with maize and or trees at Kikwe ward. From the observation made, the most destructive species of maize crops were species of the genera *Macrotermes* compared with *Odontotermes*. These finding present one of very few accounts on maize in Tanzania.

Findings from this study are in line to several findings with regards to *Macrotermes*, for instance; in India and Uganda species of *Macrotermes* have been reported to cause a loss of 10-30% in maize yield per year before and after harvest (Sekamatte *et al.*, 2003; Joshi *et al.,* 2005; Sileshi *et al.,* 2009). It has been further reported that the *Macrotermes* can cause up to 100% damage on millet, cassava, groundnuts and rice (Maayiem *et al.,* 2012; Machar *et al*., 2016)

The members of the genera *Odontotermes* identified in this study were found in close association and damage to *Gravillea robusta*, *Terminalia mantale*, *Moringa oleifera*, *Jacaranda mimosifolia* and *Acrocarpus fraxinifolius* as identified at the TPRI. Of these, the *Gravillea robusta* was the most susceptible tree to *Odontotermes* followed by *Acrocarpus fraxinifolius*.

This study has also identified leaf powders of *Tephrosia vogelii,* as locally available remedies for termites. Such finding indicates *T. vogelii* as potential candidate in developing bio-termiticides. Other researchers have shown that the use of *T. vogelii* leaf powder may ensure mortality of 85 to 94% in *Sitophilus zeamais* to treated stored food products (Ogendo *et al.* (2003). Similarly, the number of insect bruchids was reduced to 94% from stored leguminous seed products treated with powder of *Tephrosia vogelii* (Koona and Dorn, 2005; Wang *et al.*, 2011; Stevenson *et al.*, 2012). Furthermore, the aqueous extracts prepared from *T. vogelii* caused mortality of 50-62% in golden flea beetles (*Aphthona whitfieldi*) within eight days of post-treatments under laboratory conditions (Igogo *et al.,* 2011). In Africa, *T. vogelii* is one of the pesticidal plants which their extracts possess strong poisons used for illegal fishing especially in rural areas (Neuwinger, 2004).

Likewise, interesting results were also obtained from leaf powder of *E. dalrympleana* than it was *C. lusitanica*, *A. indica* and *L. camara*. The genus *Eucalyptus* is highly documented for its significance in the management of diverse insect pests including termites. For instance, research data reported by Gupta *et al.* (2011) proved that 10% essential oils of *Eucalyptus* species can cause 100% mortality within 30 minutes in treated termite workers of *Odontotermes obesus* under laboratory conditions. Moreover, essential oils from *eucalyptus* have been found to have insecticidal activity against stored food grains insect pests (Batish *et al.,* 2008). In addition, *eucalyptus* essential oils have been reported to kill 100% of stored grain beetles (*Tribolium castaneum, Sitophilus oryzae* and *Callosobruchus maculatus*) at 370 µl/l after 24 hours (Negahban and Moharramipour, 2007). Another study has confirmed the positive reduction of *Haematobia irritans* (Horn fly) to cattle using oil extracts of *eucalyptus* (Sfara *et al.,* 2009).

Based on the results of this study, moderate mortalities of termites were recorded from *C. lusitanica*, *A. indica* and *L. camara*. The least effectiveness exhibited by these botanicals could perhaps be linked to the bioactive compounds not being strong enough to cause lethal effect on experimental termites used in the current study. These results cannot be ignored in comparison to negative control. This little significant effect showed by *C. lusitanica*, *A. indica* and *L. camara* demands advanced extraction technologies in order to reduce loss of bioactive ingredients/compounds. Previous studies have demonstrated efficacious results on different tested crop insect pests. For instance, *A. indica* extracts strongly inhibited growth of caterpillars, *Pseudaletia unipuncta* and *Trichoplusia ni* (Akhtar *et al.,* 2008). This concurs with assertions by the report of El-Samahy *et al.* (2014) where *A. indica* oil extracts minimized significantly the number of *Tuta absoluta* in vegetable tomatoes compared with fields without treatments.

