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ORIGINAL RESEARCH ARTICLE

Effects of aqueous extracts of six plant materials and four synthetic insecticides on the mortality of subterranean termites, *Macrotermes subhyalinus* (Isoptera: Termitidae) in the laboratory

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Abstract

The aim of the study was to perform a comparative evaluation of the toxic effects of selected botanical and synthetic insecticides on the subterranean termites, *Macrotermes subhyalinus*. Workers and soldiers of *M. subhyalinus* were exposed to various concentrations (0, 50, 100, 150 and 200 mg/ml) of the aqueous extracts of six plant materials; *Anchomanes difformis* (leaf, rhizome), *Curcuma longa* (rhizome), *Tithonia diversifolia* (leaf, root), and *Zingiber officinale* (rhizome) and termites' mortality were monitored at 24, 48, 72 and 96 h post-exposure durations. Similarly, the termites were exposed to 0.001, 0.01, 0.1, and 1 % w/v of four synthetic insecticides; chlorpyrifos, dichlorvos, cypermethrin and cyhalothrin. All the plant materials and synthetic insecticides exhibited termiticidal activity even at the lowest concentration tested. For the plant materials, the LD_{50} values were highest in the groups treated with *T. diversifolia* (root) for most of the exposure durations while the LD_{50} values were lowest in *A. difformis* (rhizome) group at most of the exposure durations. For the synthetic pesticides, the LD_{50} values were highest in in the groups treated with dichlorvos for most of the exposure durations while the LD_{50} values were lowest in cypermethrin group at most of the exposure durations. These data suggest that *Anchomanes* rhizome has the highest termiticide activity among plant materials while cypermethrin was the most potent of the four synthetic insecticides. The results of the present study indicated that all the screened plant materials produce termiticide activity comparable to those of synthetic termiticides, and are therefore potential candidates for termiticide formulation for incorporation into integrated management of termites.

Keywords Botanical termiticides · *Macrotermes*, mortality · Synthetic insecticides · Termites' control

Introduction

The subterranean termites, *Macrotermes subhyalinus* is a large-sized, mound-building social insects that is highly abundant in tropical regions of the world especially in East and West Africa (Malaka 1996; Vesala et al. 2017; Phillips et al. 2021). They are pests of agriculture and forestry, and their infestation has been reported to be responsible for up to 60% yield loss of crops in Africa (Mitchell 2002; Johnson et al. 2010; Nyagumbo et al. 2015; Negassa and Sileshi 2018). Certain forest trees especially the *Eucalyptus* are under constant attack of termites, eventually leading to their mortality (Santos et al. 2016; Alamu et al. 2018). Recently, there is a growing concern on the contribution of *M. subhyalinus* along with other termites' species to global warming through production of huge amount of greenhouse gases like methane, nitrous oxide and carbondioxide (Konemann et al. 2017).

Various approaches are being employed in the control of termites including the non-chemical methods such as the use of termite-resistant materials for building (mechanical barrier), debris removal, heating (treating the wooden materials to a temperature that exceeds 120 °F for at least 30 mins), wood replacement, biological control e.g. introduction of pathogenic fungi etc. (Qasim et al. 2015). The use of synthetic pesticides like organochlorines, organophosphates, pyrethroids etc. either as contact pesticides, repellents, fumigants or dusts is by far the most common of the control methods of termites but with the attendant problems of non-target organism toxicity, high mammalian

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toxicity, environmental contamination, low level of biodegradability and development of resistance, hence the need for alternatives to these synthetic chemical pesticides (Ahmed et al. 2006; Ahmed and Qasim 2011).

In recent times, the use of botanicals as alternatives to less-environmentally tolerable synthetic pesticides in the control of termites' infestation is becoming popular (Ajayi et al. 2012; Osipitan and Oseyemi 2012; Addisu et al. 2014; James et al. 2016; Ajayi et al. 2018; Kassie 2019). The botanical pesticides are relatively harmless to non-target organisms, and contain a wide arrays of chemical compounds such as saponin, flavonoid, alkaloids, cardiac glycosides etc. which act concertedly on the behavioural and physiological processes in termite organisms (Oni et al. 2018; Hikal et al. 2017). Also, the tendency of termites developing resistance to botanical termiticides is very low (Saxena 2014). Since Africa is blessed with a wide array of plants in different families that could be potentially useful as botanical pesticides, research efforts should be made towards assessing various local plants as potential botanical pesticides. To this end, four locally available plants; Mexican marigold (*Tithonia diversifolia*), Forest Anchomanes (*Anchomanes difformis*), Tumeric (*Curcuma longa*) and ginger (*Zingiber officinale*) were assessed for their termiticidal properties against the subterranean termite, *Macrotermes subhyalinus* in the present study. Previous studies have established the insecticidal properties of these plants against pests of stored grains, (Akinkurolere 2007; Mpumi et al. 2016), however, not much is known about their potentials as termiticides. Also, the termiticidal activity of four common synthetic insecticides (chlorpyrifos, dichlorvos, cypermethrin, and cyhalothrin) were determined. It is hoped that the results of this study will identify potential botanicals for incorporation into integrated management of the menace of termites.

