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Original article

Essential oils of cinnamon, turmeric and neem as potential control agents against home-invading acid flies (*Paederus fuscipes*) and darkling beetles (*Luprops tristis*)

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ABSTRACT

Objectives: *Paederus fuscipes* and *Luprops tristis* constitute Kerala's two most notorious home-invading arthropod pests. To control their infestations, indoor application of pesticides is commonly practiced, which is detrimental to human health and the environment. This study explores the bioactive properties of plant essential oils as a control agent against them.
Methods: We analyzed the constituents of oils, their repellence, and fumigant toxicity against *P. fuscipes* and *L. tristis*. The constituents and the bioactive compounds in oils were analyzed using Gas Chromatography-Mass spectroscopy analysis. For the evaluation of the repellence activity of the plant essential oils- two choice bioassays were performed, where the control was treated with acetone, and the test contained a mixture of oil in acetone (0.1 μl/cm^2). Fumigant toxicity of oils was done by no choice bioassay (0.1 μl/ml air). To determine the potency of the oils, lethal concentration 50 (LC_{50}) was determined; LC_{50} refers to the concertation of a substance in the air required to kill 50 % of the test animals over a period of time. LC_{50} of cinnamon oil no choice assay with 0.04 μl/ml, 0.06 μl/ml, 0.08 μl/ml, 0.1 μl/ml and 1.2 μl/ml concentration was performed.
Results: Of the three plant essential oils, turmeric oil was the best repellent against both *P. fuscipes* (86.66 ± 11.54) and *L. tristis* (40 ± 20). Cinnamon oil showed the highest activity as a fumigant with 100 % and 73.33 ± 46.18 % mortality in *P. fuscipes* and *L. tristis* after 8 h of exposure. The analysis of the constituents indicated the presence of over 63 different chemical compounds in the three oils. The three plant essential oils tested showed insect deterrent activity, with turmeric oil as the best repellent and cinnamon oil as the best fumigant against pests.
Conclusions: The activities shown were significant enough to be used to replace/add to the conventionally used pesticides, especially in indoor settings. These oils in themselves or by isolating the specific compounds could pave the way to developing more effective and greener pest control methods.

1. Introduction

The Malabar region in Kerala, which forms a part of the global biodiversity hotspot of Western Ghats has been undergoing radical changes in its land-use patterns and consequent loss of biodiversity and ecological balance of the system (Shochat et al., 2010; Jha et al., 2000). With the increased invasion of human settlements and land conversion, the disruption in the balance is manifested in many evident patterns; a prominent one is the increased invasion of pests. Even though humans and arthropods have been sharing homes since ancient times, the unprecedented encroachment of

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human settlements into the wild has resulted in the reciprocal invasion of arthropod pests into human houses (Bertone et al., 2016). The darkling beetles (*Luprops tristis*) and the acid fly (*Paederus fuscipes*) are the most notorious arthropod pests that have invaded human residents in the Malabar region. The former is a nuisance pest invading the residential areas close to rubber plantations, whereas the latter is a health pest associated with a dermatological condition called Paederus dermatitis (Sabu et al., 2008; Bong et al., 2012).

Luprops tristis (Coleoptera: Tenebrionidae) is a litter-dwelling darkling beetle, which has been reported to invade the residential areas close to rubber plantations in large numbers following short spells of summer rains (Abhitha et al., 2010). The invasion occurs in numbers ranging from 0.5 million to 4.5 million, after which they enter into an extended period of dormancy lasting up to 9 months (Sabu et al., 2008). Although the beetle in itself is harmless when stressed, it releases an odorous phenolic substance which, if it comes in contact with skin can cause burns. The heavy infestation has also caused many residents to abandon their homes because of the invasion of *L. tristis*.

P. fuscipes or the acid fly is a health pest. It neither bites nor stings, but accidental brushing or crushing causes them to release the toxin Pederin, and this potent vesicant causes *Dermatitis linearis* in humans (Frank & Kanamitsu, 1987). This toxin is more potent than cobra venom and belongs to a class of anti-tumor compounds produced by an uncultivable strain of *Pseudomonas aeruginosa* (Frank & Kanamitsu, 1987). These beetles are voracious predators found in paddy, rice, and other plantations. They exhibit positive phototaxis and invade houses and residential areas in academic buildings (Frank & Kanamitsu, 1987). Recently these infestations are on the rise and have even caused the temporary closure of educational campuses in Malabar (Personal observation).