The mortality of *Sitotroga cerealella* and *Acanthoscelides obtectus* were 84.2% and 86.0%, respectively when exposed into 2.0% v/w essential oils of *C. lusitanica* for a day (Bett *et al.* (2016). Laboratory experiments conducted by Verma and Verma (2006) showed that 5% chloroform extracts of *L. camara* can cause mortality of 68.7% to termite workers within two days. Similar study, 10% v/w from hexane extracts of *L. camara* achieved to kill high degree of larvae potato insect pests, *Phthorimaea operculella* (Iannacone and Lamas, 2003).

The repellency test presents very useful information which can be used by ecologists and conservationists who discourage killing of insects in the name of biodiversity and their important roles they play in the ecosystems. For instance, termites decompose wooden components and recycle them and later on improve soil structure and texture (Singha *et al.,* 2010). In addition, the activities of termites in 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 (Jasmi and Ahmad, 2011). The *C. lusitanica, T. vogelii* and *E. dalrympleana* were the most effective insecticidal plants which repelled termites from this study. Such results implied that these plants can be used for repelling termites. These results are in line with a report by Bett *et al.* (2016) who reported that the essential oils (0.20% v/w) of *C. lusitanica* repelled coleopteran insect pests by 65 to 93% from stored products. On the other hand, high percentage repellency (90%) has been identified to *Prostephantus truncatus* in stored products treated by powders of *T. vogelii* (Chebet *et al.*, 2013). Even though there is a limited information of *E. dalrympleana*, yet the species of the same genus are well studied and documented. For example, 30g powder of *Eucalyptus globulus* caused a significant repellency of 80% to termites (Kamatenesi-Mugisha *et al.*, 2013; Tsegay *et al.*, 2018). The rest botanicals were *A. indica* and *L. camara* which showed moderate repellency against *Macrotermes*. These results are closely related to the previous findings. Chebet *et al*. (2013) justified that plant powders of *Lantana camara* and *Azadirachta indica* can cause repellency of 73% and 88% on *Prostephantus truncatus*, respectively. Interestingly, a single topical application of chloroform *L. camara* flower extracts to volunteers ensured protection of 100% in 120 minutes and 75.8% for 420 minutes from bites of mosquito species (*Aedes* spp.) (Dua *et al.,* 2003).

Field trials has established information needed as a benchmark for field applications using *C. lusitanica*, *T vogelii*, *E. dalrympleana*, *L. camara* and *A. indica* against termites. Among these botanicals, *E. dalrympleana* and *C. lusitanica* were the best candidates which have demonstrated promising results. These results corroborate with the report findings of studies by Mugisha-Kamatenesi *et al*. (2008) on Ugandan basins of Lake Victoria who concluded that small scale farmers used *T. vogelii* and *C. lusitanica* to protect field crops from moths, weevils, aphids, stem borers, rodents, pod borers, bean flies and termites. In Tanzania, *T. vogelii* is commonly used to control both stored products and field insect pests (Mihale *et al.,* 2009). Furthermore, *T. vogelii* has shown significant reduction of weed biomass and favoured increased biomass of wheat yields (Wang *et al.*, 2011). Field research in ponds verified a significant mortality caused by *T. vogelii* leaf extracts to fishes, rotifers and larvae of mosquitoes (Agbon *et al.*, 2004). Though there is no quantified information about the applicability of *E. dalrympleana*, various species of genus *Eucalpytus* are highly recognized and reported to have considerable effects against variety of agricultural crop insect pests. Field trials conducted in India indicated that the *Eucalyptus globulus* extracts reduced the larvae of *Henosepilachna vigintioctopunctata* significantly (Reddy *et al.*, 1990). These results correspond to a report obtained by El-Samahy *et al.* (2014) where the *A. indica* oil extracts minimized significantly the number of *Tuta absoluta*'s larvae in tomatoes compared with fields without treatments.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