Materials and methods

Culturing and collection of termites

Subterranean termite, *Macrotermes subhyalinus* were cultured in the premises of the Federal University of Technology, Akure, Nigeria (latitude 7.2972 ºN; longitude 5.1461 ºE) by placing plastic buckets that have been perforated at the base on bare soil. The plastic containers contained shredded cartons, soft wood and were left for 2 weeks in a shaded environment. Workers and soldiers of *M. subhyalinus* used for the bioassays were collected along with the soil particles from the buckets and their surroundings with the aid of a camel hair brush into transparent plastic containers. The collected termites were taken to the Research Laboratory of the Department of Biology, Federal University of Technology, Akure, Nigeria, and were acclimated in the laboratory for 24 h. The plastic containers were sprayed with water prior to taking them to the laboratory in order to maintain the relative humidity at approximately 80%.

Collection of the plant materials and preparation of plant extracts

Fresh and healthy Mexican marigold, *Tithonia diversifolia*, (leaf and root) and Forest Anchomanes, *Anchomanes difformis,* (leaf and rhizome) were obtained on the campus of the Federal University of Technology Akure, Nigeria while Tumeric, *Curcuma longa,* and Ginger, *Zingiber officinale* were purchased from a local market within Akure metropolis, Ondo State, Nigeria. The plant materials were thoroughly rinsed with water to remove dirts and allowed to drain. Approximately twenty grams (20 g) of each of the fresh plant materials was weighed into mortar and ground with a pestle. The extract was constituted in 100 ml of water to give 200 mg/ml stock and allowed to stand for 24 h. The solution was then shaken thoroughly and sieved with a muslin cloth. Serial dilutions containing 0 (control), 50, 100, 150, and 200 mg/ml (undiluted stock) of the plant extracts were later prepared from the stock solution.

Collection of soil samples

Soil samples were collected into clean, oven-dried beakers and were sieved using 3 mm sieve in order to attain a uniform consistency of the sample and filled up into a conical flask. The conical flask containing the soil samples was autoclaved at 110 ℃ for 1 h to kill all pathogenic microorganisms in the soil.

Exposure of termites to aqueous plant extracts and synthetic insecticides

Approximately 40 g of autoclaved soil was weighed into Petri dishes, and were admixed with 2 ml of each of the various concentrations of the plant extracts or distilled water (control). The four synthetic pesticides; chlorpyrifos, dichlorvos, cypermethrin and cyhalothrin used in the experiment were purchased from a chemical store within Akure metropolis, Nigeria. A similar experimental set up was performed for the synthetic insecticides at four different concentrations; 1, 0.1, 0.01, and 0.001 % w/v (based on the active ingredients of the insecticides). The Petri dishes were allowed to air dry for about 1 h in the laboratory prior to introduction of the termites. Ten termites (eight workers and two soldiers) were placed into each Petri dish containing the treated soil. All the treated Petri dishes were then placed in a carton and covered with a black cloth to simulate the dark galleries of termites. There were four replicates for each treatment and the termites were checked for mortality at 24, 48, 72 and 96 h post treatment.

Table 1 Percentage mortality of *M. subhyalinus* at different durations following exposure to 50 mg/ml of aqueous extracts of plant materials

Plant material	Percentage mortality over time 24 h	48 h	72 h	96 h
A. difformis (rhizome)	15.00 ± 1.22^{d}	35.00 ± 2.88^{cd}	47.50 ± 2.50^{c}	57.50 ± 2.50^{b}
A. difformis (leaf)	15.00 ± 2.04^{d}	27.50 ± 3.23^{c}	42.50 ± 2.50^{c}	55.00 ± 2.89^{b}
T. diversifolia (leaf)	2.50 ± 0.29^{a}	12.50 ± 2.50^{a}	25.00 ± 2.04^{a}	42.50 ± 1.44^{a}
T. diversifolia (root)	10.00 ± 0.00^{c}	20.00 ± 0.00^{b}	30.00 ± 0.00^{b}	42.50 ± 2.50^{a}
Z. officinale (rhizome)	5.00 ± 0.58^{b}	17.50 ± 1.44^{b}	35.00 ± 2.04^{b}	52.50 ± 2.50^{b}
C. longa (rhizome)	10.00 ± 0.00^{c}	30.00 ± 0.00^{c}	45.00 ± 2.89^{c}	62.50 ± 2.50^{c}

