

# Effects of Selected Pesticidal Plants on Termites Affecting Maize Production in Arusha, Tanzania

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**How to cite this paper:** James, S., Ndakidemi, P.A. and Mbega, E.R. (2020) Effects of Selected Pesticidal Plants on Termites Affecting Maize Production in Arusha, Tanzania. *American Journal of Plant Sciences*, 11, 510-527.

<https://doi.org/10.4236/ajps.2020.113036>

**Received:** August 26, 2019

**Accepted:** March 24, 2020

**Published:** March 27, 2020

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## Abstract

Investigations under laboratory and field conditions were carried out with purpose of understanding the effects of pesticides of *Cupressus lusitanica*, *Tephrosia vogelii*, *Eucalyptus dalrympleana*, *Lantana camara* and *Azadirachta indica* in the control of termites which affect maize production in Arusha, Tanzania. Termites were collected before and during maize season of 2018 and identified at the Tropical Pesticides Research Institute (TPRI) laboratory. A total of 5279 out of 5307 termite species identified belong to genus *Macrotermes*, 23 species to genus *Odontotermes* and 5 species were unknown. The results entailed that the area is rich in species of genus *Macrotermes*. Moreover, concentrations *i.e.* 5 g, 10 g and 20 g of each botanical were tested for *Macrotermes* spp. mortality and repellency ability in the laboratory using a completely randomized design (CRD) with three replicates. The results showed that 98.33% *Macrotermes* spp. mortality was caused by *T. vogelii* followed by 93.33% recorded from *E. dalrympleana* after 24 hours. Besides, *C. lusitanica* repelled *Macrotermes* spp. by 97% followed by 95% recorded from *T. vogelii* and *E. dalrympleana* each. For field trials, 20 g of each botanical was applied using randomized complete block design (RCBD) with four replicates. The results obtained from field indicated that *T. vogelii* was more effective to protect maize with an average of 6 maize stands and 3.4 kg of dry total weight of maize grains next to positive control per plot. Also, average of 4 maize stands and 3 kg dry total weight of maize grains were recorded from treatments of *E. dalrympleana* and *C. lusitanica* each. Such results highlight the potential of developing bio-termiticides from *T. vogelii*, *C. lusitanica* and *E. dalrympleana* to control *Macrotermes* spp.

## Keywords

Damage, Mortality, Pesticidal Plants, Repellency, Termites, Maize

## 1. Introduction

Maize is one of the staple food crops that are rich in carbohydrates and it is consumed by the majority of people in Africa [1] [2]. It is also used as the source of income by the most African communities [1]. The crop is of importance for livelihood of people, yet its production is constrained by various insect pests such as termites [3]. The most known destructive termite species to maize include *Microtermes* spp., *Macrotermes* spp. and *Pseudacanthotermes* spp. [4]. These species have been reported to cause high losses in pre- and post-harvest of maize in developing countries. For example, in some African countries, such as Mozambique, Zambia, Uganda and Malawi, damage on different crops including maize has been reported [2] [5]. In other African countries, such as Ethiopia, 45% - 50% maize damage has been documented [6] [7]. In addition, effects of termites to other crops, for example, groundnuts and coconuts, have been documented; Nigeria, Burkina-Faso, Niger and Mali encounter a loss of 30% in groundnuts annually [8] and up to 50% groundnuts loss occurs in India yearly [9]. In Tanzania, damage by termites on coconuts (20% - 100%) has been reported especially during the dry seasons [10].

Furthermore, in Arusha region of Tanzania, termites have been reported to attack agricultural crops, some trees in gardens and public parks [11] [12]. Managing termites is possible with use of synthetic pesticides, however, the chemicals are hazardous to the environment and people [13] [14] [15]. So, search for alternative, affordable, eco-friendly and appropriate management strategies for insect pests such as use of bio-pesticidal plants is urgently needed [16] [17]. Previous studies have shown that *T. vogelii*, *Eucalyptus* spp., *A. indica*, *C. lusitanica* and *L. camara* are commonly used by small scale farmers of Tanzania and Uganda to control moths, weevils, aphids, stem borers, rodents, pod borers, bean flies and termites in field crops [18] [19]. In addition, leaves of *C. lusitanica* have been used to treat cold and cough symptoms, treat dermatophytes on human skin and repelling insect pests from stored seeds or grains [20]. In other studies, a repellency of 73% to 90% on treated *Prostephanus truncatus* has been obtained from research conducted by [21] using leaf powders of *A. indica*, *L. camara* and *T. vogelii*. In Africa, crushed fresh leaves of *T. vogelii* are used as poisons for illegal fishing especially in rural areas [22].

