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Analysis of Some Plant Extracts' Repellency and Land Use Impacts on Termites

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ABSTRACT

It is known that insects have lived on Earth since about 500 million years ago. Humans, on the other hand, have started to be harmful to the ecosystem since they started living on earth only 200,000 years ago. The damage caused by humans to the environment is incomparable with the damage caused by other animals. Until the early 1900s, agricultural activities were mostly done organically. Along with the general industrialization, farmers began to industrialize agriculture. The most dangerous advances were in the production of pesticides and mineral fertilizers, because their effects on plant physiology and the biotope were crucial. Insects are among the most affected in the biotope because since the development of pesticides the planet has lost 70% of the world's insect population. Termites have been one of the species most damaged by insecticide applications. Although conventional pesticides fail to control termites, it seems that such pesticides continue to be used all the time. In addition, the side effects of pesticides in the soil are a great ecology harm. In our research, natural plant extracts, one of the environmentally friendly solutions, were used to control (repel) termites. Plant extracts from three plants (*Lantana camara*, *Tephrosia vogelii* and *Euphorbia tirucalli*) were tested as termite repellents. After crushing fresh leaves, they were soaked in water for 24, 48 and 72 hours. Three doses, 1:9, 2:8 and 3:7 (pounded plants: water), of these extracts were applied to the plots around the active termite mounds. The number of days it took for termites to colonize the treated parcels (repellent effect) was evaluated. The results obtained showed that the soaking time of the plant extracts does not make a significant difference. However, doses and plant variety showed significant differences compared to control plots. The highest repellent effect was determined as 31.3(±1) and 31(±1) days at 3:7 doses of *E. tirucalli* soaked in water for 72 hours and *T. vogelii* soaked in water for 48 hours, respectively. However, 1:9 dose of *E. tirucalli* soaked in water for 72 hours has a lower (13(±1) days) repellent effect. Land use analysis, on the other hand, shows that agricultural and residential areas are installed into termite biotopes. Pastures, crop fields and settlements are the main three land uses found in Kinyinya (east of Burundi). Settlements and crop fields are expanding exponiently. Pastures are the last relatively stable termite biotopes and are gradually transformed in settlements or crop fields. However, considering the effects of termites on the soil, they have great potential to be used as a support to farmers in recycling organic matter. For this reason, it turns out that

it is important to use environmentally friendly plant extracts for the protection of termites.

Keywords: insect repellents, termite repellents, termites and land use, insect ecology, termite ecology.

INTRODUCTION

Insects appeared approximately 480 million years ago and co-evolved with plants (Grimaldi & Engel 2005). According to human definitions, insects have both beneficial and harmful roles in the ecosystem. Insects can be harmful to agricultural crops, timber and stored goods, and as vectors of some diseases (including some pandemics). However, insects are keystone species of ecosystems; they recycle nutrients, take part in pollination, are effective in dispersing seeds, maintain soil structure and fertility, regulate the populations of other organisms, and are a food source for other taxa (Gullan & Cranston, 2014; Schowalter, 2020). More than 80% of described animals and more than 50% of all described organisms are insects (Schowalter, 2020). More than 80% of all insect species have not yet been identified; considering the threats facing insect species, it is thought that some species may become extinct before they are identified (Gullan & Cranston, 2014; Schowalter, 2016). Before 12,000 BC, there was almost no sign of agriculture in the world, but people began to cultivate, domesticated plants and raise animals in the Neolithic. They later incorporated these plants and animals into all kinds of environments. Agriculture became the main factor in the transformation of the ecosphere. Gains in production (agricultural) and gains in productivity respectively increased the number of people and social classes began to emerge (Baker & Goucher, 2015).

With the industrial revolution, agricultural mechanization, chemical fertilizers and pesticides production, and long-distance distribution of food products emerged, the same efforts were also made in seed production, all these developments were in favor of big farmers in developed countries. Small-scale farmers in Africa are still using very primitive methods. These small-scale farmers cannot fully compete with big farm companies in the food market. They are also dependent on them, that small-scale farmers have become dependent on industries and big farm companies, especially on seeds, fertilizers and pesticides. Many products in plant protection are patented. Consequently, the rural farmers have had to abandon their original plant protection methods, as each pesticide requires permission from the major pharmaceutical and pesticide industries (Barton 2018). In the human history, for different epochs, humans have faced tough circumstances, which needed the use of extra means to control some pests. The Black Death (*Yersinia pestis*) caused the death of approximately 50 million people in Europe between 1346 and 1353 and lasted until 1654 in some regions (Cantor 2001). A major factor leading to the collapse of the coffee industry in Sri Lanka (then Ceylon) at the end of the 19th century was the lack of an effective fungicide (Ordish 1952). The Great Famine in Ireland between 1845 and 1852 was caused by potato blight (*Phytophthora infestans*). This fungal disease spread from Mexico and reached Ireland from the USA by sea. The lack of an effective fungicide at the time also contributed to the spread of the disease (Matthews 2018). In the documented cases and undocumented ones, the main cause of eruption of pests is the loss of ecosystem equilibrium. In order to keep alive the cultivated plants in the fields, humans developed pesticides. The history of pesticides can be divided into three main periods: the period before pesticides from the Neolithic period to the 1900s, the early days of pesticides from 1900 to 1960, and the period after the 1960s. The effects of pesticides to the nature were kept as secrets or taboos until Carson (1960) published them. The problem lies in the destruction of the ecosystems (land use). Insects are struggling to survive the new ecosystems in which they lose their first food and habitats. Those insects who don't succumb from lack of food and habitats will try to adapt on new food sources (sometimes the new cultivated plants). In controlling these new enemies, humans will use pesticides (not selective). These pesticides, instead of eliminating the plant enemy, will also destroy some natural enemies and newer pests appear. It becomes a vicious circle where the result is the destruction of the ecosystems.