This study has demonstrated that there are at least two genera of termites namely *Odontotermes* (which dominates trees such as *Gravillea robusta*, *Terminalia mantale, Moringa oleifera*, *Jacaranda mimosifolia* and *Acrocarpus fraxinifolius*) and *Macrotermes* (which dominates maize) The current study has further confirmed that *T. vogelii* is the best pesticidal plant which exhibited positive mortality of *Macrotermes* next to positive control (bakiller dust) followed by *E. dalrympleana*. The *C. lusitanica, T. vogelii* and *E. dalrympleana* showed the highest performance in repelling termites of *Macroterme*s under laboratory conditions. Also, the field trials showed that *T. vogelii* was the best pesticidal plant in protection of maize plants against destructive termites followed by *C. lusitanica* and *E. dalrympleana*. The average amount of maize grain yields in kilograms harvested from all plots with treatment of *T. vogelii* was high followed by those obtained from treatment of *E. dalrympleana* as well as *C. lusitanica*. This entails that *T. vogelii*, *E. dalrympleana* and *C. lusitanica* possess strong insecticidal compounds which can suppress any *Odontotermes* and *Macrotermes* around the treated maize crops.

## 5.2 Recommendations

This study recommends:

(i) Further studies are recommended on characterizing termite species that were not identified in this study and on identification of chemical ingredients from the identified effective plants for formulation of bio-termiticides in Tanzania.

(ii) Further research including molecular studies on termite diversity and identity from wide geographical areas and their role in agricultural crop damage

(iii) Verification of the ability of the powders from *T. vogelii*, *E. dalrympleana* and *C. lusitanica* in the management of termites specially to find whether or not their applications cannot cause negative effects to non-target organisms.