Besides, report by Ogendo *et al.* (2003) concluded that leaf powders of *T. vogelii* can cause up to 94% mortality in *Sitophilus zeamais* (Motschulsky), *Rhyzopertha dominica* (F.), *Sitophilus oryzae* (L.), *Callosobruchus chinensis* (L.), *Oryzaephilus surinamensis* (L.) and *Tribolium castaneum* (Herbst) candidates under laboratory conditions [23]. Also, *Eucalyptus* powders have been found to be strong to control *S. zeamais* in stored maize grains within 56 days [24]. The diverse use of these pesticidal plants is due to presence of bioactive compounds. For instance, *T. vogelii* possesses high amounts of rotenone and deguelin [25]. Rotenone and deguelin are toxic compounds and can kill many aquatic organisms including fishes since they are poisons when introduced into water [26].

They have ability to inhibit the function of respiratory enzymes in fishes [27]. *Lantana camara* contains ursolic acid stearylglucoside as active compound which causes dehydration, lung and heart problems, nephrosis, constipation, less mobility and lowering reproduction in animals such as mice [28] [29]. Besides, *Azadirachta indica* contains Azadirachtin compounds which when it comes into contact with beneficial insects affect by repelling them from their homes and causes feeding deterrence, blocking sugar and receptor cells, disrupting growth and moulting, inhibits oogenesis and oviposition in female and interrupts sperm production in male insects [30]. The *C. lusitanica* and *E. dalrympleana* leaves have aromatic compounds and compounds of essential oils including  $\alpha$ -cedrene,  $\beta$ -cedrene, bornyl acetate, cedrol, epimanool, agathadiol and 1,8-cineole [31] [32]. When these compounds are not handled well during field application, can suppress other non-targeted organisms like beneficial insects. For example, it has been reported that these compounds can repel and affect important agricultural crop pollinators such as butterflies [33].

Regarding the above potential highlights of botanical powders as control agents for crop plant insect pests, the current study was designed to identify termites affecting maize production and evaluate the efficacy of leaf powders of *T. vogelii*, *E. dalrympleana*, *A. indica*, *C. lusitanica* and *L. camara* against termite species from laboratory to field applications.

## 2. Materials and Methods

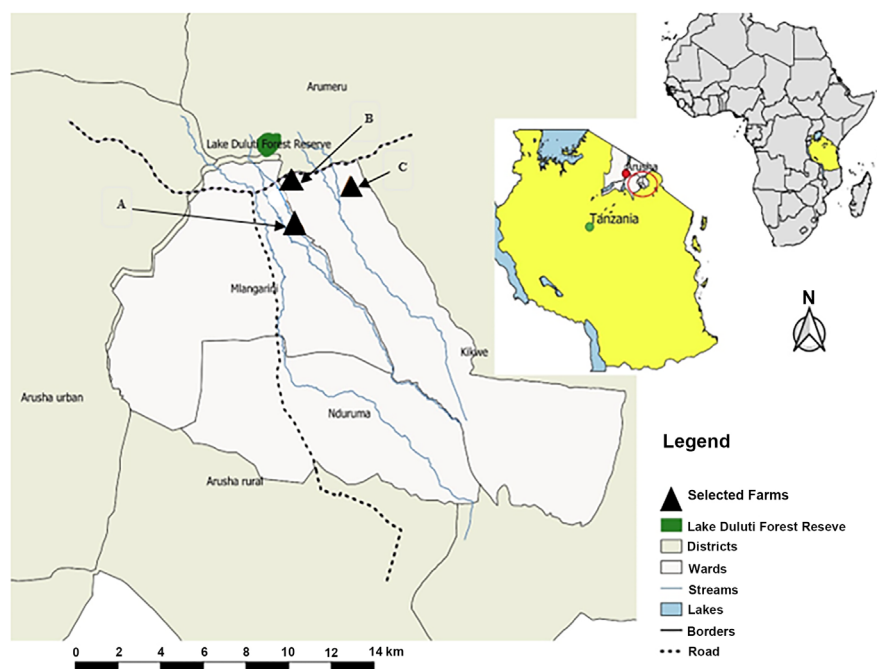
### 2.1. Study Area Description

The study was conducted at Kikwe Ward in Arumeru District of Arusha region. The district has area of 2966 km<sup>2</sup> equivalent to 3.5% of Arusha region, located between 35°E and 37°E longitudes as well as 3°S latitudes [34]. Arumeru district receives bimodal rainfall, March to May and November to December. The average monthly rainfall is about 83.3 mm to 375 mm and temperatures of about 20°C to 35°C [35]. The main crops grown in Arumeru district are coffee, beans, banana, vegetables and maize [36] [37].