Small farmers, especially in Burundi, have less information about the ecology and ecosystems. Their ancestors used to have friendly control methods, which were less harmful to the nature. With advertisements from the pesticide companies, they became dependent to the use of pesticides. One of the dangerous case in the nature is the use of pesticides against termites. Termites are not a true problem in the agricultural ecologies. Termites are big farmer's friends. They recycle a big quantity of soil than any other group of animal in the tropics. Farmers need to develop methods, which can protect termites in their ecosystems. In this research, we are developing a method that can help control termites during the vegetative stages of the plants. After the vegetative stages, termites will be free to recycle the garden/field (Holt & Lapage 2000, Wood 1996). Termites (Insecta: Isoptera) are one of the social insect groups. The Isoptera order has relatively less species diversity than many other insect orders, as of April 2012, it consists of 3105 individuals and fossil species, including 12 families and 330 living and fossil genera. One termite's colony consists of the king, the queen (mainly for laying eggs), soldiers (especially for the security of the colony), and workers (feeding the termite soldiers, moving the queen and, to some extent, participating in the security group when the colony is under attack). The queen and the king remain in the nest (Engel et al. 2009). Termites improve the soil structure, increase soil fertility by moving from one layer to another while digging tunnels, create new soil particles by mixing their feces and soil, saliva and fine pieces of the soil they cut, improve the biological, chemical and physical properties of the soil and thus contribute to the development of plants (Wood 1996). Termites play the most important role in soil ecology. They are among the main macroinvertebrate decomposers in arid and semiarid environments. They also create effects by creating biological structures (mounds, galleries, covers, etc.) with different soil physical and chemical properties (Holt & Lapage 2000). How did termites become enemies in agriculture? During their evolution and longer before humans introduced agriculture, termites were engineering soils. Humans introduced new plants and modified the ecosystems. They built wooden houses and filled with printed books or any other materials made of cellulose. The termites in their natural role of decomposer, they interfered with those human projects and became enemies.

The word termite connotes destruction in humans‘ minds, but not all termite species are harmful and only a small portion of the termite species reported as destructive are responsible. Of the 3015 termite species, only 371 (12.4%) were reported as destructive and only 104 (3.5%) were considered serious pests. However, the damage caused by these pest species is extensive. Termites attack many cellulose-containing materials, and financial losses from this destruction amount to billions of dollars per year (Rouland-Lefèvre 2010). Some examples of financial losses. It is reported to be $1.5 billion in Australia, $217 billion in China, $200–300 million in Indonesia, $0.8–1.0 billion in Japan, $4–5 million in Malaysia, $500 million in Thailand, and $1.5 billion in the USA (Govorushko 2018).

Chemical pesticides have failed to control termites with countless side effects. Humans are not only destroying termites with pesticides. Land use system is another way which influences termites' life. The main human activities affecting termite ecology are settlement, agriculture and road traffic networks. Settlement which is mostly coupled with traffic is the number one ennemy of termites because it destroys completely their ecology. Agriculture affects termite ecology firstly by destroying the ecology because natural vegetation is replaced by field crops; termites lose their natural foods, the natural soil structure and texture is destroyed and most times termite mounds are destroyed completely. Pesticides in Agriculture are another land use climax because it harms not only termites, but also the fauna living in symbiosis with termites. Even if botanical pesticides have been shown promising with less side effects, the conventional methods of pesticide applications don't has less effects on termites in their galeries. In order to use botanical pesticides efficiently, there is a big need to focus on ecology of termites. In this research, three plant extracts (*Lantana camara*, *Tephrosia vogelii* and *Euphorbia tirucalli*) have been tested as repellents against termites.

MATERIAL AND METHODS

Study Area

This study was carried out in Kinyinya district in Ruyigi province (east of Burundi). In terms of the African ecosystems, historically and generally, this region is identified as the Miombo forests. It has been determined that Miombo forests are also in danger of extinction due to the impact of human activities. These forests are ecosystems in which termites have a significant share in terms of biodiversity. Miombo forests are considered one of the richest ecosystems in the world in terms of termites (Chirwa et al. 2008). Although termites are found throughout Burundi, they are particularly concentrated in the Miombo region. The term Miombo is used to describe forest areas in central, southern and eastern Africa (Figure 1), dominated by the plant genera Brachystegia, Julbernardia and/or Isoberlinia belonging to the legume family (Fabaceae, subfamily Caesalpinioideae). The genus Brachystegia and three species of each related genus are found in Miombo forests (White 1983).

Kinyinya district (located in the south of Ruyigi province) covers 11.4% of the province (Ruyigi: 2338.88 km^2) and 0.9% of the country (Burundi: 27834 km^2) with an area of 267.30 km^2 (Fig. 1). This district has an average altitude of 1300 m and is located in the natural region of Moso, characterized by an average annual precipitation of 1200 mm and an average temperature between 14°C and 28°C. The vegetation is savannah type and the wild macrofauna is not rich. Kinyinya district uses a traditional method of agriculture and is characterized by small farms, primitive tools and a workforce of household members. While production is generally done for domestic consumption, some of it is sold in the market for some goods and services. Banana, rice, corn, cassava, sweet potato and beans are the main crops grown in Kinyinya district. Other food products such as sorghum, peanuts, pigeon pea (*Cajanus cajan*) and finger millet (*Eleusine coracana*) are also produced in the district. The cultivation of fruit trees (avocados, citrus fruits, papaya, palm trees, pineapple) is unstructured and generally primitive (République du Burundi 2006).