Each value is mean ± Standard deviation of four (4) replicates. The means with the same alphabets in the same column are not significantly different

Data analysis

The mortality data were converted to percentages and subsequently arcsine transformed. The transformed data were tested for normality using Shapiro-Wilk test and subsequently analyzed using a one-way analysis of variance (ANOVA). This was followed by Tukey's HSD tests in cases of significant difference. Also, the LD_{50} (dose of the extracts/synthetic insecticides that resulted in the mortality of the 50% of test organisms) were determined using the Log-Probit analysis. Statistics were performed using SPSS version 17, and significance was assumed at $p \leq 0.05$.

Results

Effects of different concentrations of aqueous extract of plant materials on the mortality of *M. subhyalinus*

The percentage mortality of the subterranean termite, *M. subhyalinus* due to treatment with 50, 100, 150 and 200 mg/ml of the aqueous extract of the plant materials are shown on Tables 1, 2, 3 and 4 respectively. There was significant difference in the percentage mortality due to treatment with botanicals at all the concentrations tested in the study ($p < 0.05$). At 50 mg/ml exposure concentration, *T. diversifolia* (leaf) caused the least mortality to the termites for the four exposure durations while *A. difformis* (rhizome) resulted in the highest mortality of the termites for most of the exposure durations (Table 1). At 100 mg/ml exposure concentration, the aqueous extracts of *C. longa, Z. officinales,* and *A. difformis* caused significantly higher mortality of the termites in comparison to the groups treated with aqueous extracts of *T. diversifolia* (leaf and root) (Table 2). At 150 mg/ml exposure concentration, the aqueous extract of *A. difformis* resulted in significantly higher mortality of the termites at most of the exposure durations compared to other plant extracts (Table 3). At 200 mg/ml exposure concentration, the plant materials resulted in 100% mortality of the termites by 96 h exposure with the exception *A. difformis* (leaf) and *T. diversifolia* (root) in which the percentage mortality was 75 and 87.5% respectively (Table 4). Also, the percentage mortality of the termites increased progressively with increasing exposure duration for all the plant materials at all the concentrations tested in the study.

Effects of different concentrations of synthetic pesticides on the mortality of *M. subhyalinus*

The percentage mortality of the subterranean termite, *M. subhyalinus* due to treatment with 0.001, 0.01, 0.1 and 1% (w/v) of the synthetic pesticides are shown on Tables 5, 6, 7 and 8 respectively. The treatment of the termites with different concentrations of the synthetic pesticides resulted in significant difference in the percentage mortality of

Table 2 Percentage mortality of *M. subhyalinus* at different durations following exposure to 100 mg/ml of aqueous extracts of plant materials

Plant material	Percentage mortality over time 24 h	48 h	72 h	96 h
A. difformis (rhizome)	27.50 ± 1.44^{c}	45.00 ± 2.04^{d}	57.50 ± 2.50^{c}	70.00 ± 2.04^{b}
A. difformis (leaf)	17.50 ± 1.44^{b}	37.50 ± 2.50^{c}	55.00 ± 2.04^{c}	70.00 ± 2.04^{b}
T. diversifolia (leaf)	15.00 ± 2.89^{b}	30.00 ± 2.04^{bc}	50.00 ± 0.04^{b}	55.00 ± 2.89^{a}
T. diversifolia (root)	10.00 ± 0.00^{a}	20.00 ± 0.00^{a}	35.00 ± 2.04^{a}	55.50 ± 2.50^{a}
Z. officinale (rhizome)	12.50 ± 1.44^{a}	27.50 ± 1.44^{b}	52.50 ± 2.50^{bc}	72.50 ± 1.44^{b}
C. longa (rhizome)	12.50 ± 2.00^{ab}	32.50 ± 2.50^{c}	50.00 ± 0.00^{b}	72.50 ± 2.50^{b}

Each value is mean ± Standard deviation of four (4) replicates. The means with the same alphabets in the same column are not significantly different

Table 3 Percentage mortality of *M. subhyalinus* at different durations following exposure to 150 mg/ml of aqueous extracts of plant materials