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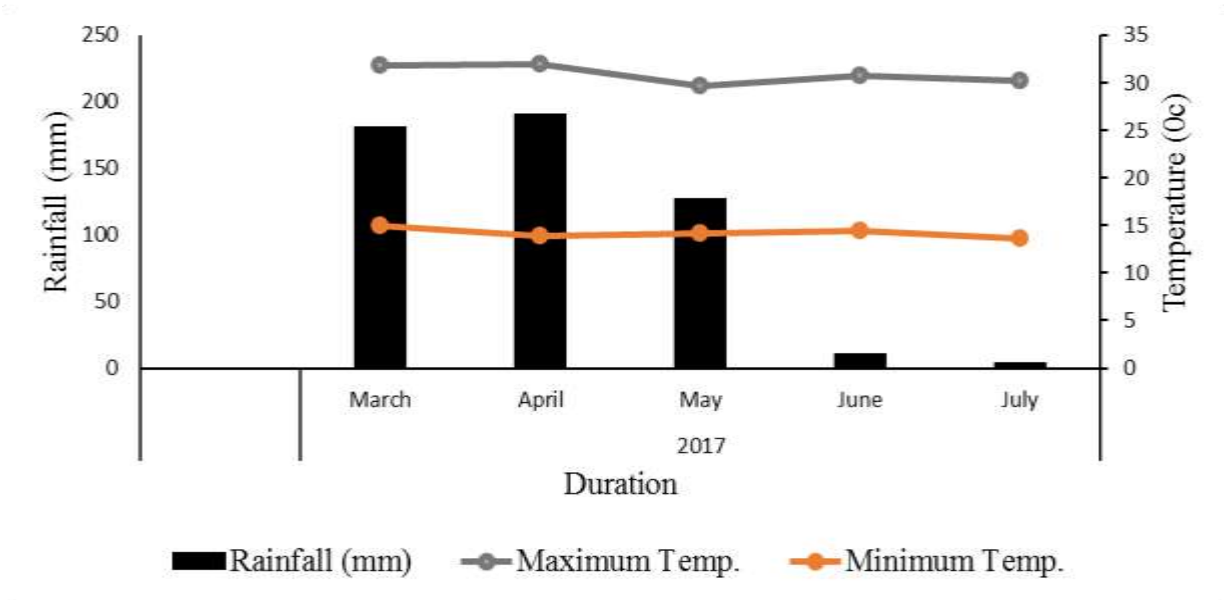
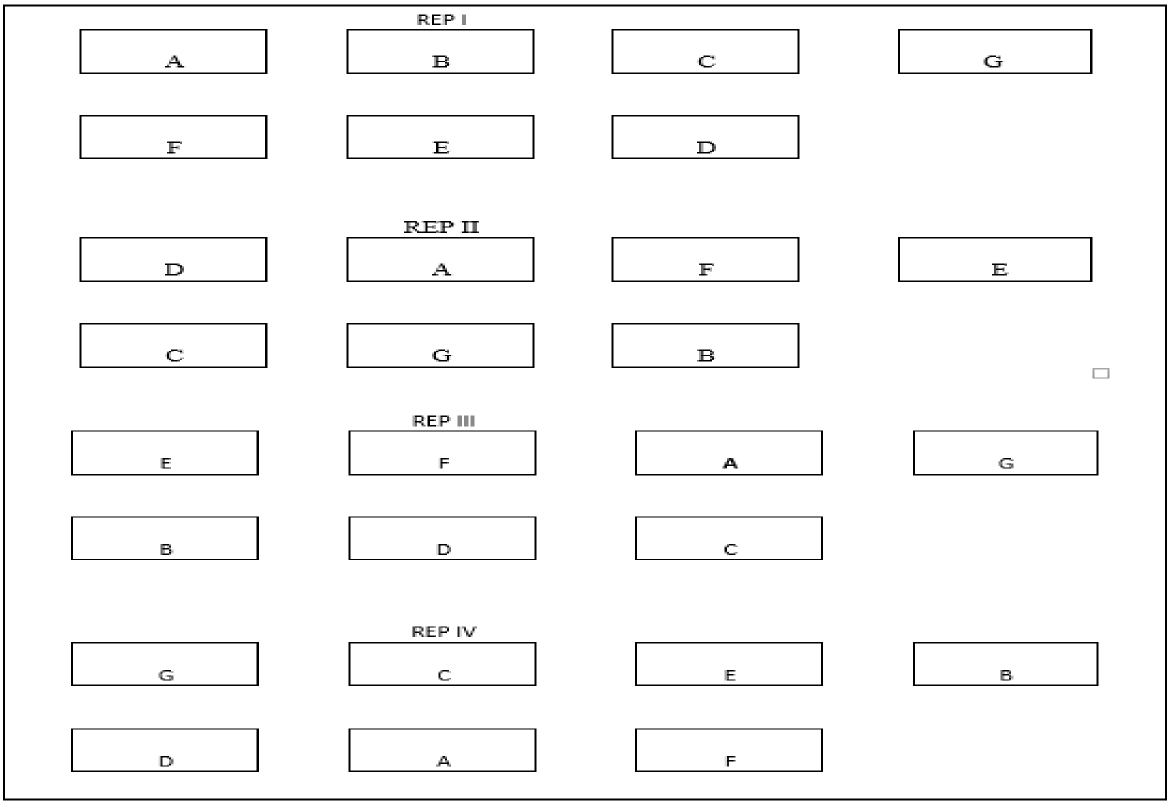
**APPENDENCES**

**Appendix 1**: Rainfall and temperatures




Source: Tanzania Meteorological Agency (TMA)

**Appendix 2**: Experimental field layer out (RCBD)




Where by A = *T. vogelii*, B = *L. camara*, C = *E. dalrympleana*, D = *C. lusitanica*, E = *A. indica*, F = No treatment (Negative control) and G = Positive control (Bakiller dust).

**Appendix 3**: Mortality test layer out (CRD)

| | | |
|---|---|---|
| Tv 5g | Cl 5g | Ai 20g |
| Neg 5g | Ai 5g | Post 1g |
| Tv 20g | Lc 5g | Lc 5g |
| Cl 5g | Ed 10g | Tv 20g |
| Post 1g | Tv 10g | Ai 10g |
| Cl 20g | Lc 20g | Ed 20g |
| Tv 10g | Ed 20g | Lc 10g |
| Ai 10g | Neg 5g | Ai 5g |
| Lc 10g | Post 1g | Lc 20g |
| Ed 5g | Lc 10g | Cl 10g |
| Cl 10g | Ai 10g | Neg 5g |
| Ai 20g | Tv 5g | Tv 10g |
| Ed 20g | Ai 20g | Cl 20g |
| Lc 5g | Tv 20g | Ed 10g |
| Ed 10g | Cl 10g | Tv 5g |
| Ai 5g | Ed 5g | Cl 5g |
| Lc 20g | Cl 20g | Ed 5g |

Where by Tv = *Tephrosia vogelii*, Cl = *Cupressus lusitanica*, Ed = *Eucalpytus dalrympleana*, Lc = *Lantana camara*, Ai = *Azadirachta indica*, Neg = Negative control (maize leaf powder) and Post = Positive control (Bakiller dust).