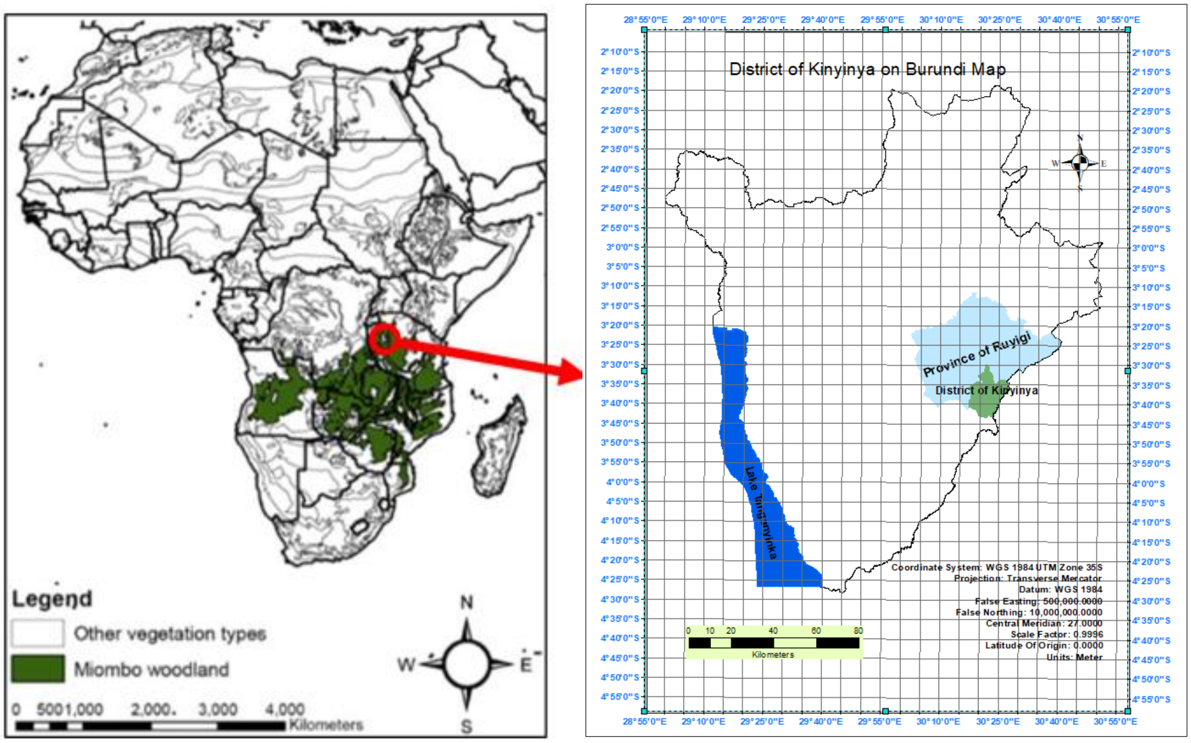

Figure 1: Location of the district of Kinyinya in Burundi and in Mimbo Forest

Research Methods

In this research we are facing two pivotal problematics: a) small-scale farmers are struggling to control termites in their fields with conventional pesticides methods; b) this research looks beyond the status of termites as pests: we analyse the ecological situation in the fields.

We run a thorough survey in order to find out which chemical pesticides are used against termites in the area. Other main questions were: a) the alternative solutions against termites, b) the plants mostly attacked by termites and which are not, c) which botanical pesticides were recorded to have been used in the past against termites. We selected among the local pestidicidal plants those that we used in our experimentations.

Termites are social insects which move in mass under the soil in galeries. Because they stay all the time in galeries, the conventional methods of insecticide application failed in controlling them. We developed a method which can help to keep termites away from (attacking) plants. Combining the properties of some local pesticidal plants and the termite ecology, we experimented the repellency ability of those plants. Termites are social insects. Attempts of feeding isolated individual termites have been unsuccessful (Agarwala 1955). In order to overcome this problem, preparations were applied to the plots without isolating the termites. We installed plots (1m x 1m) around active termite mounds. The plants which are more attractive to termites were mixed with the soil in the plots.

Preparation of Plant Extract and Formulation

Plant extracts were prepared based on methods used in similar studies (Rando et al., 2011; Kumar et al., 2017; Pavela, 2017). First, fresh leaves were crushed in a wooden mortar for 30 minutes. The resulting paste-like plant extract was kept in cold water for 24, 48 and 72 hours before use. The main reason for choosing this method is the current economic and technological conditions of local farmers. Each plant material was prepared separately. Three doses were applied to each plant and the doses were made up of fresh leaves 1:9, 2:8 and 2:8 as indicated below:

- 1:9 = 10-gram plant material, 90-gram water.
- 2:8 = 20-gram plant material, 80-gram water.
- 3:7 = 30-gram plant material, 70-gram water.

The prepared herbal aqueous extracts were applied to the experimental plots in liquid form.

As some plants with insecticidal effects have been used in various ways throughout history; in this research, it was tried to be obtained from three plants by aqueous extraction method. Additionally, aqueous extractions from fresh plant parts were emphasized. The amount was 150 ml in each plot. Traditionally, the amounts used by farmers vary (100-250 ml/m2). In this research, we used the average of what farmers used: 150 ml. After mixing the plants with soil, the pesticidal plant extracts were applied in the plots. Since blocks were not effective in the experiments, random parcels were arranged according to the experimental design. A total of 99 (= 33 x 3) replicates were carried out in 33 applications, including three plant doses (1:9, 2:8 and 3:7 which made 3^3= 27), 3 control and 3 Chlorpyrifos applications (27+3+3=33).

Considering the historical applications of pesticidal plants in Kinyinya, furthermore considering the economic situation of the local farmers, cold water extracts were opted as the extraction method. Three plants were chosen among a list of local pesticidal plants. These plants are: *Euphorbia tirucalli* L. (Euphorbiaceae), *Tephrosia vogelii* (Hook) (Fabaceae) and *Lantana camara* L. (Verbenaceae). First of all, active termite mounds (containing termites that are colonizing the surounding environment) have been identified. Then, plots were created around the mounds (between a radius of 10 and a radius of 20 meters). The area of each plot is determined as one square meter (1 m^2). Field preparations were made by digging the parcels using a hoe. As feed to attract termites to the plots; soybean (*Glycine max*) harvest wastes (which is the most preferred field plant by termites in the region) and *Imperata cylindrica* (L.) (Poaceae) grasses (which is the most preferred wild plant by termites). In the plots we applied a mixture of soybean harvest wastes and dry *L. cylindrica* grasses; 3 kg in each plot. Before realising repellency trials, we realised mortality trials. In the mortality trials. Preparations for the mortality trial were prepared using extracts of *E. tirucalli*, *T. vogelii* and *L.* camara soaked in cold water for 48 hours and we 3:7 dose in each preparation.

Statistically Analysis

One-way and factorial ANOVA (Analysis of Variance) test was used to compare the results from different plots where the pesticidal plant extracts were applied. LSD (Least Significant Differences) test was applied to compare the process averages at the α = 0.05 level. All analyzes were performed with JMP Pro 13 software.

Data Source

Raw geographical information system (GIS) data about Burundi were obtained from Geographical Institute of Burundi (IGEBU) and Google Earth. Termite mounds coordinates were collected with a GPS. In analysing the impacts of land use on termites, we recorded the geographic coordinates of fields, pastures, termite mounds and human settlements. The results were analysed in ArcGIS maps. We analysed a plot of 847 ha belonging to two villages (Fig. 2).

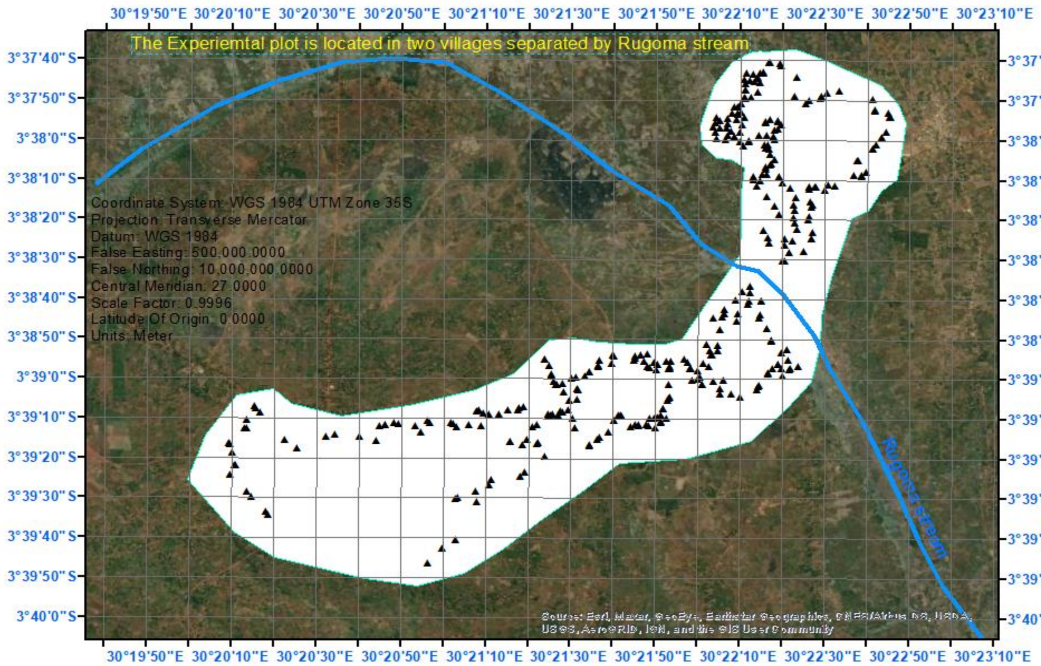

Figure 2: The experimental plot in the district of Kinyinya.

