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Research Article

Comparative Bioefficacy of Indigenous Phytoextracts against Subterranean Termites *Odontotermes obesus* Ramb. (Isoptera: Termitidae)

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Authors' Contributions
MZM conceived the idea and planned the experiment. MSA performed experiments and wrote first draft. MA provided technical assistance. MM performed experiments. ML did statistical analyses. IA proofread the manuscript for English. MAR technically revised the manuscript.

Keywords
Botanical extracts, *Odontotermes* termites, Plant essential oils, Repellency, Toxicity

Abstract | Methanolic extracts and essential oils of ten indigenous plant species were evaluated for their insecticidal and repellency potential against the subterranean termite *Odontotermes obesus* Ramb, a destructive insect pest of wooden infrastructures, agricultural crops, orchards and forest plantations. Standard filter paper disc method was used for both toxicity and repellency bioassays according to completely randomized design. The response of termite workers varied with plant species, botanical concentration and exposure time. The extracts of *Azadirachta indica* (neem) and *Nerium indicum* (oleander) appeared to be most effective against the termites with minimum LC_{50} (6.35 and 10.38%, respectively) and LT_{50} (12.11 and 17.49 h, respectively) values, followed by the extract of *Gardenia jasminoides* (gardenia). While the extracts of *N. indicum* (oleander) and *Dodonaea viscosa* (sanatha) exhibited maximum repellency (up to 78%) of termite individuals, followed by *A. indica* (neem). In addition, the essential oils of *Citrus aurantium* (sour orange) and *Cymbopogon citratus* (lemon grass) were most effective against *O. obesus* termites with minimum LC_{50} (0.44 and 0.74%, respectively) and LT_{50} (10.91 and 16.89 h, respectively) values, followed by *Allium sativum* (garlic). While *Syzygium aromaticum* (clove-bud) and *A. sativum* oils exhibited maximum repellency (up to 75%) of the termite individuals, followed by *C. aurantium*. These findings corroborate the effectiveness of indigenous plant extracts and essential oils as safe and environment-friendly alternates to hazardous synthetic insecticides, and suggest the incorporation of these phytoextracts in the future pest management programs against subterranean termites and other insect pests.

Novelty Statement | This laboratory study demonstrates the bioefficacy of indigenous plant extracts and essential oils as safe and eco-friendly alternates to hazardous synthetic insecticides and suggests the incorporation of these indigenous phytoextracts in the future bio-intensive pest management programs against insect pests such as subterranean termites.

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Introduction

With more than 3,500 described species, termites constitute a significant edaphic fauna, predominantly in semiarid and arid ecosystems. These insects play a key role in the organic matter transformations, plant litter decomposition and soil fertilization (Rouland-Lefevre, 2010; Jouquet *et al*., 2011; Majeed *et al*., 2012). In spite of their great ecological importance, many termite species are destructive pests of agricultural and urban settings and cause significant damage worth billions of US dollars each year (Su and Scheffrahn, 2000; Ahmed *et al*., 2005; Rouland-Lefèvre, 2010; Chand *et al*., 2018). Subterranean termites attack on many of the agricultural and horticultural crops, forest plantations, orchard trees and wooden infrastructures (Rouland-Lefèvre, 2010). In Indo-Pak regions, many crops including sugarcane, cotton, wheat, gram and wooden structures in urban settings are severely infested by the subterranean termites (Rajagopal, 2002; Iqbal and Saeed, 2013). Economically most important genera of subterranean termites attacking these crops and wooden structures are *Coptotermes*, *Microtermes* and *Odontotermes*, and the most important termite species include *Odontotermes obesus, O. guptai, Coptotermes heimi, Microtermes obesi* and *M. mycophagus* (Ahmed *et al*., 2005, 2011; Manzoor *et al*., 2011; Aihetasham *et al*., 2017).

In Pakistan, farmers rely on different traditional and conventional methods for the prevention and suppression of subterranean termites. Mostly they utilize persistent synthetic agro-chemicals for termite control in their agricultural crops and in urban settings. This irrational and extensive use of conventional synthetic insecticides usually results into various ecological perturbations including environmental contamination, biodiversity eradication and human health hazards (Desneux *et al*., 2007; Isman, 2008; Edwards, 2013). Hence, there is a need to look for new biorational and eco-friendly strategies against these insect pests such as plant-derived chemicals exhibiting anti-termitic and/or repellent properties as safe alternatives to hazardous synthetic termiticides (Dubey *et al*., 2010; Lima *et al*., 2013). Many previous studies have characterized the essential oils and extracts of different plant species for their potential insecticidal action against subterranean termites and other insect pests of economic importance (Isman, 2008; Dubey *et al*., 2010; Majeed *et al*., 2018).