The area harbors a high population of termites that affect maize crops, however, no quantified figures are available on maize loss. Therefore, three sites namely A, B and C located at 03°25'23.2"S and 036°48'03.0"E, 03°25'28.3"S and 036°48'00.7"E and 03°25'30.5"S and 036°47'43.1"E respectively, were established in this Ward at Gomba farms for the study (Figure 1). Also laboratory experiments were carried out at the Nelson Mandela African Institution of Science and Technology (NM-AIST) and the Tropical Pesticides Research Institute (TPRI) laboratories.

### 2.2. Source of Pesticidal Plants Used in this Study

Leaves of *C. lusitanica*, *T. vogelii*, *E. dalrympleana*, *L. camara* and *A. indica* were collected in January 2018 from their natural environments at Nambala village in Kikwe Ward. The leaves collected were air dried at room temperature of 25°C in



**Figure 1.** Study site.

the NM-AIST laboratory for 21 days [38]. All dried leaves were crushed separately into 35 grams of powders, packed, labeled and stored in dark room (NM-AIST laboratory) prior to use. The powder size used in this study was 5, 10 and 20 grams adopted with modification [24].

### 2.3. Termite Sampling before Maize Season

Before maize season (January to February 2018) three sites from three farms were purposively selected at Kikwe ward based on history of presence of termites. In each farm two transects of 100 m long were established and quadrats of 5 m × 2 m were conducted twenty times along each transect at interval of 5 m based on Coulibaly *et al.* (2013) protocol with modifications [39]. From each quadrat five holes were randomly dug up to 20 - 30 cm depth to collect termites (soldier castes and worker castes). In each hole 4 termites were collected making a subtotal of 20 termites per quadrat and a total of 400 termites per transect and a total of 800 termites/farm. As per methodology a total of 2400 termites were collected from three farms and put into different labeled (with respect to location) small bottles (diameter 3 cm, height 5 cm) containing 70% alcohol prior to identification.

### 2.4. Termite Sampling during Maize Season

From March to July 2018, termites (both soldier and worker castes) were collected randomly from three experimental sites (experimental plots). Holes were dug up to 20 - 30 cm depth to search and collect termites following systematic random sampling technique. A total of 2907 termites were collected from all experimental plots. This sampling process was done once per month until harvest.

## 2.5. Termite Identification

A total of 2400 termites (before field experiments) and 2907 termites (from experimental plots during maize season of 2018) were transported to Tropical Pesticides Research Institute laboratory for identification. Soldier castes were sorted and their morphological features were observed using Stereo-microscope based on Bouillon and Mathot (1965) and Pearce *et al.* (1992) methodology [40] [41].

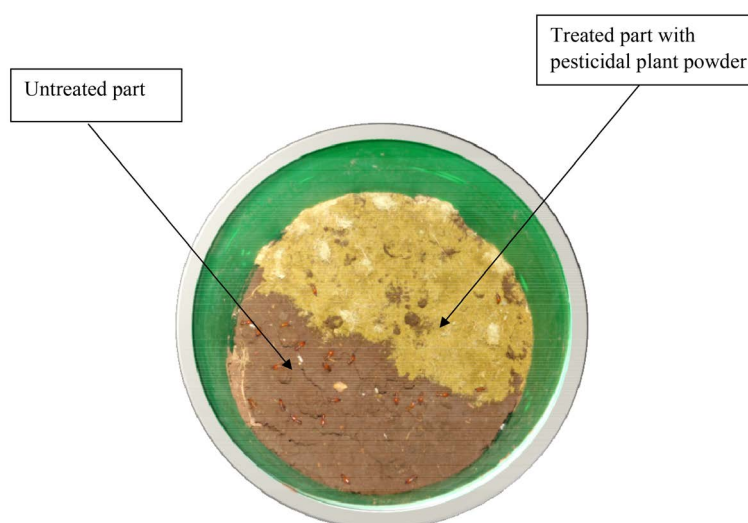
## 2.6. Collection of Termites for Laboratory Experiments