RESULTS AND DISCUSSION

Responses of Termites to Applications of Different Plant Extracts and Chlorpyrifos: Mortality and Behavioral Effects

The preparations were prepared using extracts of *Euphorbia tirucalli*, *Tephrosia vogelii* and *Lantana camara* soaked in water for 48 hours. The plant ratio in each preparation is 30% and the water ratio is 70% (3:7 dose). Because termites are social insects, special conditions are required for laboratory studies. Since there was no suitable laboratory in Burundi, controlled tunnels were created underground in the field using bamboo trees and some soil. Termites were placed inside the tunnels. After applying plant extract preparations, Chlorpyrifos and plain water on the termites, the condition of the termites was checked. Three variables (alive, fainted, and dead) were controlled.

According to the results, *L. camara* ($F = 617.5$; $df = 17$; $p<0.0001$), *T. vogelii* ($F = 247.875$; $df = 17$; $p<0.0001$) and *E. tirucalli* ($F = 78.679$; $df = 17$; $p<0.0001$), significant differences were observed in the condition of the termites. Additionally, significant differences were observed in the condition of termites in the application of Chlorpyriphos ($F = 78.679$; $df = 17$; $p<0.0001$).

The first check of the termites was made at the 12th hour, the second at the 24th hour, and the third at the 48th hour, and it was understood that there was no change in their condition. Sporadic deaths were observed in the "control" and "plant extracts" groups after approximately 3 days. Termites are known to move in groups and communicate via hormones; deterioration of cohesion creates stress. Termites cannot feed in isolation. These plants don't act as termite killers, the next step is to test if the plant extracts act as repellents.

Effect of Different Dosage and Soaking Time on Termite Repellency

In this research, cold water soaking method was used as the preferred extraction method. The method was chosen because of the economic and technological challenges faced by farmers in Burundi. Agriculture in Burundi is generally focused on meeting daily needs, with limited investment in food and agricultural technologies. In this context, it is important to develop local herbal pesticides and simple extraction methods to provide support to farmers. In this paragraph, the effect of soaking times (24, 48 and 72 hours) of plant extracts on termite repellent effectiveness was evaluated (Table 1 and Figure 3). In this evaluation, the effects of different doses (1:9, 2:8 and 3:7) on three groups (24 hours, 48 hours, 72 hours) plus control were examined using ANOVA analysis. The variable being soaking time, inside the same application, the change is not significant (all the results are indicated by the same letter. This means that for the same plant extract, soaking time is not a significant factor. The control group showed consistently lower mean values compared to the other groups. These results suggest that inside the same group, the factor time (hour) is not significant.

Table 1: Effects of different Dosage and Soaking Time (ANOVA summary)

	Soaking Time			
Doses	24	48	72	Control
1:9	10,47^{ab}	11,57^{a}	10,37^{ab}	5,97^{b}
2:8	16,97^{c}	18,33^{c}	16,97^{c}	5,97^{b}
3:7	26,77^{e}	29,20^{e}	26,30^{e}	5,97^{b}

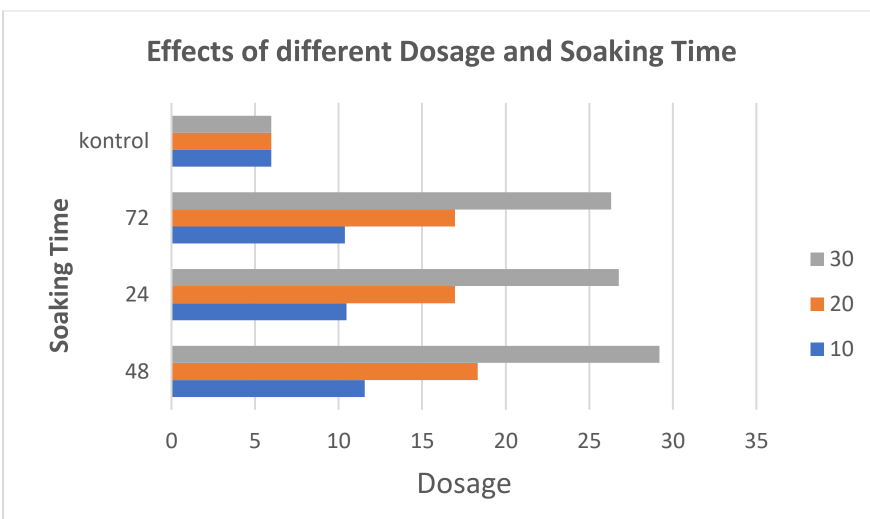

Figure 3: Effects of different Dosage and Soaking Time (above 30 stands for 3:7, 20 for 2:8 and 10 for 1:9).

Effect of Different Doses of Plant Extracts on Termite Repellency

In this study, the data obtained as a result of trials at three different doses were evaluated in order to make the pesticidal plant extracts both economical and effective. Three plant extracts (*E. tirucalli, T. vogelii* and *L. camara*) and at three different soaking times of these extracts (24, 48 and 72 hours) were applied. Additionally, there is a control group in the experiment. The results from ANOVA are presented in Table 2 and Fig. 4). The results are as follows:

Table 2: Effect of Different Doses of Plant Extracts (ANOVA summary)

	Doses		
	1:9	2:8	3:7
E.tirucalli	$13,77^{m}$	$22,43^{r}$	$29,43^{s}$
L.camara	$10,37^{n}$	$14,53^{m}$	$24,20^{r}$
T.vogelii	$8,27^{p}$	$15,20^{m}$	$28,63^{s}$
Control	$5,97^{q}$	$5,97^{q}$	$5,97^{q}$

1:9 dose (F=30.1166, df=11, p=0.0001): a significant difference was detected.
2:8 dose (F=172.4585, df=11, p<0.0001): a significant difference was detected.
3:7 dose (F=128.5230, df=11, p<0.0001): a significant difference was detected.