Keeping in view the destructive nature of subterranean pest termites and the environmental concerns of persistent synthetic termiticides being used against these pests, this study was primarily intended to evaluate some effective and indigenous plant promising essential oils and extracts of some selected species under laboratory conditions which can be integrated with other control tactics in future IPM programs against subterranean pest termites.

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Materials and Methods

Insect culture

The intact parts of a subterranean termite nest were collected from the infested stubbles of sugarcane (*Saccharum officinarum* L. var. BF-237) field (32°07'58"N; 72°41'32"E) from the surroundings of College of Agriculture, University of Sargodha. The species was identified to be *O. obesus* Ramb. These termite nest portions, harboring termite individuals inside them, were maintained for a few days in a cubic glass box (60 cm^3) at 27±2°C and 65% relative humidity. Only active and healthy worker termite individuals were used in the toxicity and repellency bioassays.

Extraction of botanicals

Methanolic extracts and essential oils of ten native plant species (Table 1) were evaluated against termites in this study. For this purpose, different plant parts were collected from the surrounding area of College of Agriculture, University of Sargodha. These plant materials were washed with distilled water, shade-dried at room temperature (25°C) for about a week, and then were powdered using an electric blender. Botanical extracts were prepared using Soxhlet apparatus (Sigma-Aldrich, Germany) using methanol as extraction solvent (Predescu *et al*., 2016). The solid (plant material) to solvent ratio was 1:10 (w/v). While, the plant essential oils were extracted with the help of steam distillation using a Clevenger-type apparatus. All botanical extractions were carried out in the laboratory of the Department of Food Science and Nutrition, College of Agriculture, University of Sargodha. A rotary evaporator (Büchi R-3000; Büchi Laboratoriums-Technik, Flawil, Switzerland) set at 41°C was used to remove surplus extraction solvent from the botanical extracts. Extracted botanical extracts and essential oils were placed in the refrigerator at 4°C in dark colored hermetic glass vials until their use in bioassays.

Toxicity bioassays

Standard filter paper disc method was employed to determine the toxicity of botanical extracts and essential oils against subterranean termites as described previously (Akbar *et al*., 2019). Bioassays were performed according to CRD with five replications for each treatment. Briefly, 9 cm discs of filter paper (Whatman No. 1) were immersed for 5 to 10 sec in three different concentrations of plant extracts (*i.e.* 10, 20 and 40%) and plant essential oils (*i.e.* 0.5, 1.0 and 2.0%) and were dried on a towel paper at room temperature (25°C) for 15 to 20 min. Then, these treated filter paper discs were placed in 9 cm glass Petri plates.

Table 1: Different botanical extracts and plant essential oils evaluated under laboratory conditions against worker individuals of subterranean termites (*Odontotermes obesus*).

Botanical names	Common/ vernacular names	Family	Major bioactive constituents	Extraction type	Plant parts extracted
Allium sativum	Garlic	Amaryllidaceae	Diallyl disulfides, dipropyl Disulfides (Sabiu *et al*., 2019)	Essential oil	Bulbs
Azadirachta indica	Neem	Meliaceae	Azadirechtins and triterpenoids (Benelli *et al*., 2017)	Botanical extract	Leaves and fruits
Citrus aurantium	Sour orange	Rutaceae	Flavanone, β-pinene, α-terpineol, limonenes (Dodia *et al*., 2010)	Essential oil	Fruit peels and seeds
Cymbopogon citratus	Lemon grass	Poaceae	Citral, citronellol, citronella, myrcene (Dodia *et al*., 2010)	Essential oil	Leaves
Datura alba	Dhatura	Solanaceae	Tropane alkaloids (Dodia *et al*., 2010)	Essential oil	Leaves and seeds
Dodonaea viscosa	Sanatha	*Sapindaceae*	Flavonoids, phenols, tannins, saponins, lupeol, and stigmasterol (Al-Snafi, 2017)	Botanical extract	Tender stems
Gardenia jasminoides	Gardenia	Rubiaceae	Iridoid glycosides (Li *et al*., 2018)	Botanical extract	Leaves and stems
Nerium indicum	Oleander	Apocynaceae	Oleandrin and oleandrigenin (Dodia *et al*., 2010)	Botanical extract	Leaves
Parthenium hysterophorus	Parthenium	Asteraceae	Parthenin (sesquiterpene derivatives) (Dodia *et al*., 2010)	Botanical extract	Leaves and tender stems
Syzygium aromaticum	Clove bud	*Myrtaceae*	Eugenol, E-caryophyllene (Zeng *et al*., 2010)	Essential oil	Buds