Plant material	Percentage mortality over time 24 h	48 h	72 h	96 h
A. difformis (rhizome)	37.50 ± 2.50[d]	60.00 ± 2.04[d]	72.50 ± 2.50[c]	77.50 ± 2.50[c]
A. difformis (leaf)	22.50 ± 2.50[c]	42.50 ± 2.50[c]	55.00 ± 2.88[b]	67.50 ± 2.50[b]
T. diversifolia (leaf)	15.00 ± 2.89[a]	32.50 ± 2.50[b]	50.00 ± 2.04[b]	75.00 ± 2.89[c]
T. diversifolia (root)	12.50 ± 1.44[a]	27.50 ± 2.50[a]	40.00 ± 2.04[a]	60.00 ± 2.04[a]
Z. officinale (rhizome)	17.50 ± 1.04[b]	45.00 ± 2.89[c]	70.00 ± 2.04[d]	92.50 ± 2.50[e]
C. longa (rhizome)	12.50 ± 2.50[a]	32.50 ± 2.50[b]	52.50 ± 2.50[b]	82.50 ± 2.50[d]

Each value is mean ± Standard deviation of four (4) replicates. The means with the same alphabets in the same column are not significantly different

the mortality at different exposure durations ($p < 0.05$). At 0.001% exposure concentration, dichlorvos caused the least mortality to the termites for the four exposure durations while cypermethrin caused the highest mortality of the termites for most of the exposure durations (Table 5). At 0.01% exposure concentration, exposure to cypermethrin caused significantly higher mortality of the termites in comparison to the groups treated with other synthetic pesticides (Table 6). At 0.1% exposure concentration, cypermethrin exposure resulted in the highest mortality of the termites at all the exposure durations while dichlorvos caused the least mortality effect to the termites at all the exposure durations (Table 7). At 1% exposure concentration, the four synthetic pesticides resulted in 100% mortality of the termites by 96 h exposure (Table 8). Also, just as for the botanical pesticides, the percentage mortality of the termites increased progressively with increasing exposure duration for all the synthetic pesticides at all the concentrations tested in the study.

Median lethal doses (LD_{50}) of aqueous plant extracts

The lethal doses of all the plant extracts required to achieve 50% mortality of the termites (LD_{50}) at different exposure periods are shown in Table 9. The LD_{50} values were lowest in *A. difformis* (rhizome) group at most of the exposure durations (020.45, 9.02, and 6.32 mg/ml for 24, 48, and72 h respectively) while *T. diversifolia* (root) group had the highest LD_{50} values for most of the exposure durations (1404.25, 52.03, 17.59, and 7.40 mg/ml for 24, 48, 72, and 48 h respectively).

Median lethal doses (LD_{50}) of the synthetic insecticides

The lethal doses of all the synthetic insecticides required to achieve 50% mortality of the termites (LD_{50}) at different exposure periods are shown in Table 10. The LD_{50} values were lowest in cypermethrin group at the four exposure durations (0.04, 0.003, 0.001, and 0.001% for 24, 48, 72, and 48 h respectively) while the dichlorvos group had the highest LD_{50} values (0.19, 0.1, 0.008, and 0.005 for 24, 48, 72, and 48 h respectively).

Discussion

In the present study, attempt was made to evaluate the aqueous extract of plant materials for termiticidal activities against the subterranean termite, *M. subhyalinus* through contact toxicity and systemic poisoning when admixed with soil. The results obtained indicated that most of the plant materials exhibited some termiticidal effects at varying degrees of potency. This observation was in agreement with reports of previous studies that have shown that

Table 4 Percentage mortality of *M. subhyalinus* at different durations following exposure to 200 mg/ml of aqueous extracts of plant materials

Plant material	Percentage mortality over time 24 h	48 h	72 h	96 h
A. difformis (rhizome)	52.50 ± 2.50[d]	87.50 ± 2.50[e]	95.00 ± 2.88[d]	100.00 ± 2.50[c]
A. difformis (leaf)	32.50 ± 2.50[c]	57.50 ± 3.33[c]	65.00 ± 2.88[b]	75.00 ± 2.89[a]
T. diversifolia (leaf)	30.00 ± 2.04[c]	67.50 ± 2.50[d]	100.00 ± 0.00[d]	100.00 ± 0.00[c]
T. diversifolia (root)	17.50 ± 1.44[a]	40.00 ± 0.00[a]	60.00 ± 0.00[a]	87.50 ± 2.50[b]
Z. officinale (rhizome)	25.00 ± 1.73[b]	45.00 ± 2.04[b]	85.00 ± 1.22[c]	100.00 ± 0.00[c]
C. longa (rhizome)	17.50 ± 2.50[a]	50.00 ± 4.08[c]	67.50 ± 4.79[b]	100.00 ± 0.00[c]