**Appendix 4**: Repellency test layer out (CRD)

| | | |
|---|---|---|
| Neg 5g | Tv 5g | Lc 10g |
| Cl 5g | Ed 10g | Cl 5g |
| Tv 5g | Lc 5g | Tv 5g |
| Ai 10g | Tv 10g | Neg 5g |
| Ed 10g | Cl 5g | Tv 10g |
| Ai 5g | Lc 10g | Ed 10g |
| Lc 10g | Ed 5g | Ai 5g |
| Tv 20g | Cl 20g | Lc 20g |
| Cl 20g | Ai 5g | Cl 20g |
| Ai 20g | Tv 20g | Ai 10g |
| Ed 5g | Ai 10g | Lc 5g |
| Lc 5g | Ed 20g | Cl 10g |
| Tv 10g | Lc 20g | Tv 20g |
| Ed 20g | Neg 5g | Ed 20g |
| Lc 20g | Cl 10g | Ai 20g |
| Cl 10g | Ai 20g | Ed 5g |

Where by Tv = *Tephrosia vogelii*, Cl = *Cupressus lusitanica*, Ed = *Eucalpytus dalrympleana*, Lc = *Lantana camara*, Ai = *Azadirachta indica* and Neg = Negative control (maize leaf powder).

# RESEARCH OUTPUT

## Output 1: Paper Presentation

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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[84,86].

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[89]. 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.

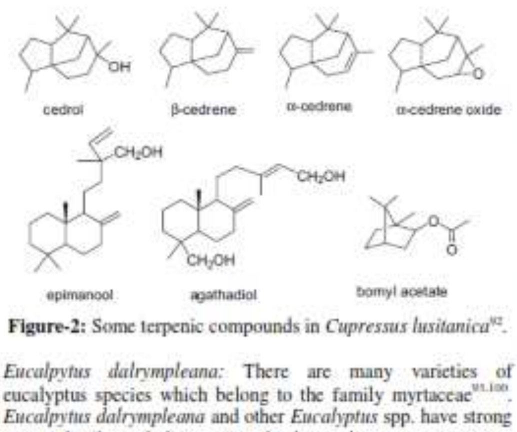


**Figure-2:** Some terpenic compounds in *Cupressus lusitanica*[92].

*Eucalpytus dalrympleana:* There are many varieties of eucalyptus species which belong to the family myrtaceae[93,100]. *Eucalpytus 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 *Eucalpytus 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.

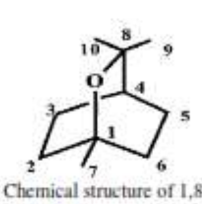


**Figure-3:** Chemical structure of 1,8-cineole[107].

*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[38]. 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.