For *E. tirucalli*, the mean values increased significantly as the dose increased: 13.77m for the 1:9 group, 22.43r for the 2:8 group and 29.43s for the 3:7 group. These results indicate a dose-dependent effect in this plant species. In the *L. camara* application, a similar trend was observed with a steady increase in mean values as the doses increased: 10.37n for the 1:9 group, 14.53m for the 2:8 group and 24.20r for the 3:7 group. The dose-dependent effect was significant, but was lower than that of *E. tirucalli* application. It showed a dose-dependent effect in the trial conducted with the *T. vogelii* species. Average values were found to be 8.27p, 15.20m and 28.63s for groups of 1:9, 2:8 and 3:7, respectively. The effect was again found to be less pronounced than in *E. tirucalli* but similar to that in *L. camara*. In the control group, the mean value was consistently 5.97q at all dose levels, indicating that there were no significant differences in this group. The control group showed consistently lower mean values compared to the other groups; This shows that the practices had a significant impact on the experimental groups. In summary, the analysis result revealed a dose-dependent effect in the plant species tested, with *E. tirucalli* showing the most pronounced response to increasing doses. While *L. camara* and *T. vogelii* exhibited similar dose-dependent effects, the control group had consistently lower mean values, indicating no significant effect of the treatments. These results emphasize that doses vary on the repellent effect of plant species.

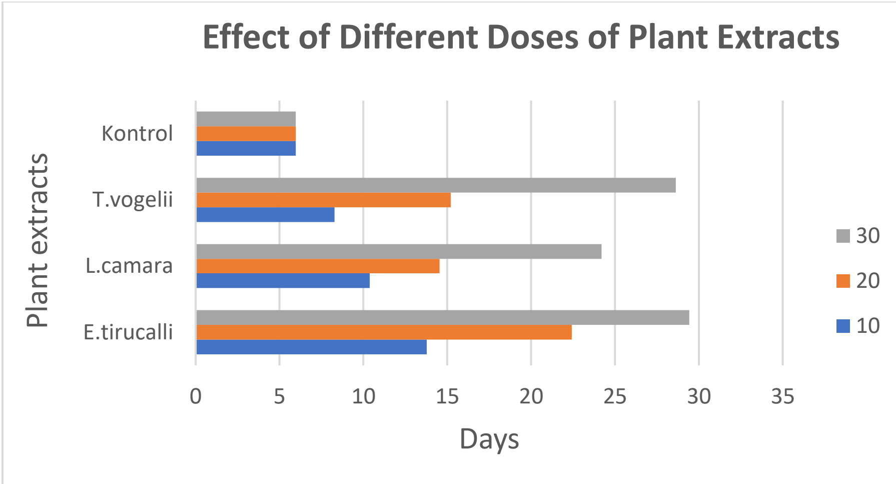

Figure 4: Effect of Different Doses of Plant Extracts (above 30 stands for 3:7, 20 for 2:8 and 10 for 1:9).

Effect of Plant Extracts According to Different Doses and Soaking Times on Termite Repellency
The repellent effect of different soaking times and doses of plant extract on termites was examined.

Table 3: Effect of Plant Extracts According to Different Doses and Soaking Times (ANOVA summary)

		Plant extracts			
Doses	Soaking Time	*L.camara*	*T.vogelii*	*E.tirucalli*	Control
1:9	24	$10{,}67^{b}$	$8{,}33^{a}$	$12{,}33^{c}$	$6{,}33^{a}$
	48	$10{,}67^{b}$	$8{,}00^{ab}$	$11{,}33^{b}$	$6{,}33^{a}$
	72	$9{,}67^{a}$	$8{,}33^{a}$	$13{,}00^{c}$	$6{,}33^{a}$
2:8	24	$14{,}33^{d}$	$14{,}33^{d}$	$22{,}00^{f}$	$6{,}33^{a}$
	48	$14{,}67^{d}$	$17{,}00^{e}$	$23{,}33^{f}$	$6{,}33^{a}$
	72	$14{,}67^{d}$	$14{,}33^{d}$	$22{,}00^{f}$	$6{,}33^{a}$
3:7	24	$25{,}00^{g}$	$26{,}33^{g}$	$29{,}00^{h}$	$5{,}67^{a}$
	48	$25{,}33^{g}$	$31{,}00^{h}$	$31{,}33^{h}$	$5{,}67^{a}$
	72	$22{,}33^{f}$	$28{,}67^{h}$	$28{,}00^{h}$	$5{,}67^{a}$

1:9 x 24 hours: $F=19.1538$, $df=11$, $p=0.0005$
1:9 x 48 hours: $F=3.4327$, $df=11$, $p=0.0724$
1:9 x 72 hours: $F=15.7037$, $df=11$, $p=0.0010$
2:8 x 24 hours: $F=192.1667$, $df=11$, $p<0.0001$
2:8 x 48 hours: $F=231.4583$, $df=11$, $p<0.0001$
2:8 x 72 hours: $F=59.2179$, $df=11$, $p<0.0001$
3:7 x 24 hours: $F=241.8039$, $df=11$, $p<0.0001$
3:7 x 48 hours: $F=219.4444$, $df=11$, $p<0.0001$
3:7 x 72 hours: $F=229.7037$, $df=11$, $p<0.0001$

For *L. camara*, mean values increased with higher dose and were similar across soaking times. In the 1:9 group, mean values were 10.67b, 10.67b and 9.67a for soaking times of 24, 48 and 72 hours, respectively, and in the 2:8 group, mean values were 14.33d, 14.67d and 14.67d for the same soaking times, and for the 3:7 group, it was 25.00g, 25.33g and 22.33f, respectively.

For *T. vogelii*, mean values increased at higher doses and showed some variability across soaking times. In the 1:9 group, the mean values were 8.33a, 8.00ab and 8.33a for soaking times of 24, 48 and 72 hours, respectively, and in the 2:8 dose group, mean values were 14.33d, 17.00e and 14.33d for the same soaking times, and for the 3:7 group, it was 26.33g, 31.00h and 28.67h. For *E. tirucalli*, mean values increased at higher doses and fluctuated slightly during soaking times. In the 1:9 group, the average values were 12.33c, 11.33b and 13.00c for the soaking times of 24, 48 and 72 hours, respectively, and in the 20-dose group, the mean values were 22.00f, 23.33f and 22. In the control group, mean values remained relatively constant across all doses and soaking times and ranged from 5.67a to 6.33a.

In summary, the analysis revealed that dose and soaking time had a protective effect on termites, with higher doses generally leading to increased mean values. The effect of soaking time was less effective among plant varieties, but some fluctuations were observed. The control group showed no significant changes in soaking times or doses. Further research may be necessary to understand the mechanisms underlying these findings and the potential applications of these findings in the study context.