Each value is mean ± Standard deviation of four (4) replicates. The means with the same alphabets in the same column are not significantly different

Table 5 Percentage mortality of *M. subhyalinus* at different durations following exposure to 0.001 % w/v of aqueous extracts of plant materials

	Percentage mortality over time			
Plant material	24 h	48 h	72 h	96 h
Chlorpyrifos	7.50 ± 2.50[b]	20.00 ± 4.50[b]	27.50 ± 2.50[b]	32.50 ± 2.50[b]
Dichlorvos	2.50 ± 0.50[a]	5.00 ± 2.89[a]	5.00 ± 2.50[a]	20.00 ± 4.08[a]
Cypermethrin	15.00 ± 2.89[c]	30.00 ± 4.80[c]	37.50 ± 2.50[c]	50.00 ± 2.50[d]
Cyhalothrin	10.00 ± 4.08[bc]	20.00 ± 4.50[b]	27.50 ± 2.50[b]	40.00 ± 4.08[c]

Each value is mean ± Standard deviation of four (4) replicates. The means with the same alphabets in the same column are not significantly different

aqueous extracts of plant materials when applied to filter paper or mixed with soil cause mortality and repellent effects on termite indicating their efficacy against several species of termites and thus depicting botanicals extracts as potential biopesticides for the management of termite (Blaske and Hertel 2001; Blaske et al. 2003). The termiticidal actions of these plant materials have been linked to the presence of toxic and insect repelling compounds in the plant materials, some of which include alkaloids, saponins, tannins and flavonoids (Blaske and Hertel 2001; Blaske et al. 2003; Adegoke et al. 2010; Adebo et al. 2018; Oni et al. 2018). The contact toxicity of the plant extracts was probably due to systemic actions of the active ingredients of the extracts on the organs and tissues of the termites that results in mortality. The active ingredients upon contact with the termites were absorbed and distributed into tissues and organs where they interfere with the normal functioning of the organism such as feeding deterrent and disruption of ATP metabolism (Mpumi et al. 2016).

The use of synthetic insecticides for the control of termites' population is popular all over the world (Riekert and van Berg 2003; Ahmed et al. 2017). Although, their usage has serious environmental concerns, they are still being used since the alternative botanical pesticides are still being developed. The efficacy of common insecticides against *M. subhyalinus* was determined using contact toxicity. The results indicated that all the four synthetic insecticides have termiticidal properties in the following order; cypermethrin > cyhalothrin > chlorpyrifos > dichlorvos. In tandem with this finding, Ahmed and Qasim (2011) also reported a high termiticide activity of selected synthetic pesticides against subterranean termites in a farm building.

The lethal effects of the various plant extracts and synthetic insecticides used in the present study were both concentration- and time-dependent. All the plant materials and synthetic insecticides tested evoked higher mortality with increasing concentrations of the insecticides with 100% mortality being recorded at the highest concentrations (200 mg/ml for the plant extracts and 1 % w/v for the synthetic insecticides) used in the study. This observation was consistent with reports of similar studies which also used botanicals to control termites in which concentration-dependent toxicity of the botanical pesticides against termites were reported (Addisu et al. 2014; Verma et al. 2016; Bakaruddin et al. 2018). The higher mortality at the high concentrations could be due to increased availability of the active compounds in the extracts and synthetic insecticides. Also, we observed increased mortality which corresponds with increasing exposure duration in the present study. All the plant materials and the synthetic insecticides showed highest toxicity values at 96 h which was the longest exposure duration tested. These results confirmed the moderate persistence of these plant materials which make them to be suitable for use as botanical pesticides.

Comparatively, inferencing from the 24 h LD_{50} data, the termiticidal activity of the plant materials could be ranked as *A. difformis* (rhizome) > *T. diversifolia* (leaf) > *Z. officinale* (rhizome) > *A. difformis* (leaf) > *T. diversifolia* (root) > *C. longa* (rhizome). The use of 24 h LD_{50} data for ranking of termiticidal activity in

Table 6 Percentage mortality of *M. subhyalinus* at different durations following exposure to 0.01 % w/v of aqueous extracts of plant materials

	Percentage mortality over time			
Plant material	24 h	48 h	72 h	96 h
Chlorpyrifos	10.00 ± 4.08[a]	20.00 ± 0.04[a]	27.50 ± 4.79[a]	35.00 ± 2.89[b]
Dichlorvos	10.00 ± 4.08[a]	20.00 ± 4.08[a]	25.00 ± 4.79[a]	27.50 ± 2.50[a]
Cypermethrin	20.00 ± 4.08[b]	30.00 ± 0.24[b]	40.00 ± 4.08[b]	52.50 ± 4.79[d]
Cyhalothrin	15.00 ± 2.89[a]	32.50 ± 2.84[b]	37.50 ± 2.50[b]	42.50 ± 2.50[c]