Treatment solutions were prepared using distilled water and the same was applied in the control Petri-plates. Ten active and healthy worker termite individuals were placed on each of the treated filter paper discs and Petri plates were placed in an incubator (MIR152, Sanyo Electric Co. Ltd., Osaka, Japan) set at 27±2°C, 65% relative humidity and 16:8 h light-dark photoperiod. Data regarding the mortality of termite individuals were noted at 6, 12, 24 and 48 h post-exposure. Moribund individuals which were unable to move upon caressing by the tip of camel hair brush were recorded as dead.

Repellency bioassays

For the determination of repellency potential of plant extracts and essential oils, two halves of a filter paper disc (9 cm diameter) were fixed in a Petri plate (9 cm diameter). One half was treated with different concentrations of plant extract or essential oil, while the other half was treated with the distilled water. After ensuring the evaporation of solvents from treated filter papers, ten active and healthy termite worker individuals were introduced in the center of each Petri plate and these Petri plates were placed in the incubator at 26±2°C, 65% relative humidity and 16:8 h light-dark photoperiod. The experimental design was completely randomized with five replications for each treatment. The numbers of termite individuals at each half of the filter paper in each Petri plate were recorded at 2 and 6 h post-exposure.

Statistical analysis

In addition to the graphical representation of data regarding the percent termite mortality or repellency in response to different plant extracts and essential oils, data were analyzed statistically using Statistix® 8.1 (Statistix, Tallahassee, Fl, USA). Median lethal time (LT_{50}) and median lethal concentration (LC_{50}) values were worked out by probit analysis using POLO-PC® regression software. Mortality data was corrected with the help of Abbott's formula (Abbott, 1925) prior to the probit analysis. Moreover, the means of treatments were further compared by using factorial analysis of variance followed by Fisher's least significant difference (LSD) test using time intervals and treatment concentrations as factors.

Results and Discussion

Response of termites against botanical extracts

According to results, all plant extracts exhibited considerable mortality of termite individuals and this termite mortality response was time and concentration dependent as it increased along with time interval and concentration of botanicals (Figure 1). There was a significant effect of all botanical extracts on termite mortality ($P \leq 0.001$; Supplementary Table 1). Moreover, concentrations of botanical extracts, time intervals and their interaction had a significant effect as well on the termite mortality, except for *P. hysterphorus* extract. At 6 h, maximum mortality of termites was observed for 40%

extract of *A. indica* (26%) followed by *D. viscosa* (18%), while *A. indica* and *N. indicum* showed maximum mortality at 12 h observation (Figure 1). Extracts of *G. jasminoides* and *A. indica* were more effective against termites as per the observation at 24 h post-treatment. At 48 h, maximum average mortality of termites was 100, 88 and 86% exhibited by 40% extracts of *A. indica*, *G. jasminoides* and *N. indicum*, respectively (Figure 1).