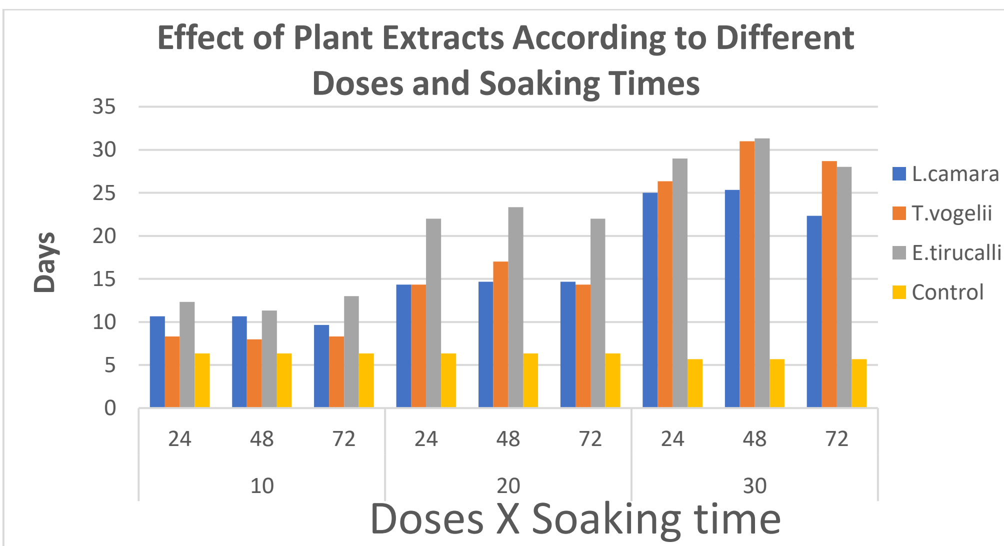

Figure 5: Effect of Plant Extracts According to Different Doses and Soaking Times (above 30 stands for 3:7, 20 for 2:8 and 10 for 1:9).

In economic terms, termites are among the critical pests that cause significant damage to agricultural products and wood derived materials. The constant use of chemicals in the fight against termites has revealed the need for safer products of plant origin in order to protect the environment. This study shows that water extracts obtained from fresh leaves of three different plants in Kinyinya district (Burundi) have the potential to have a repellent effect on termites.

The plant-derived repellents used are expected to have little negative impact on the environment (Addisu et al. 2014). The plant extracts tested in this study, *E. tirucalli, T. vogelii* and *L. camara*, are thought to be environment friendly as they can save all non-target organisms from insecticidal effects. The complex mixtures of secondary compounds are plant defense regulators and reduce resistance development in insects thanks to multiple mechanisms of action (Kortbeek et al. 2019; Erb and Kliebenstein, 2020). In various studies using plant extracts in agricultural areas and at home, it has been reported that the results obtained for human and animal health safety are promising for pest management (Pascual-Villalobos and Robledo, 1999; Scott et al. 2004). Thus, replacing synthetic insecticides with biopesticides has become an accepted and appropriate form of control in the world and has been encouraging. It was determined that the 3:7 dose of L. camara soaked in water for 72 hours had a repellent effect for 29 days, and the 3:7 dose of L. camara soaked in water for 24 hours had a repellent effect for 25 days. In some studies, it was stated that *L. camara* had a toxic effect, and in some studies it was stated that it had a repellent effect similar to ours. The toxic effect of *L. camara* has been previously studied in tobacco caterpillar *Spodoptera litura* (Deshmukhe et al. 2011), stored grain pests (Rajashekar et al., 2014), cabbage butterfly *Pieris brassicae* (Sharma and Gupta, 2009) and rice moth *Corcyra cephalonica*. has also been reported. Ayalew (2020) reported that stored corn can be protected from the *Sitophilus zeamais* pest by using *L. camara* leaf extracts and oils, and the researcher stated that its repellent and toxic effect on insects may be due to the presence of bioactive compounds such as 1-Eicosano, Paromomycin Phytol, Pyrroline and Pyrrolysine. Again similar to our results, Yuan and Hu (2012) showed the strong repellent and moderately toxic and anti-feeding effects of the chloroform extract of L. camara leaf on Reticulitermes flavipes. Some studies have also been conducted with other plants that have a repellent effect on termites. Similar to our study, Asiry et al. (2022) reported that significant crop losses occurred in Saudi Arabia due to damage to crops by termites, and that the ethanolic extract of *L. camara* and *Ruta chalepensis* L. plants at a concentration of 500 mg/kg was administered to the subterranean termite *Psammotermes hybostoma* (Desneux) and has a repellent effect of 88% and 70%, respectively. The researchers showed that all tested plant extracts were effective against the termite *P. hybostoma* and stated that they had termicidal potential and could be used in the management of the *P. hybostoma* pest.

Testing of plant extracts showed significant differences in their repellent effects on termites. The highest repellent effect was determined as 31.3 and 31 days, respectively, at 3:7 doses of *E. tirucalli* soaked in water for 72 hours and *T. vogelii* soaked in water for 48 hours. However, a 1:9 dose of *E. tirucalli* soaked in water for 72 hours had a lower (13 days) repellent effect. Additionally, a 2:8 dose of *E. tirucalli* soaked in water for 48 hours has a repellent effect of approximately 14.3 days. In their study, Agbidye et al. (2020) applied 0.5% E. tirucalli methanol extract to *D. oliveri* and *F. capensis* trees and found that they were not exposed to termite attack until the 6th and 8th weeks, respectively. There are other studies on the different effects of *E. tirucalli*. For example, *E. tirucalli* has antifungal effects (Mohamed et al. 1996), fishicidal properties (Neuwinger, 2004), antiviral characters (Betancur-Galvis et al., 2002), and antibacterial properties (Rahuman et al., 2008) has been stated by some researchers. Although E. tirucalli is known to be harmful to humans and animals, it has also been reported to have larvicidal, fungicidal, antiviral and antibacterial properties. However, little has been reported about its termicidal properties against termites (Agbidye et al., 2020). The latex of *E. tirucalli* has been reported as a toxic substance applied to arrows used in local fishing and hunting in tropical Africa (Neuwinger, 2004). In their study, Lina et al. (2020) stated that nanoemulsion concentrations of *T. vogelii* provided a control effect on the cabbage pest *Crocidolomia pavonana* F. (Lepidoptera: Pyralidae). dos Santos et al. (2020) reported that the essential oil of *T. vogelii* had an insecticidal effect on the strawberry aphid *Aphis forbesi* Weed (Hemiptera: Aphididae) after 24 hours. In a study by Zhang et al. (2022), they stated that the extract obtained from two strains of *T. vogelii* had a 100% insecticidal effect on *Aphis gossypii* and a 90% insecticidal effect on *Bemisia tabaci*. Stevenson et al. (2013) stated that *T. vogelii* plant is a known nitrogen-fixing variety and is grown as green manure in Indonesia and many African countries. The plant is also used as a windbreak. The crude extract from *T. vogelii* leaves is used for tick and larvae control on animals in Uganda, while it is also effective against mosquito larvae, soft-bodied insects (aphids) and mites (red spiders). Farmers in South Africa use dried *T. vogelii* leaves to protect stored legume seeds from bruchid damage. To control harmful insects in beans and cowpeas in warehouses, dried leaves are ground into powder and mixed with the product. *T. vogelii*, which was also used in fishing in the past, is now banned. Additionally, this plant has low potency against beneficial insects (Stevenson et al. 2013).