Each value is mean ± Standard deviation of four (4) replicates. The means with the same alphabets in the same column are not significantly different

Table 7 Percentage mortality of *M. subhyalinus* at different durations following exposure to 0.1 % w/v of aqueous extracts of plant materials

	Percentage mortality over time			
Plant material	24 h	48 h	72 h	96 h
Chlorpyrifos	10.00 ± 4.08[a]	35.00 ± 5.00[b]	47.50 ± 4.60[c]	52.00 ± 4.70[b]
Dichlorvos	12.50 ± 2.50[a]	22.50 ± 2.50[a]	27.50 ± 4.60[a]	32.50 ± 2.50[a]
Cypermethrin	25.00 ± 2.89[b]	40.00 ± 4.70[b]	50.50 ± 4.06[c]	65.00 ± 2.70[c]
Cyhalothrin	27.50 ± 2.58[b]	32.50 ± 2.50[b]	37.50 ± 2.50[b]	47.50 ± 2.50[b]

Each value is mean ± Standard deviation of four (4) replicates. The means with the same alphabets in the same column are not significantly different

Table 8 Percentage mortality of *M. subhyalinus* at different durations following exposure to 1 % w/v of aqueous extracts of plant materials

	Percentage mortality over time			
Plant material	24 h	48 h	72 h	96 h
Chlorpyrifos	100.0 ± 0.00^{c}	100.0 ± 0.00^{a}	100.0 ± 0.00^{a}	100.00 ± 0.00^{a}
Dichlorvos	95.00 ± 2.89^{c}	100.0 ± 0.00^{a}	100.0 ± 0.00^{a}	100.00 ± 0.00^{a}
Cypermethrin	67.50 ± 2.50^{b}	100.0 ± 0.00^{a}	100.0 ± 0.00^{a}	100.00 ± 0.00^{a}
Cyhalothrin	57.50 ± 2.50^{a}	97.50 ± 2.50^{a}	100.0 ± 0.00^{a}	100.00 ± 0.00^{a}

Each value is mean ± Standard deviation of four (4) replicates. The means with the same alphabets in the same column are not significantly different

Table 9 Median lethal dose (LD_{50}) obtained for aqueous plant materials extracts on *M. subhyalinus*

	LD_{50} (Lower limit - Upper limit) (mg/ml) per post-treatment hours			
Plant material	24	48	72	96
A. difformis (Leaf)	78.76 (42.47 – 115.05)	17.20 (14.20 – 23.31)	8.20 (6.45 – 9.73)	3.18 (0.00 – 6.36)
A. difformis (Rhizome)	20.45 (18.29 – 23.65)	9.02 (7.30 – 10.68)	6.32 (4.46 – 7.78)	4.70 (1.88 – 6.62)
C. longa (Rhizome)	1822.08 (157.72 – 3486.44)	35.23 (20.68 – 49.78)	8.44 (5.05 – 11.23)	4.09 (2.24 – 5.49)
T. diversifolia (Leaf)	37.92 (28.46 – 65.48)	16.72 (14.31 – 20.89)	9.61 (7.4 – 11.87)	6.93 (4.80 – 8.62)
T. diversifolia (Root)	1404.25 (209.24 – 2598.77)	52.03 (35.20 – 108.54)	17.59 (14.31 – 24.77)	7.40 (5.03 – 9.29)
Z. officinale (Rhizome)	55.24 (40.73 – 90.32)	22.19 (19.25 – 27.02)	8.14 (7.27 – 8.96)	5.22 (4.21 – 6.07)

Table 10 Median lethal dose (LD_{50}) obtained for the different synthetic termiticides on *M. subhyalinus*