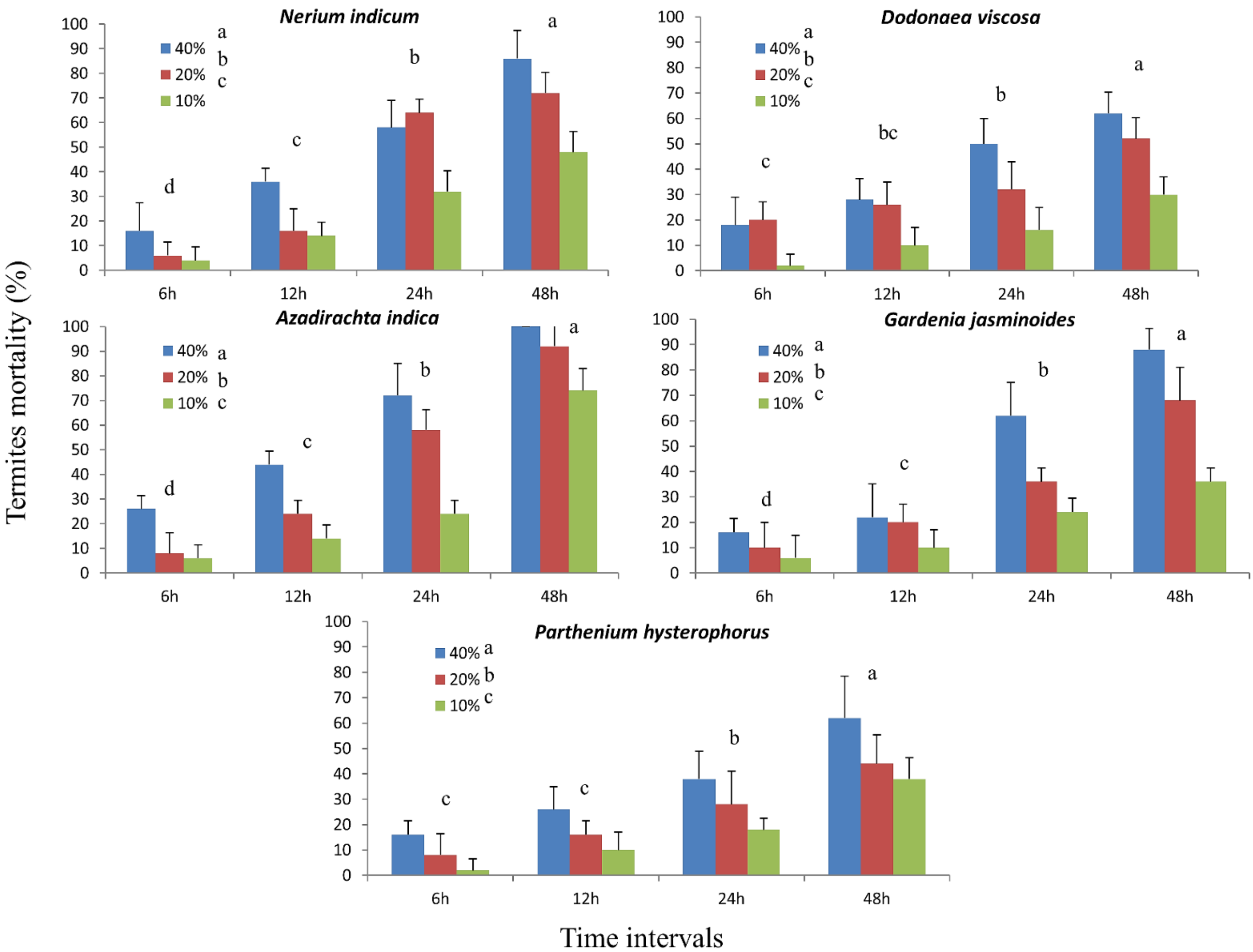

Figure 1: Percent mortality of termite (*Odontotermes obesus*) individuals exposed to methanolic extracts of different plants. Columns represent average percent mortality of worker termites ± standard error (n = 5). For each botanical extract, different alphabets indicate statistical difference among the concentrations and time intervals (one-way factorial ANOVA; LSD at α = 0.05).

Table 2: Median lethal concentration (LC_{50}) values of different botanical extracts evaluated against worker individuals of subterranean termite (*Odontotermes obesus*).

Botanicals	Observation time (h)	LC_{50} (%)	Lower and upper 95% Fiducial limits (%)	X^2 (df = 13)*	P-value
A. indica	24	19.26	15.84 – 23.22	67.49	< 0.001
	48	6.35	3.39 – 8.36	79.97	< 0.001
D. viscosa	24	39.52	30.25 – 66.17	61.92	-< 0.001
	48	21.89	17.75 – 27.67	37.85	< 0.001
G. jasminoides	24	28.31	23.44 – 36.90	45.34	< 0.001
	48	13.58	11.03 – 15.89	64.06	< 0.001
N. indicum	24	18.67	10.34 – 29.77	86.49	< 0.001
	48	10.38	6.62 – 13.29	70.47	< 0.001
P. hysterophorus	24	78.84	43.36 – 1085.32	59.99	< 0.001
	48	22.47	13.83 – 46.48	82.75	< 0.001

*Since the significance level is less than 0.15, a heterogeneity factor is used in the calculation of confidence limits.