Repellent Effect of Chlorpyrifos on Termites

It is thought that Chlorpyrifos has a similar effect with the 2:8 and 3:7 doses of plant extracts, but it is more appropriate not to recommend its use due to the side effects of Chlorpyrifos in the soil. Considering the importance of termites in the soil and the side effects of chlorpyrifos on soil microbiology, it is understood that this substance is not a recommendable repellent method. Termites are very important in the soil, but a big problem in rural agricultural areas is that farmers do not know enough about the importance of termites. In this study, the repellency effect of chlorpyrifos was determined to be 21.5 days on average (Table 4).

Table 4: Repellent effect of Chlorpyrifos on termites

Application	Repellency effect (±1 day)	Genel mean ±1 (day)
Chlorpyrifos	21	21,56±1
Chlorpyrifos	23	
Chlorpyrifos	21	
Chlorpyrifos	22	
Chlorpyrifos	21	
Chlorpyrifos	21	
Chlorpyrifos	20	
Chlorpyrifos	23	
Chlorpyrifos	22	
Control	4	5,67±1
Control	6	
Control	7	

Termite Mounds and Land Use Analysis

The area from two villages (847 ha) was selected as a sample and digitalized with GIS. According to the data obtained, it was observed that the mounds were intertwined with agricultural and residential areas. Houses and agricultural areas are among the habitats of termites. Comparing data from geographical information systems from 2005 and digitalized Google Earth data from 2020 (Fig. 6 and 7), it is seen that there were significant changes in land use between this period. These changes in land use can have major impacts on termite ecology. Most of the pastures have been turned into agricultural areas and residential areas surface has doubled. Although pastures are considered a good habitat for termites, they are greatly disturbed by human activities. This is an bad indicator not only for termites, but also for other insects, fauna and local flora.

According to this data, if we consider that there were the same mounds in 2005 and 2020, it shows that termite mounds were negatively affected and in their living spaces over time. As long as termite mounds are located in areas used by humans, termites will be perceived as harmful to them. In this case, people will apply insecticides to destroy termites.

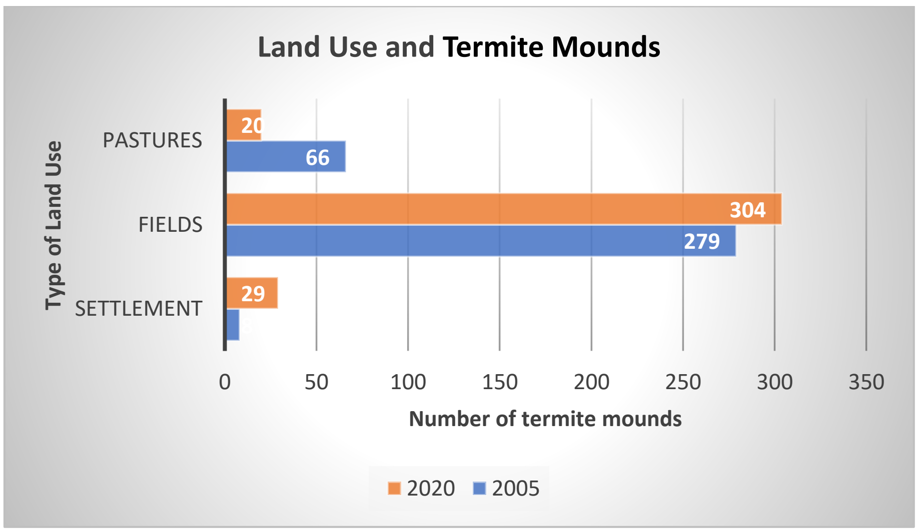

Figure 6: Land and termite mounds

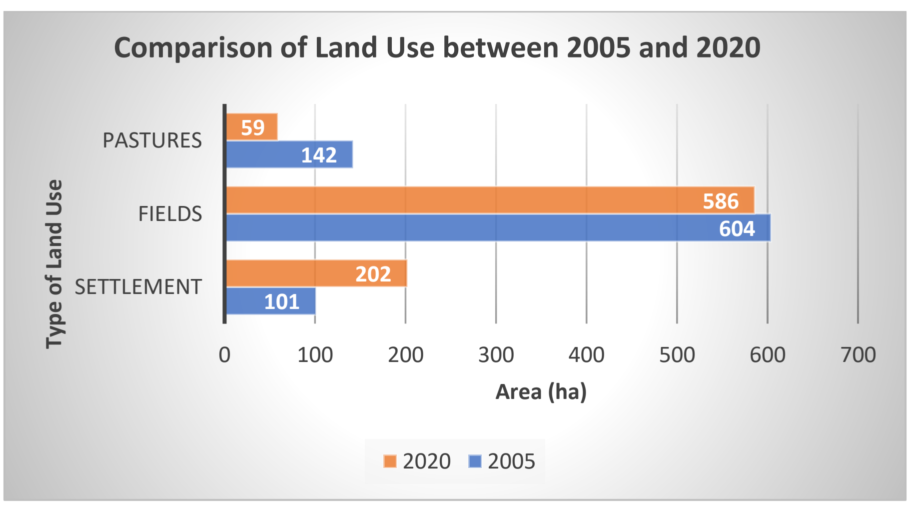

Figure 7: Comparison of land use between 2005 and 2020

As a result, it is important to reduce the interaction between termites and humans and use more sustainable methods of termite control. In this context, biological control methods and plant extracts can be used in termite control as an alternative to chemical insecticides. These methods aim to keep the termite population under control by using natural enemies of termites or plant extracts that have a negative effect on termites. Since it has been observed that the habitats of termites are intertwined with human settlements and agricultural areas in the examined areas, various strategies need to be adopted to reduce such interactions. First, greater separation of termite habitats and human activities should be ensured. In this way, there will be less need to use chemical insecticides to prevent termite damage in human settlements. Additionally, it is important to carefully plan and manage land use to avoid damaging termite habitats and preserving biodiversity. In this process, it should be aimed to keep agricultural areas and residential areas as far away from the habitats of termites as possible and to provide areas suitable for termites' natural enemies and biological control methods.