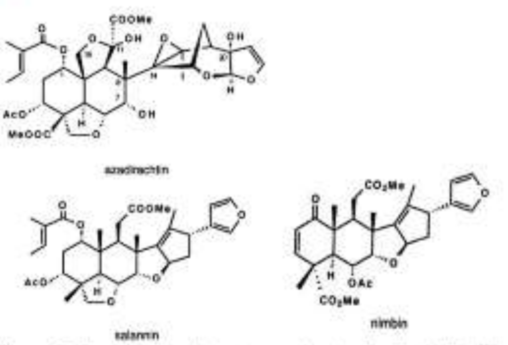


**Figure-5:** Some of chemical structures in *Azadirachta indica*[119].

***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.

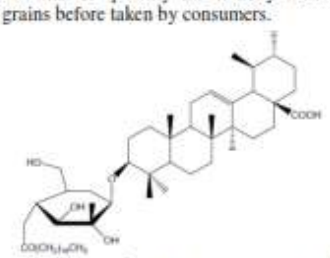

**Figure-6:** A chemical structure of ursolic acid stearoylglucoside[128].

## 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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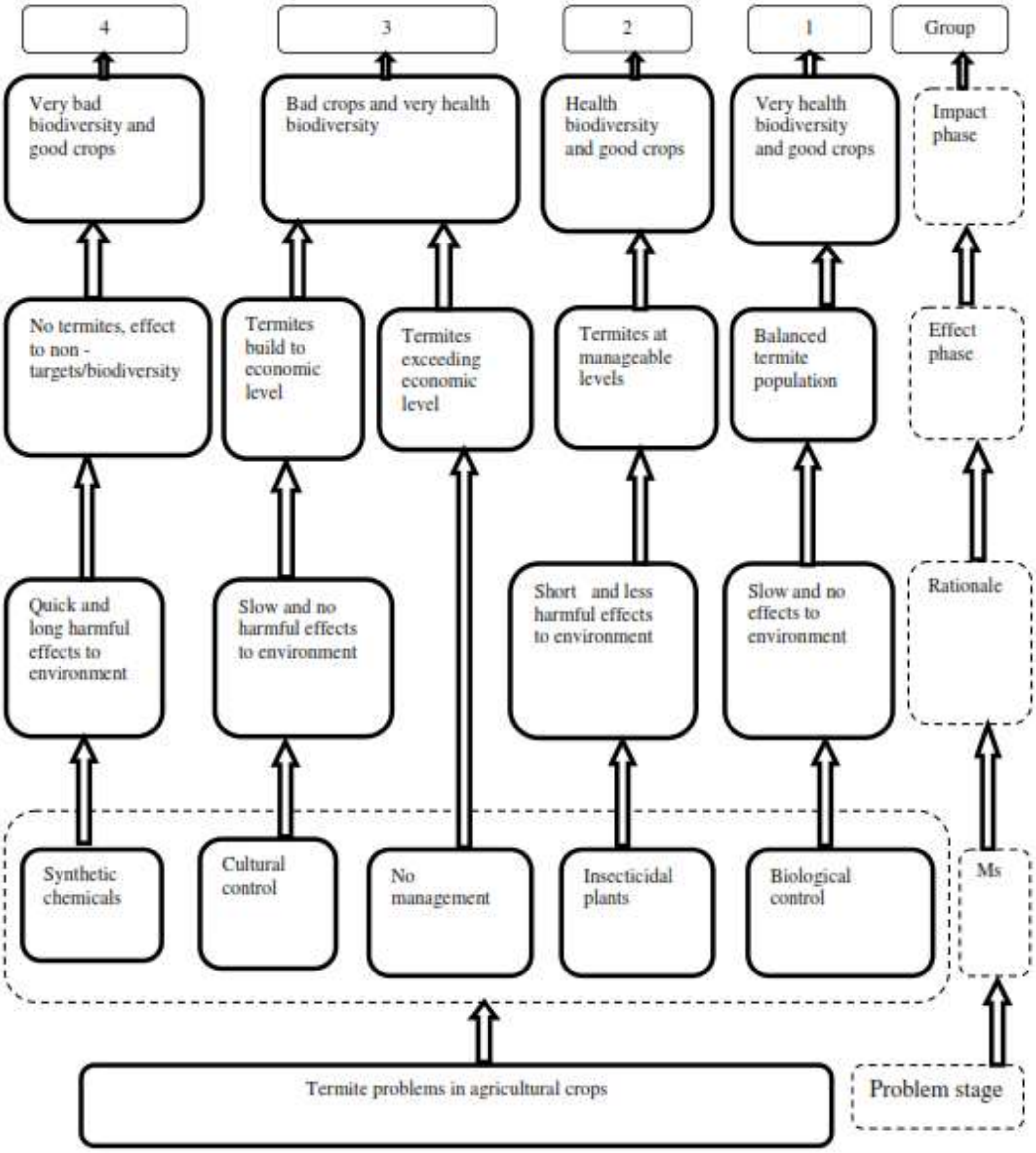


**Figure-7:** Termite management practice model and its effect on crop and biodiversity. In this model, four methods with regard to management have been described. In group 1, the termite management option leads to very health biodiversity and good crops; group 2, termite management option leads to health 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.