Termite species of genus *Macrotermes* were collected from three experimental sites/plots. At these sites holes were dug up to 20 - 30 cm following systematic random sampling. Soil containing *Macrotermes* spp. was placed on the polyethene plastic sheet, then termites were swept into ventilated polyethene plastic boxes (22 × 7 × 7) using camel hair brushes [42]. The *Macrotermes* spp. preferred feeding plant materials (sun dried maize leaves and stems) were added followed by moistened cotton wool to maintain moisture condition (65%) for the survival of the termites [43]. The selection to species of genus *Macrotermes* in this study has basically considered the effects of these species in maize production before harvesting in Arumeru district.

## 2.7. 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. 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 of genus *Macrotermes* from the same colony were added followed by addition of powder of the treatment. One gram of Bakiller dust (Carbaryl 5% w/w + Lambda cyhalothrin 0.1% w/w) was used as positive control based on manufacture's recommendation whereas 5 g powder prepared from mixture of sun dried leaves and stems of maize (*Macrotermes* spp. preferred feeding plant materials) 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* were used. The mortality rates were recorded at 6, 12, 18 and 24 hours after application.

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 rates was poured on top of soil in the bucket to half the diameter (Figure 2) and twenty termites of the same colony were placed on the center of the bucket and were visually observed whether or not they would move away or towards the plant powders. As of the previous description, this



**Figure 2.** Repelled termites by *C. lusitana* (among plant powder treatments).

experiment was arranged in a completely randomized design (CRD) with three replicates. The repellency ability of the treatment was recorded after one hour.

## 2.8. Testing the Efficacy of the Pesticidal Plants in the Fields

For field experiments, three sites were established for trials in Gomba maize farms where there is high abundance of *Macrotermes* spp. which affect maize production before harvesting. The experiments were conducted during maize growing season from March to July in 2018 and the distance from one site to another was 500 meters. In each site, every plot had 150 cm long and 90 cm wide and the distance separation from plot to plot was 50 cm. Eight maize plants (PAN 691) were germinated in each plot (two rows each with 4 maize plants planted 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. lusitana*, *T. vogelii*, *E. dalrympleana*, *L. camara* and *A. indica* at the rate of 20 g, 2 g of positive control [Bakiller dust (Carbaryl 5% w/w + Lambdacyhalothrin 0.1% w/w)] and without treatments as negative control were applied in the third week following randomized complete block design (RCBD) in four replications. Botanical leaf powders and Bakiller dust were applied around the maize stems. The application of botanical leaf powders and the controls were re-applied and monitored on treated plants every after 14 days until harvest.

## 2.9. Data Collection

Termites were collected from the field for identification, a number of dead 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 (b) as described by [32] and

[43], respectively. Since each plot had 8 maize plants before damage by termites, careful counting and recording of maize stands was done to each plot in respect to treatments. Also average total dry weight of maize grains were obtained from only maize stands in respect to treatments. On the other hand, maize which found fallen down due to termite damage was not considered for harvest.

$$PM = \frac{(MTT - MTC)}{(100 - MTC)} \times 100 \quad (a)$$

*PM* = Percent Mortality

*MTT* = Mortality of Termites in Treatment

*MTC* = Natural Mortality of Termites in Control

$$PR = \frac{(T - C)}{(T)} \times 100 \quad (b)$$

*PR* = Percent repellency

*T* = All termites counted from the part without treatment

*C* = All termites counted from the part with treatment

## 2.10. Data Analysis

Collected termites from field were identified to genus level. Also before Analysis of Variance (ANOVA), Bartlett's test was run using R- Studio on collected data of termite mortality, repellency, average maize stands and average total dry weight of maize grains produced. The output showed that the *p*-values for mortality, repellency, average maize stands and average total dry weight of maize grains were 0.4009, 0.9966, 0.9290 and 0.0820, respectively. This means that we cannot reject the null hypothesis because the *p*-values are not less than 0.05. Or there is no evidence to suggest that the variances in mortality, repellency, average maize stands and average total dry weight of maize grains are different from treatments. Therefore, an option to transfer data to Analysis of Variance (ANOVA) was done to determine the significant differences. Differences among treatment means were determined using Duncan's multiple range test at *p* = 0.05 using GenStat 15 edition statistical package.