According to probit analysis, *A. indica* was the most effective at 48 h (LC_{50}= 6.35%) followed by *N. indicum* (LC_{50}= 10.38%) and *G. jasminoides* (LC_{50}= 13.58), while extracts of *N. indicum* and *A. indica* showed minimum LC_{50} values (18.67 and 19.26%, respectively) at 24 h post-treatment (Table 2). Same effectiveness trend was recorded in case of LT_{50} values. Similarly, 40% extracts of *A. indica* and *N. indicum* showed minimum LT_{50} values (12.11 and 17.49 h, respectively) (Table 3). Maximum LC_{50} (78.84%) and LT_{50} (62.17%) values were recorded for *P. hysterophorus* extracts (Table 3).

Regarding repellency potential of these botanical extracts against subterranean termites, maximum repellency was exhibited by 40% extracts which was not statistically different from that of 20% extracts but was significantly higher than the repellency by 10% extracts (Table 4). According to factorial analysis of variance, extracts of *N. indica* and *D. viscosa* were the most repellent and caused significant repellency of subterranean termite individuals for all three concentrations tested, followed by *G. jasminoides*, while minimum average repellency (44%) was exhibited by extract of *P. hysterophorus* extract (Table 4).

Effect of plant essential oils on termites

Toxicity bioassays with plant essential oils revealed that there was a significant effect of all essential oils on termite mortality ($P \leq 0.01$; Supplementary Table 2). All essential oils tested in the study showed significant mortality of subterranean termite individuals. Just like botanical extracts, mortality response was time and concentration dependent and increased by the time intervals and essential oils concentrations (Figure 2). Moreover, concentrations of essential oils, time intervals and their interaction had a significant effect as well on the average termite mortality (Supplementary Table 2). At 6 h, maximum termite mortality was observed for 2% essential oil of *A. sativum* (26%), while minimum mortality (2%) was exhibited by 0.5% oils of *D. alba* and *C. citratus* (Figure 1). A similar trend was observed at 12 h post-treatment. At 24 h, essential oils of *A. sativum* and *C. citratus* showed maximum termite mortality (84 and 54%, respectively) followed by *S. aromaticum* (45%). At 48 h, maximum average mortality of termites was exhibited by 2% essential oils of *A. sativum* (100%), *C. citratus* (90%) and *S. aromaticum* (78%), while essential oil of *D. alba* was least effective against termites (Figure 2).