	LD_{50} (Lower limit - Upper limit) (% w/v) per post-treatment hours			
Synthetic termiticides	24	48	72	96
Chlorpyrifos	0.16 (0.009 – 0.023)	0.005 (0.01 – 0.009)	0.003 (0.01 – 0.005)	0.002 (0.01 – 0.003)
Dichlorvos	0.19 (0.12 – 0.054)	0.1 (0.007 – 0.026)	0.008 (0.002 – 0.14)	0.005 (0.002 – 0.008)
Cypermethrin	0.04 (0.021 – 0.06)	0.003 (0.002 – 0.006)	0.001 (0.001 – 0.008)	0.001 (0.001– 0.01)
Cyhalothrin	0.07 (0.03 – 0.22)	0.005 (0.003 – 0.13)	0.003 (0.01 – 0.005)	0.001 (0.001 – 0.001)

the present study was due to the fact that by 96 h post treatment, termiticidal activity was very high and nearly the same for all the plant materials tested in the present study. The high termiticidal effect of *A. difformis* as observed in the present study has also been supported by reports from previous studies that have reported toxic effects of extracts of *A. difformis* to storage beetles (Adedire and Akinkurolere 2005; Akinkurolere et al. 2006, 2007). The differences in the termiticidal properties of the different parts of the same plants, for example higher activity in the rhizome of *A. difformis* in comparison to the leaf was observed. This is an indication that different parts of the plant differed in their phytochemical components (Raya et al. 2015; Madike et al. 2017).

In conclusion, the results of the study indicated that the plant materials exhibited some forms of termiticidal activities that are persistent and could therefore be promising alternatives to the non-environmental friendly synthetic pesticides which have hitherto be used in the control of termite infestation. The incorporation of highly potent *A. difformis* with low doses of active synthetic pesticides would offer an integrated approach for the management of termites' infestation thus helping to reduce the quantity of synthetic pesticides in use. Further studies are therefore encouraged towards the elucidation of the underlying mechanisms of termiticidal effects of these plant materials with a view of producing commercial termiticides from them.

Declarations

Conflict of interest The authors declare that they do not have conflicts of interest.

References

Addisu S, Mohamed D, Waktole S (2014) Efficacy of botanical extracts against termites, *Macrotermes spp*. (Isoptera:Termitidae) under laboratory conditions. Int J Agric Res 9:60–73

Adebo CT, Adeyemi JA, Adedire CO (2018) Biochemical and histopathological effects of a bioinsecticide, *Anchomanes difformis* (Blume) Engler rhizome powder on Wistar rats. Comp Clin Pathol 27:1545–1550

Adedire CO, Akinkurolere RO (2005) Bioactivity of four plant extracts on coleopterouspest of stored cereals and grain legumes in Nigeria. Zool Res 26:243–249

Adegoke EA, Akinsanya A, Naqvi SHZ (2010) Studies of Nigerian medicinal plants: preliminary survey of plant alkaloids. J W Afr Sci Assoc 13:13–33

Ahmed S, Hassan B, Yaqoob MM, Nisar MS, Rashid A (2017) Efficacy of chlorpyrifos and fipronil in relation to soil depths against subterranean termites. J Entomol Acarol Res 49:6386. https://doi.org/10.4081/jear.2017.6386

Ahmed S, Mustafa T, Riaz MA, Hussain A (2006) Efficacy of insecticides against subterranean termites in sugarcane. Int J Agr Biol 8:508–510

Ahmed S, Qasim M (2011) Foraging and chemical control of subterranean termites in a farm building at Faisalabad, Pakistan. Pak J Life Soc Sci 9:58–62

Ajayi OE, Adedara W, Oyeniyi EA (2018) Termiticidal efficacy of extracts of two indigenous plants against *Macrotermes subhyalinus* Rambur (Blattodea: Termitidae). Niger J Entomol 34:109–122

Ajayi OE, Adedire CO, Lajide L (2012) Evaluation of partially purified fractions of crude extracts of the leaves of *Morinda lucida* (Benth) and *Datura stramonium* (L) for suppression of wood damage by subterranean termites. J Agric Sci 4:125–129

Akinkurolere RO, Adedire CO, Odeyemi OO (2006) Laboratory evaluation of the toxic properties of forest *Anchomanes, Anchomanes difformis* against pulse beetle *Callosobruchus maculatus* (Coleoptera: Bruchidae). Insect Sci 13:25–29

Akinkurolere RO (2007) Assessment of insecticidal properties of *Anchomanes difformis* (P. Beauv.) powder on five beetles of stored produce. J Entomol 4:51–55

Alamu OT, Ewete FK, Jimoh SO (2018) Occurrence and diversity of termite species in Eucalyptus plantations in Afaka, Kaduna State, Nigeria. J Res For Wildl Environ 10:33–38

Bakaruddin NH, Dieng H, Sulaiman SF, Majid AH (2018) Evaluation of the toxicity and repellency of tropical plant extract against subterranean termites, *Globitermes sulphureus* and *Coptotermes gestroi*. Inf Process Agric 5:298–307

Blaske VU, Hertel H (2001) Repellent and toxic effects of plant extracts on subterranean termites (Isoptera: Rhinotermitidae). J Econ Entomol 94:1200–1208