Future research on termites will provide important information to increase the effectiveness of biological control methods and understand the effects of changes in termite habitats. This information can play an important role in reducing the interaction between termites and humans by contributing to the development of sustainable and environmentally friendly methods of termite control. While forests and savannas are known as the natural habitats of termites, Miombo forests are also an important region where termites live. However, agricultural activities and the clearing of land for human settlement have led to significant changes in the ecological structure of Miombo forests. The fact that people continue their settlement and farming activities by using forest areas has caused the habitats of termites and other wild fauna to shrink.

Almost every plant species in nature is a food source for many insects. Insects become harmful when they feed on plants that humans do not want. Agricultural crops and horticultural crops are consumed by a variety of insects, posing a risk from the moment the seed is planted until it is harvested, stored or consumed. When insects compete with humans for the same food, we consider them pests. Insects are considered harmful to humans if they sting, bite, disturb, pollute or negatively affect people's lives. Additionally, insects can damage homes, clothing, or other products that people produce, store, or use. Insects that harm humans and animals, destroy food, and damage structures and the environment are called pests that compete with humans. As García-Lara and Serna Saldivar (2016) and Schowalter (2020) stated in their studies, some insects are considered pests because they threaten human health, destroy food, damage our structures or the environment, or cause general discomfort or anxiety. The intertwining of termite mounds and the study area brings up two important points. First, it may not be entirely possible to apply chemical control methods without damaging termite mounds. Destruction of mounds is ecologically dangerous. Second, the sustainable coexistence of termites and agriculture can be used to the benefit of both farmers and the overall ecology.

Termites contribute greatly to the decomposition of soil humus in tropical ecosystems. From a metabolic perspective, the decomposition of plant material is carried out mainly by free-living fungi and bacteria. However, in many tropical habitats, termites also consume large amounts of plant material, contributing to the mineralization of a significant portion of the humus. This effect is particularly important in drier regions such as deserts and dry savannas, where the rainy season is short and populations of flies, beetles, bacteria and fungi inhibit the degradation of waste and cattle manure. As a result, termites are one of the important animal groups with a large biomass in the tropics. Although they cause serious damage to fields and homes, their role in the ecosystem is often overlooked. The best approach to combating termites is to intervene by taking their ethology and biotope into consideration. However, people mostly see termites as pests and try to control them with methods such as pesticides. However, pesticides cannot provide sufficient success in controlling termites. The ecology and ethology of termites were evaluated and an approach was tried to be developed that takes into account both the ecology of termites and the needs of farmers. It seems that the use of pesticides is not a suitable solution, especially in the socio-economic conditions of Burundi's rural farmers. Additionally, there is no pesticide industry in Burundi and all agricultural pesticides are imported. In one of the poorest countries in the world, where the Gross Domestic Product (GDP) is below US$370, farmers are unlikely to invest in pesticide use.

The use of plant extracts in insect control is the most cost-effective and easily applicable method for farmers. This research was conducted in the Kinyinya district of Ruyigi province, Burundi. The area includes part of the Miombo forests, which are in danger of extinction. Human pressure on ecosystems is the main cause of biodiversity loss. Pesticide use is one of the important factors of this loss. Therefore, it is important to find and use nature-friendly alternatives to pesticides. The extracts obtained from three plants (Euphorbia tirucalli, Tephrosia vogelii, Lantana camara) was used. Plant extracts were tested by soaking in water for different periods of time (24, 48 and 72 hours) and in three doses. It has been determined that plant extracts, especially in high and medium doses, have a repellent effect. After the application, the time taken for termites to colonize the land was evaluated and it was seen that the repellent effect lasted for approximately 20-30 days.

CONCLUSIONS AND RECOMMENDATIONS

The data obtained in this research show that water extracts obtained from *Euphorbia tirucalli*, *Tephrosia vogelii* and *Lantana camara* have a repellent effect on termites. These results, when compared to other studies conducted in the last 10 years, support that plant extracts are effective and environmentally friendly methods of termite control.

For example, Cheng et al. (2009) examined the chemical compositions and larvicidal activities of leaf essential oils obtained from two *Eucalyptus* species and showed that these compositions were effective against termites. Sileshi et al. (2009) investigated the integration of ethno-ecological and scientific termite knowledge for termite management and human welfare in Africa. Liu et al. (2014) investigated the insect repellent and insecticidal effects of essential oils obtained from Kaempferia galanga roots against Liposcelis bostrychophila. Bläske and Hertel (2001) examined the insect repellent and toxic effects of plant extracts against subterranean termites. Cynthia et al. (2016) conducted a study evaluating the toxicity and repellent effects of plant extracts on termites (*Macrotermes bellicosus*). Jimma (2014) examined the effectiveness of plant extracts against termites (*Macrotermes spp.*) under laboratory conditions. Kartal et al. (2006) investigated the effects of essential oil compounds and plant extracts on rot and termite resistance on wood. Ahmed et al. (2016) evaluated the effect of different plant extracts on termite species (*Heterotermis indicola*). Alshehry et al. (2014) investigated the insecticidal effects of plant extracts against subterranean termites (*Psammotermes hybostoma*). Finally, a review study by Verma et al. (2009) emphasized the importance of biological alternatives in termite control and showed that plant extracts are effective in termite control. These studies mentioned above investigate the potential applications of different plant species and extraction methods in termite control. This suggests that plant extracts are an area that needs further investigation in termite control and may offer new and effective solutions. Moreover, the results of these studies support the results of this study, confirming that plant extracts are a promising method for termite control.

The study contributes to understanding the roles of termites in the ecosystem, while also encouraging research into environmentally friendly and sustainable termite control methods. Considering the negative environmental and health effects of traditional chemical pesticides, the alternative methods presented by this study are of great importance. Future research can be based on this study and addressed from a broader perspective. First of all, it is important to examine the different types of plants that can be effective in termite control. In this way, diversity can be achieved by offering alternatives other than existing plant species. In addition, studies should be conducted to optimize extraction methods and application techniques to determine the most effective doses and application techniques of plant extracts in termite control. This will help achieve more successful results by increasing the effectiveness of plant extracts in termite control.

Studies should be conducted on the economics and feasibility of plant extracts in termite control. Such studies will help evaluate factors related to the production, application, and cost-effectiveness of plant extracts and determine their usability in commercial termite control. This study provides an important beginning on the use of plant extracts in termite control. Future studies will contribute to expanding knowledge in this field and developing environmentally friendly, sustainable and effective termite control methods. While these studies support the sustainability of agricultural production, they will also help protect ecosystem health and biodiversity.

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