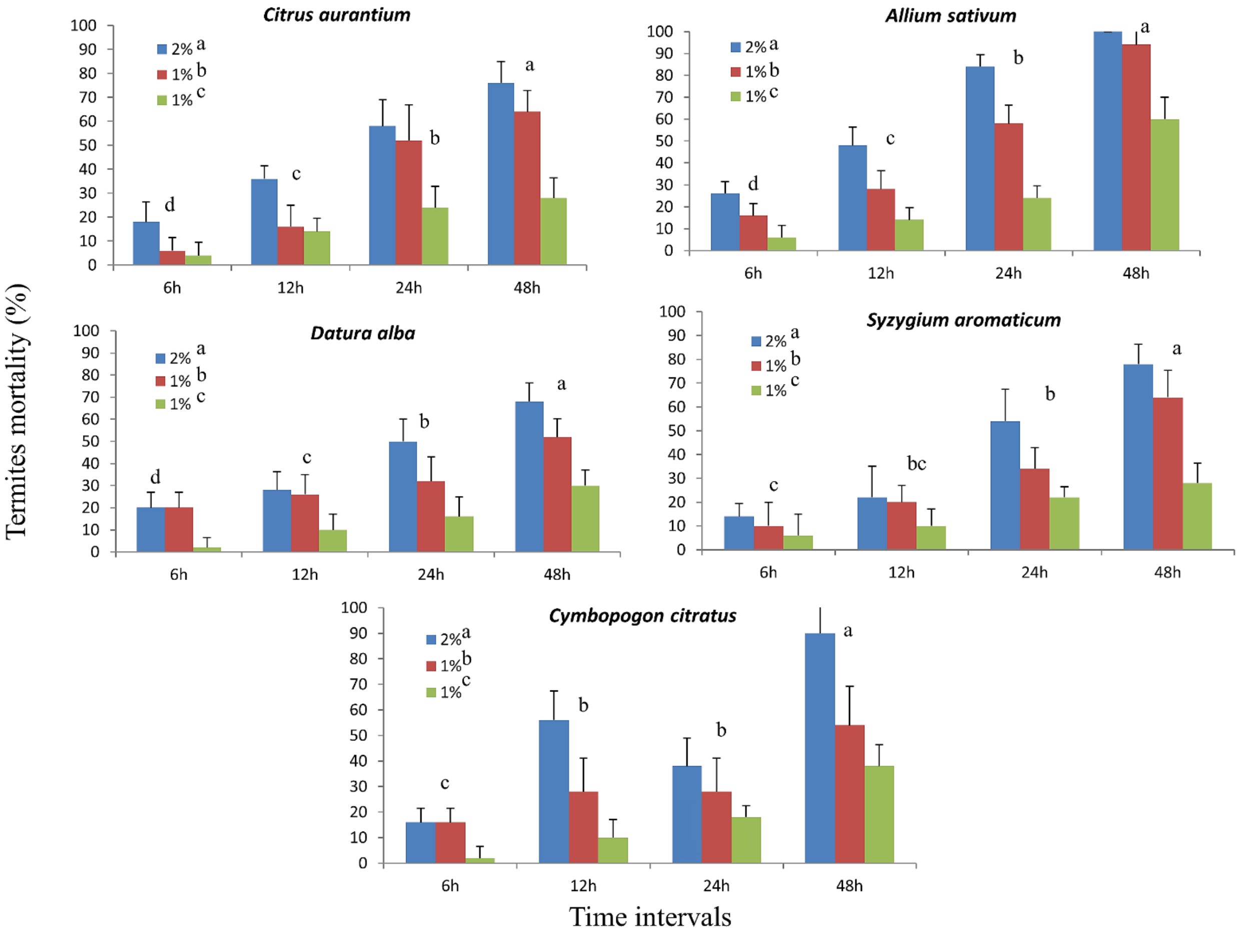

Figure 2: Percent mortality of termite (*Odontotermes obesus*) individuals exposed to essential oils of different plants. Columns represent average percent mortality of worker termites ± standard error (n = 5). For each botanical extract, different alphabets indicate statistical difference among the concentrations and time intervals (one-way factorial ANOVA; LSD at α = 0.05).

Table 3: Median lethal time (LT_{50}) values for worker individuals of subterranean termite (*Odontotermes obesus*) exposed to different plant extracts under laboratory conditions.

Plant extracts	Botanical concentration (%)	LT_{50} (h)	Lower and upper 95% fiducial limits (h)	X^2 (df = 18)*	P-value
A. indica	20	19.20	16.85 – 21.99	111.09	< 0.001
	40	12.11	10.34 – 14.00	111.95	< 0.001
D. viscosa	20	52.90	35.77 – 113.29	71.09	< 0.001
	40	27.57	22.13 – 36.74	78.88	< 0.001
G. jasminoides	20	31.20	25.45 – 40.94	111.63	< 0.001
	40	18.47	15.63 – 21.98	134.36	< 0.001
N. indicum	20	23.82	20.36 – 28.38	121.03	< 0.001
	40	17.49	14.77 – 20.77	110.49	< 0.001
P. hysterophorus	20	62.17	42.78 – 125.81	102.07	< 0.001
	40	33.11	25.64 – 48.37	96.63	< 0.001

*Since the significance level is less than 0.15, a heterogeneity factor is used in the calculation of confidence limits.

Table 4: Percent repellency of worker individuals of subterranean termite (*Odontotermes obesus*) by different plant botanical extracts.

Essential oil concentrations	Time	*A. indica* B	*D. viscosa* A	*G. jasminoides* B	*N. indicum* A	*P. hysterophorus* C
2.0% A	2h	70.0±7.1	92.0±8.4	66.0±5.5	90.0±7.1	50.0±12.2
	6h	64.0±5.5	86.0±8.9	60.0±7.1	76.0±20.7	46.0±15.2
1.0% B	2h	66.0±5.5	84.0±5.5	54.0±11.4	76.0±5.5	44.0±23.0
	6h	62.0±8.4	82.0±8.4	56.0±5.5	78.0±11.0	34.0±11.4
0.5% C	2h	48.0±8.4	68.0±8.4	48.0±13.0	58.0±8.4	42.0±8.4
	6h b	46.0±5.5	58.0±8.4	50.0±7.1	50.0±7.1	48.0±17.9

* Values are means of three independent measures ± standard deviations. Alphabets indicate significant difference between the plant essential oils and their concentrations (Factorial ANOVA; Tukey HSD test at $\alpha = 0.05$).