Blaske VU, Hertel H, Forscheler BT (2003) Repellent effects of isoborneol on subterranean termites (Isoptera: Rhinotermitidae) in soils of different composition. J Econ Entomol 96:1267–1274

Hikal WM, Baeshen RS, Ahl HAH (2017) Botanical insecticide as simple extractives for pest control. Cogent Biol 3:1404274. https://doi.org/10.1080/23312025.2017.1404274

James WM, Logan RHC, Wood TG (2016) Termite (Isoptera) control in agriculture and forestry by non-chemical methods: a review. Bull Entomol Res 80:309–330

Johnson RA, Lamb RW, Wood TG (2010) Termite damage and crop loss studies in Nigeria: a survey of damage to groundnuts. Trop Pest Manag 27:325–342

Kassie WB (2019) Evaluation of selected botanical extracts against Mendi termite *Macrotermes subhyalinus* (Isoptera: Termitidae), under laboratory condition. Curr Res Agric Sci 6:135–140

Konemann CE, Kard BM, Royer TA, Payton ME (2017) Carbon dioxide and methane emissions from different-sized groups of eastern subterranean termites. Southwest Entomol 42:321–329

Madike LN, Takaidza S, Pillay M (2017) Preliminary phytochemical screening of crude extracts from the leaves, stems, and roots of *Tulbaghia violacea*. Int J Pharmacog Phytochem Res 9:1300–1308

Malaka SLO (1996) Termite in West Africa. 1st edition, University of Lagos Press, pp 151

Mitchell JD (2002) Termites as pests of crops, forestry, rangeland and structures in southern Africa and their control. Sociobiology 40:47–69

Mpumi N, Mtei K, Machunda R, Ndakidemi PA (2016) The toxicity, persistence and mode of actions of selected botanical pesticides in Africa against insect pests in common beans, *p. vulgaris*: A Review. Am J Plant Sci 7:138–151

Negassa W, Sileshi GW (2018) Integrated soil fertility management reduces termite damage to crops on degraded soils in western Ethiopia. Agr Ecosyst Environ 251:124–131

Nyagumbo I, Munamati M, Mutsamba EF, Thierfelder C, Cumbane A, Dias D (2015) The effects of tillage, mulching and termite control strategies on termite activity and maize yield under conservation agriculture in Mozambique. Crop Prot 78:54–62

Oni MO, Kofoworols T, Ogugbite OC, Ofuya TI, Adunola P (2018) Susceptibility of *Macrotermes subhyalinus* (Ramburi) (Isoptera:Terminidae) to oil of Acalypha godseffiana (Muell. Arg). Appl Trop Agric 23:126–131

Osipitan AA, Oseyemi AE (2012) Evaluation of the bio-insecticidal potential of some tropical plants extracts against termite (Termitidae:Isoptera) in Ogun State, Nigeria. J Entomol 9:257–265

Qasim M, Lin Y, Fang D, Wang L (2015) Termites and microbial biological control strategies. South-Asian J Multidiscip Stud 1:33–62

Phillips S, Scheffrahn RH, Piel A, Stewart F, Agbor A, Brazzola G et al (2021) Limited evidence of C_4 plant consumption in mound building *Macrotermes* termites from savanna woodland chimpanzee sites. PLoS One 16(2):e0244685. https://doi.org/10.1371/journal.pone.0244685

Raya KB, Ahmad SH, Farhana SF, Mohammad M, Tajidin NE, Parvez A (2015) Changes in phytochemical contents in different parts of *Clinacanthus nutans* (Burm. f.) lindau due to storage duration. Bragantia 74:445–452

Riekert HF, van den Berg J (2003) Evaluation of chemical control measures for termites in maize. S Afr J Plant Soil 20:1–5

Santos A, Santos JC, Cardoso JR, Serra JE, Zanuncio JC, Zanetti R (2016) Sampling of subterranean termites *Syntermes spp*. (Isoptera: Termitidae) in a eucalyptus plantation using point process and geostatistics. Precis Agric 17:421–433

Saxena RC (2014) Antifeedants in the tropic pest management. Insect Sci Appl 8:731–736

Verma S, Sharma S, Malik A (2016) Termiticidal and repellency efficacy of botanicals against *Odontotermes obesus*. Int J Res Biosci 5:52–59

Vesala R, Nisken T, Lijmatainen K, Boga H, Pellika P, Rikkinen J (2017) Diversity of fungus-growing termites (*Macrotermes*) and their fungal symbionts (*Termitomyces*) in the semiarid Tsavo Ecosystem, Kenya. BioTropica 49:279–427

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