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**Output 2: Poster Presentation**

# Termite Species Identification and Their Sustainable Management Using Botanical Pesticides in Arusha, Tanzania

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## Introduction

Maize (*Zea mays*) is an important dietary staple food and source of carbohydrates in the most developing countries (Sekamatte *et al.*, 2003). The crop being of important, yet its production is constrained by diverse insect pests such as termites. Managing termites is possible with use of synthetic pesticides, however, the chemicals are hazardous to the environment and people (Weichenthal *et al.*, 2010). Thus, search for alternative eco-friendly management strategies for termites such as use of bio-pesticidal plants is urgently needed.

## Objective

**Specific objectives**

i. To identify termite species that damage maize crops and trees of economic importance in Arumeru District.
ii. To screen the effective selected pesticidal plants for controlling termites under laboratory conditions.
iii. To assess the efficiency of selected pesticidal plants in termite management under field conditions in Arumeru District.

## Methodology

- A total of 1600 termite samples were collected taken to Tropical Pesticides Research Institute (Arusha). They were identified morphologically using Identification Keys.
- Leaves of *T. vogelii,, C. lusitanica, E. dalrympleana, A. indica* and *L. camara* were collected from Kikwe ward and left to air dry in NM-AIST laboratory for 30 days. Then dried leaves were crushed into powder, labelled and packed under dark room prior to use.
- Weights of 5g, 10g and 20g of each pesticdal plant were used in treatment of 20 termites in completely randomized design (CRD) with 3 replications (laboratory).
- Weight of 20g of each pesticidal plant was used to treat each maize plant following randomized complete block design (RCBD) with four replications.
- Damaged and health maize crops were recorded.
- Maize grains were harvested and weighed in Nm-AIST laboratory.

## Results

The results show that 800 out of 1600 termite samples were identified as *Odontotermes* (Fig. 1a) and 750 termites were *Macrotermes* (Fig. 1b). In terms of efficacy, *T. Vogelii* caused mortality of *Macrotermes* from 93-98% while *E. dalrympleana* was about 80-93% after 24hrs in laboratory.

*Tephrosia Vogelii* protected maize crops significantly next to positive control followed by *C. lusitanica* and *E. dalrympleana* against field termites (Fig. 2). Also the maize grain yields were high in *T. Vogelii* compared with others (Fig. 3).

(a) (b)

**Fig. 1. Termite species**

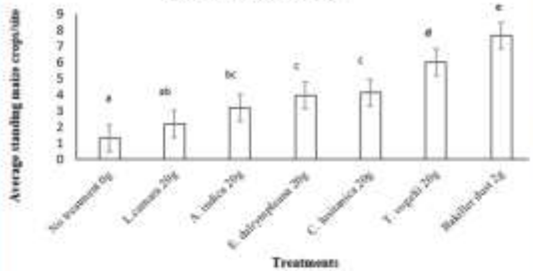


**Fig. 2. Efficacy of botanicals against field termites**

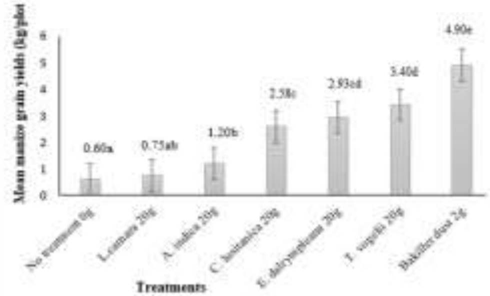


**Fig.3. Maize grain yields in different treatments**

## Discussion

Understanding the termite species which constrain maize production open window for an appropriate management of termites which to increased food/maize security.

## Conclusion and recommendation

The study has identified two termite species of *Odontotermes* and *Macrotermes* which cause a great loss of maize. Also *T. Vogelii, C. lusitanica* and *E. dalrympleana* have shown positive control filed termites, therefore there is need to consider them for development of bio-termicides alternative to hazardous chemicals.

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