Table 5: Median lethal concentration (LC_{50}) values of different plant essential oils evaluated against worker individuals of subterranean termite (*Odontotermes obesus*).

Botanical extract	Observation time (h)	LC_{50} (%)	Lower and upper 95% Fiducial limits (%)	X^2 (df = 13)*	P-value
C. aurantium	24	0.87	0.87 – 0.96	27.71	< 0.001
	48	0.44	0.34 – 0.51	79.07	< 0.001
C. citratus	24	3.94	2.17 – 54.26	59.99	-< 0.001
	48	0.74	0.54 – 0.92	129.98	< 0.001
D. alba	24	1.98	1.51 – 3.30	61.92	< 0.001
	48	1.00	0.84 – 1.19	34.91	< 0.01
A. sativum	24	1.77	1.38 – 2.77	48.77	< 0.001
	48	0.82	0.67 – 0.98	65.95	< 0.001
S. aromaticum	24	1.25	0.93 – 1.97	90.78	< 0.001
	48	0.84	0.68 – 1.00	62.68	< 0.001

*Since the significance level is less than 0.15, a heterogeneity factor is used in the calculation of confidence limits.

Probit analysis of mortality data revealed that essential oils of *C. aurantium*, *C. citratus* and *A. sativum* were most effective at 48 h with LC_{50} values of 0.44, 0.74 and 0.82%, respectively, while essential oil of *D. alba* was least effective (Table 5). A similar trend was found in case of 24 h observation. Regarding median lethal time, 2% oils of *C. aurantium* was most effective with minimum LT_{50} value (10.91%), followed by *C. citratus* (16.89%) and *A. sativum* (19.04%). Maximum LC_{50} values were exhibited by essential oils of *S. aromaticum* and *D. alba* (Table 6).

Regarding repellency potential of the essential oils, 2% concentrations of all essential oils exhibited significantly higher repellency of termites than other two concentrations (Table 7). According to factorial analysis, most effective essential oils were of *C. aurantium* and *A. sativum* which caused significant repellency of subterranean termite individuals at all three concentrations followed by *S. aromaticum*, while minimum average repellency (42.6%) was exhibited by essential oil of *C. citratus* (Table 7).

Links Researchers

Table 6: Median lethal time (LT_{50}) values of different plant essential oils evaluated against worker individuals of subterranean termite (*Odontotermes obesus*).

Plant extracts	Botanical concentration (%)	LT_{50} (h)	Lower and upper 95% fiducial limits (h)	X^2 (df = 18)*	P-value
C. aurantium	1	17.25	14.87 – 20.07	115.16	< 0.001
	2	10.91	9.83 – 12.02	58.44	< 0.001
C. citratus	1	49.41	31.93 – 133.03	134.10	< 0.001
	2	16.89	12.02 – 23.80	299.04	< 0.001
D. alba	1	52.90	35.77 – 113.29	71.09	< 0.001
	2	24.52	20.55 – 30.29	60.82	< 0.001
A. sativum	1	29.00	24.19 – 36.37	118.40	< 0.001
	2	19.04	16.40 – 22.26	61.61	< 0.001
S. aromaticum	1	34.21	27.41 – 46.76	108.57	< 0.001
	2	22.20	18.78 – 26.77	105.76	< 0.001

*Since the significance level is less than 0.15, a heterogeneity factor is used in the calculation of confidence limits.

Table 7: Percent repellency of worker individuals of subterranean termite (*Odontotermes obesus*) by different plant essential oils.

Essential oil concentration	Time	*C. aurantium* [B]	*S. aromaticum* [A]	*D. alba* [B]	*A. sativum* [A]	*C. citratus* [C]
2.0% [A]	2h	72.0±8.4*	94.0±8.9	66.0±5.5	94.0±8.9	42.0±21.7
	6h	66.0±5.5	88.0±8.4	58.0±8.4	86.0±11.4	42.0±16.4
1.0% [B]	2h	58.0±13.0	76.0±5.5	54.0±11.4	76.0±5.5	46.0±15.2
	6h	56.0±5.5	80.0±7.1	52.0±8.4	76.0±11.4	34.0±11.4
0.5% [C]	2h	48.0±13.0	66.0±11.4	48.0±13.0	58.0±8.4	42.0±8.4
	6h	48.0±14.8	46.0±11.4	52.0±11.0	46.0±5.5	50.0±18.7

* Values are means of five independent measures±standard deviations. Alphabets indicate significant difference between the plant essential oils and their concentrations (Factorial ANOVA; Tukey HSD test at α= 0.05).