## 3. Results

### 3.1. Identified Termites

The results in **Table 1** showed that 5279 (99.47%) out of 5307 were identified as *Macrotermes* spp., 23 (0.43%) as *Odontotermes* spp. and 5 (0.09%) as unknown species. Based on this study, five (5) termites were not identified to genus level due to available limited technology at the Tropical Pesticides Research Institute.

### 3.2. Mortality of *Macrotermes* spp.

The results in **Table 2** showed that there was 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* spp. compared with



**Table 1.** Some termites identified to genus level.

Termite Genera	Number of termites
<i>Macrotermes</i>	5279
<i>Odontotermes</i>	23
Unknown X	2
Unknown Y	3
Total	5307

**Table 2.** Effect of different insecticidal plants on *Macrotermes* spp. (mortality).

Treatments	Rate in g/ 5 kg soil	Mortality mean in percent (%) per time (hours)			
		6	12	18	24
<i>T. vogelii</i>	5	35.0 ± 2.89d	73.3 ± ±3.33hi	90.0 ± 2.89f	93.3 ± 1.67i
<i>T. vogelii</i>	10	50.0 ± 5.77e	83.3 ± 4.41j	93.3 ± 1.67fg	96.7 ± 1.67i
<i>T. vogelii</i>	20	78.3 ± 4.41g	88.3 ± 3.33j	95.0 ± 2.89fg	98.3 ± 1.67i
<i>L. camara</i>	5	5.0 ± 2.89ab	10.0 ± 2.89abcde	11.7 ± 1.67bc	23.3 ± 1.67cdef
<i>L. camara</i>	10	5.0 ± 2.89ab	11.7 ± 1.67bcdef	13.3 ± 1.67bc	16.7 ± 1.67bc
<i>L. camara</i>	20	10.0 ± 2.89ab	18.3 ± 3.33cdef	20.0 ± 2.89cd	33.3 ± 1.67g
<i>C. lusitanica</i>	5	1.7 ± 1.67a	10.0 ± 2.89abcd	11.7 ± 1.67bc	20.0 ± 2.89bcde
<i>C. lusitanica</i>	10	5.0 ± 5.00ab	10.0 ± 5.77bcd	11.7 ± 4.41bc	20.0 ± 2.89bcd
<i>C. lusitanica</i>	20	3.3 ± 1.67a	10.0 ± 2.89abcd	20.0 ± 2.89cd	23.3 ± 6.01cdef
<i>A. indica</i>	5	8.3 ± 4.41ab	8.3 ± 4.41abc	11.7 ± 6.01bc	16.7 ± 4.41bc
<i>A. indica</i>	10	0.0 ± 0.00a	5.0 ± 0.00ab	6.7 ± 1.67ab	11.7 ± 6.67b
<i>A. indica</i>	20	15.0 ± 5.77bc	20.0 ± 2.89df	23.3 ± 1.67d	30.0 ± 0.00dfg
<i>E. dalrympleana</i>	5	21.7 ± 4.41c	55.0 ± 2.89g	71.7 ± 3.33e	80.0 ± 2.89h
<i>E. dalrympleana</i>	10	45.0 ± 2.89de	70.0 ± 2.89h	76.7 ± 4.41e	83.3 ± 4.41h
<i>E. dalrympleana</i>	20	65.0 ± 2.89f	80.0 ± 2.89ij	93.3 ± 1.67fg	93.3 ± 1.67i
Positive control	1	100.0 ± 0.00h	100.0 ± 0.00k	100.0 ± 0.00g	100.0 ± 0.00i
Negative control	5	0.0 ± 0.00a	0.0 ± 0.00a	0.0 ± 0.00a	0.0 ± 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.

negative control. *T. vogelii* and *E. dalrympleana* were the most effective plants which caused the highest mortality of *Macrotermes* spp. at 6, 12, 18 and 24 hours. All rates of *T. vogelii* (5 g, 10 g and 20 g) and that of *E. dalrympleana* (20 g) had no significant difference from positive control after 24 hours. Moderate mortalities with 23.33%, 30% and 33.33% were recorded from *C. lusitanica*, *A. indica* and *L. camara*, respectively at rate of 20 g each one.