Combating insect pests with synthetic conventional insecticides has created the issues of environmental contamination and health hazards. This urges to search out alternate pest control strategies which are more target-specific and biorational than the hazardous synthetic pesticides. One of these strategies is the utilization of indigenous phytoextracts exhibiting anti-insect activities (Isman, 2008).

This study was aimed to evaluate the toxicity and repellency potential of essential oils and methanolic extracts of ten selected indigenous plants against subterranean termites *O. obesus*. Two bioassays were performed to assess the toxicity and repellency of plant chemicals and their results revealed that extracts of *A. indica* (neem) and *N. indicum* (oleander) appeared to be most effective botanicals with minimum LC_{50} and LT_{50} values followed by *G. jasminoides* (gardenia), while *N. indicum* (oleander) and *D. viscosa* (sanatha) exhibited maximum repellency of subterranean termite individuals. Our results are consistent with those of Ahmed *et al*. (2007) and Adnan *et al*. (2013). Many previous studies demonstrated the effectiveness of *A. indica* derivatives against a number of insect pests including subterranean termites (Schmutterer, 1990; Ahmed *et al*., 2005; Sengottayan, 2013; Benelli *et al*., 2017; Ghafoor *et al*., 2019). Similarly, *N. indicum* (oleander) has been shown effective against many sucking (Alim *et al*., 2017) and chewing insect pests (El-Shazly *et al*., 2000; Moustafa *et al*., 2018). El-Shazly *et al*. (2000) showed that ethanolic extract of oleander leaves was very effective against western-banded blow fly, *Chrysomya albiceps* (Calliphoridae) with a LC_{50} value of 164 ppm. Our results are in line with those of Ahmed *et al*. (2011) who showed that the extract of *N. indicum* exhibits anti-termitic properties and inhibits the tunneling activity of subterranean termites (*O. obesus*).

Similarly, the essential oils of *C. aurantium* (sour orange) and *C. citratus* (lemon grass) appeared to be most effective treatments with minimum LC_{50} and LT_{50} values followed by *A. sativum* (garlic) and *S. aromaticum* (clove-bud) oils. The later both oils exhibited maximum repellency of subterranean termite individuals. Our results are in accordance to those of Raina *et al*. (2007) and Pandey *et al*. (2012) who demonstrated the toxic potential of essential oils of *C. aurantium* (sour orange) against Formosan subterranean termite (*Coptotermes formosanus*) and of *C. citratus* (lemon grass) and *S. aromaticum* (clove-bud) against subterranean termites *O. assamensis*, respectively. Similarly, many previous studies have revealed the effectiveness of *A. sativum* (garlic) and *S. aromaticum* (clove-bud) against different insect pests including termites (Park and Shin, 2005; Owusu *et al*., 2008; Yang *et al*., 2010).

Conclusions and Recommendations

Based on aforementioned study results, it is concluded that the extracts of *G. jasminoides* (gardenia), *A. indica* (neem), *N. indicum* (oleander) and *D. viscosa* (sanatha) and the essential oils of *C. aurantium* (sour orange), *C. citratus* (lemon grass) and *A. sativum* (garlic) were the most effective against *O. obesus* termites. These results corroborate the efficacy of botanical extracts and essential oils as safe and eco-friendly substitutes to the highly toxic and persistent synthetic insecticides, and suggest the incorporation of these natural compounds in future bio-intensive pest management programs against insect pests such as subterranean termites. Nevertheless, in addition to their field assessment, the synergistic evaluation of these plant extracts and essential oils as demonstrated by Alim *et al*. (2017) and Benelli *et al*. (2017) constitute the future perspectives of this research work.

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Supplementary material

There is supplementary material associated with this article. Access the material online at: https://dx.doi.org/10.17582/journal.pujz/2020.35.2.229.238

Conflict of interest

The authors have declared no conflict of interest.

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