### 3.3. Repellency of *Macrotermes* spp.

The results showed significant difference ( $p \leq 0.001$ ) between treatments in repellency of *Macrotermes* spp. (Table 3). The percent repellency values recorded in treatments of *C. lusitanica* at 5 g, 10 g and 20 g have non-significant difference with that of *T. vogelii* (10 g and 20 g) and *E. dalrympleana* (10 g and 20 g). But, the percent repellency values recorded from *A. indica* and *L. camara* treatments were lower than that obtained from *C. lusitanica*, *T. vogelii* and *E. dalrympleana*.

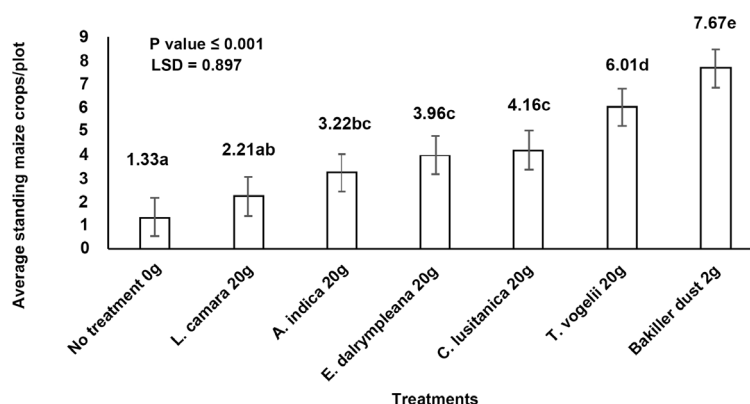
### 3.4. Effects of Pesticidal Plants Powder on Field Maize in Three Sites (at Gomba Maize Farms)

The results in Figure 3 show that there was a significant reduction ( $p \leq 0.001$ ) of maize crops damaged by termites (*Macrotermes* spp.) in treated plots compared with untreated plots. Average of maize stands per plot was 6.01, 4.16 and 3.96 with treatment of *T. vogelii*, *E. dalrympleana* and *C. lusitanica*, respectively. High average of maize grain yields were obtained from plots with treatment of *T. vogelii* (3.4 kg) followed by *E. dalrympleana* (2.93 kg) and *C. lusitanica* (2.58 kg) as depicted in Figure 4.

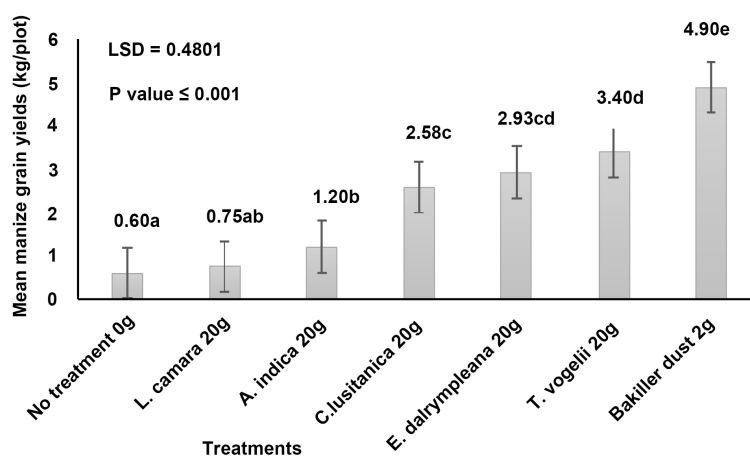
**Table 3.** Repellency bioassay in treated *Macrotermes* spp.

Treatments	Rate in g/5 kg soil	Average percent repellency
<i>T. vogelii</i>	5	88.3 ± 7.27bc
<i>T. vogelii</i>	10	95.0 ± 4.41c
<i>T. vogelii</i>	20	95.0 ± 3.33c
<i>L. camara</i>	5	76.7 ± 4.41b
<i>L. camara</i>	10	76.7 ± 6.01b
<i>L. camara</i>	20	77.7 ± 10.14b
<i>C. lusitanica</i>	5	95.0 ± 1.67c
<i>C. lusitanica</i>	10	95.0 ± 1.67c
<i>C. lusitanica</i>	20	96.7 ± 2.89c
<i>A. indica</i>	5	76.7 ± 7.64b
<i>A. indica</i>	10	83.3 ± 4.41bc
<i>A. indica</i>	20	83.3 ± 4.41bc
<i>E. dalrympleana</i>	5	86.7 ± 8.82bc
<i>E. dalrympleana</i>	10	93.3 ± 3.33c
<i>E. dalrympleana</i>	20	95.0 ± 2.89c
Negative control	5	0.0 ± 0.00a
LSD		13.320
p value		0.001

Means with the same letter (s) have no significant difference at  $p = 0.05$  using Duncan's Multiple Range Test.



**Figure 3.** Average of standing maize plants treated with different pesticidal plants and control (A, B and C).



**Figure 4.** Average total dry weight of maize grains per plot from all sites (A, B and C).

## 4. Discussion

This study identified only termite species of genera *Macrotermes* and *Odontotermes* whereas species of unknown genera (X and Y) were not identified due to available limited technology at the Tropical Pesticides Research Institute laboratory. The number of termite species identified for genus *Macrotermes* was high compared with genus *Odontotermes* and unknown genus X and Y. In addition, the observation made the area is richly covered with termite mounds of genus *Macrotermes*. The presence of termite mounds contributes to high abundance of species of genus *Macrotermes* which forage on maize plants intensively. Their foraging behavior affect maize production and this is why the current study concentrated only in trials of botanical powders against species of genus *Macrotermes*. These findings present one of very few accounts on maize in Tanzania and they are in line with several studies. In India, species of genus *Macrotermes* have been reported to cause a loss up to 25% in maize yields per year before harvesting [44]. Furthermore, in Uganda, the same has been reported to cause 10 to 30% of maize loss before and after harvest [2] [45]. The *Macrotermes* can also

cause up to 100% damage on maize [46]. Urgent management strategies which are eco-friendly and affordable are needed to control *Macrotermes* spp. such as use of botanical pesticides. Less or no studies have been conducted in control of *Macrotermes* spp. using leaf powders from *C. lusitanica*, *T. vogelii*, *E. dalrympleana*, *L. camara* and *A. indica* on maize fields. The discussion has been related with different studies conducted in different insect pests other than termites, *Macrotermes* spp. due to available limited information.

Interestingly, *T. vogelii* leaf powders were the most effective pesticide against *Macrotermes* spp. causing a mortality of 98.33% (20 g) for 24 hours. These results relate to study of Ogendo *et al.* (2003) which showed that leaf powder from *T. vogelii* caused a mortality of 85 to 94% *S. zeamais* in stored food products [23]. Moreover, *T. vogelii* powder reduced the number of eggs laid for first progeny (insect bruchids) resulting into 7.1% stored leguminous seeds damage compared with 99.8% damage in control without treatments [47]. Besides, the leaf powders of *T. vogelii* caused 93.3% *C. maculatus* mortality at concentration of 3 g per 10 g of stored cowpea seeds on the 96 hours [48].

Other results of the current study were recorded from leaf powders of *E. dalrympleana*, *C. lusitanica*, *A. indica* and *L. camara*. Among these, *E. dalrympleana* was more effective than *C. lusitanica*, *A. indica* and *L. camara* in causing mortality. However, application information availability for *E. dalrympleana* is limited, but the genus *Eucalyptus* is highly documented for its significance in the management of diverse insect pests. For instance, research data reported by [24] proved that 10 g of *E. tereticornis* leaf powder can cause 91.10% mortality for 8 weeks against stored maize weevil, *S. zeamais*. These results are in agreement with the investigation which tested crude powder, 2.0% to 4.4% w/w of *O. gratissimum* and found that 87% - 90% and 27% - 50% mortality to *C. maculatus* and *S. zeamais*, respectively [49].

Moderate mortalities recorded from *C. lusitanica*, *A. indica* and *L. camara* could perhaps be linked to the bioactive compounds not being exposed enough to cause lethal effect on experimental termites used in the current study. However, these results cannot be ignored in comparison to negative control. These significant effects showed by these botanicals demand different technologies especially from how botanicals are prepared and extracted 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* leaf extracts minimized significantly the number of *Tuta absoluta* in vegetable tomatoes compared with fields without treatments [50]. The screening for mortality against Lepidopteran and Coleopteran insect pests with two botanicals showed that the extracts from *C. lusitanica* and *E. saligna* at dose of 2.0%v/w caused high mortality against the pests (84% - 86%) [32]. This concurs with assertions by the report of [21] where *L. camara* leaf powder minimized significantly (70% - 86%) the number of Coleopteran pests from stored food cereals such as maize grains.

The repellency test presents very useful information which can be used by ecologists and conservationists who discourage killing of insects for the purpose

of biodiversity conservation 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 [51]. 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 [52].

The results of repellence bio-assay of leaf powders of *T. vogelii*, *E. dalrympleana*, *C. lusitanica*, *A. indica* and *L. camara* showed variations in terms of responses to tested *Macrotermes* spp. *C. lusitanica* leaf powder exhibited strong repellency followed by *T. vogelii* and *E. dalrympleana*. Their percent repellency values ranged from 95% to 97% at 20 g in this study. Our results are in line with a report by [32] who reported that the extracts of *C. lusitanica* repelled coleopteran insect pests by 65% to 93% from stored food products. These results corroborate with the report findings of study by [21] who identified that 90% repellency in stored maize weevils, *P. truncatus* was caused by *T. vogelii* powders. Though, there is limited information of *E. dalrympleana*, yet the species of the same genus are well studied and documented. For example, 30 g powder of *Eucalyptus globulus* caused a significant repellency of 80% to termites [19] [53]. The observed repellent activities in *A. indica* and *L. camara* were moderate against *Macrotermes* spp. These results are closely related to the previous findings. Chebet *et al.* (2013) found that powders of *L. camara* and *A. indica* can cause a repellency of 73% and 88% on *P. truncatus* respectively [21]. Interestingly, a single topical application of *L. camara* extracts to volunteers ensured protection of 100% in 120 minutes and 75.8% for 420 minutes from bites of mosquito species (*Aedes* spp.) [54].

Of the five pesticidal plants evaluated, *T. vogelii* was the most effective in terms of efficacy on field *Macrotermes* spp. control. The results of our study relate to study conducted by Mkindi *et al.* (2017) in Tanzania and Malawi, which found that *T. vogelii* reduced the number of field insect pests and damage and promoting high bean yields during harvest [55]. Furthermore, field research which used crushed *T. vogelii* leaves in ponds caused a significant mortality on fishes, rotifers and larvae of mosquitoes [56]. In addition, *T. vogelii* is effective in controlling both stored product and field insect pests [57]. The effectiveness of *T. vogelii* is due to presence of already known active ingredients such tephrosin and deguelin [58] [59]. As rotenone has known history in the insect pest control for so long before an invention of synthetic pesticides, so registration and commercialization of *T. vogelii* products are highly needed [60]. Other promising results were obtained from treatments of *E. dalrympleana* and *C. lusitanica*. Though there is less or no quantified information about the applicability of *E. dalrympleana*, various species of genus *Eucalyptus* are highly recognized and reported to have considerable effects against variety of agricultural crop insect pests. For instance, field trials conducted in India during the kharif growing season in 1988 identified that the *Eucalyptus globulus* extracts reduced the larvae of *Henosepilachna vigintioctopunctata* significantly [61]. These results corroborate with the

research findings of Paul *et al.* (2009) which showed a significant reduction in numbers of bean insect pests on farm trials in Northern Tanzania [62].

## 5. Conclusion and Recommendations

This study has demonstrated that there is termite species of genera *Macrotermes*, *Odontotermes* and species of unknown genera (X and Y). The species of genera *Macrotermes* are more abundant and destructive to maize than any other. Moreover, the current study confirms that *T. vogelii* is more effective among pesticidal plants which exhibited positive mortality of termite species of genus *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 genus *Macrotermes* under laboratory conditions. Also, the field trials showed that *T. vogelii* was more effective among pesticidal plants in protection of maize plants against destructive termites of genus *Macrotermes* followed by *C. lusitanica* and *E. dalrympleana*. The average dry weight of maize grains 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 termite species of genus *Macrotermes* around the treated maize crops. The study recommends more researches including molecular studies on termite diversity and identification from a wide geographical area and their role in agricultural crop damage. Also, verification of negative effects to non-targeted organisms is needed for the leaf powders prepared from *T. vogelii*, *E. dalrympleana* and *C. lusitanica*.

## Authors' Contribution

SJ and ERM proposed the research idea. Then SJ, ERM and PAN designed the research methodology and conducted the experiments. SJ did analysis of data obtained from laboratory and field experiments. The manuscript was prepared and approved by SJ, ERM and PAN.

## Acknowledgements

We would like to thank the Nelson Mandela African Institution of Science and Technology (NM-AIST) for providing financial support through African Development Bank (AfDB) Grant no. 2100155032816. We extend our gratitude to Tropical Pesticides Research Institute (TPRI) of Arusha for use of the laboratory for termite identification.

## Human and Animal Subject

The study does not have any data from human and animal subjects.

## Conflicts of Interest

The authors declare that they have no conflict of interest.

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