Management of these pests at their breeding grounds is complex and hence mostly, control at the site of infestation is mainly practiced by indoor application of broadscale pesticides. In most cases, these only provide temporary relief lasting hardly a week but affect the long-term health of the residents and the environment through pesticide accumulation. Pesticide poisoning is blamed for the death of thousands every year, not only do they cause direct mortality but has been associated with various types of cancer and neurological diseases such as Alzheimer's, Parkinson's, metabolic syndromes like- malnutrition, atherosclerosis, inflammation, pathogen invasion and susceptibility to infectious diseases (Lushchak et al., 2018). So more often than not for the control of nuisance pests, applying pesticides does nothing more than deteriorate the health of the residents. India is a country with abundant traditional ecological knowledge and efficient traditional medicinal practices and medicines (Kumar et al., 2007). Several such plants endemic to the Indian subcontinents are now being explored for their bioactive properties (Mukherjee et al., 2007). Although in the literature, there have been a few attempts at evaluating the insect deterrent properties of plant essential oils against *P. fuscipes,* which have produced promising results (Zhang et al., 2016, Gaffari et al., 2016). But these studies have not incorporated the endemic plants from Indian subcontinent. And there have been no published records for the same in the case of *L. tristis.*

The current study aims to explore the insect deterrent activity of three traditional medicinally used plants Neem (*Azadirachta indica*), Cinnamon (*Cinnamomum zeylanicum*), and Turmeric (*Curcuma longa*) against the home invading nuisance pests of Kerala, *Paederus fuscipes* and *Luprops tristis*. We focus mainly on the repellence and fumigant toxicity properties of three traditional medicinally used plants Neem (*Azadirachta indica*), Cinnamon (*Cinnamomum zeylanicum*), and Turmeric (*Curcuma longa*) against the home invading nuisance pests of Kerala, *Paederus fuscipes* and *Luprops tristis*. The analysis of the bioactive constituents of the essential oils of these plants could further be used to improve the formulation of the currently used pesticides making them less toxic to humans and increasing their efficacy against the target organisms.

2. Methodology

2.1. Plant essential oils

Hydro-distillate plant essential oils were procured from Akay Flavours and Aromatics Pvt. ltd., Kerala, India. The plant's essential oils included Neem (*Azadirachta indica*), Cinnamon (*Cinnamomum zeylanicum*), and Turmeric (*Curcuma longa*).

2.2. Insect sampling

2.2.1. Paederus fuscipes

The live specimens of *Paederus fuscipes* were collected by hand picking from banana plantations in Kodiyammel, Malappuram (11°13′N 75°55′E), located 925 m from Chaliyar River. The collected samples were kept in an insectarium in the Entomology lab of PG and the Research Department of Zoology, St Joseph's College, Devagiri. The dimensions of the glass insectarium were $70 \times 30 \times 35$ cm, maintained at a temperature of 29 ± 3 °C and relative humidity of 72 ± 4 %. A 12 h: 12 h (L:D) photoperiod was observed. The rearing method was adopted by Schmidt, (1999). The rearing container was lined with soil up to a height of 3 cm, and about 500 g of dried litter was placed over it. The container was also provisioned with a test tube (20 ml) filled with water, plugged with cotton, and placed horizontally to act as a water source for the beetles. A 5 ml mixture of honey and water (1:1) and killed American cockroaches (*Periplaneta americana*) were provided as a food source (Bong et al., 2012). New food was provided every-three days.

2.2.2. Luprops tristis

Live specimens of newly invaded predormancy of *Luprops tristis* were collected from St Joseph's College, Devagiri (11°15′N 75°50′E). Insects were maintained at optimum conditions in an earthen pot at temperature (27 + 0.5C) and relative humidity (70 + 5 %) (Vinod et al., 2010).

2.3. Analysis of components of essential oils

GCMS analysis has been carried out in GC–MS (Thermo Fisher Scientific, Austria); the GC measurement was started after 3 min of sample injection. The column temperature was maintained at 40 °C for 3 min and gradually elevated with a gradient of 8 °C and a temperature of 230 °C was maintained. The carrier gas used was helium at a flow rate of 0.5 mL/min. The mass spectrometric temperature was 200 °C and mass range of 20–300 *m*/*z*. The compounds were identified by comparing their Relative Strength Index (RSI) and *m*/*z* ratio by using the NIST library and comparing the literature reports.

2.4. Test for repellence

A binary choice bioassay for essential oils to test repellence activity was performed by using the methods described by Zapata et al. (2010). The vertical wall inside of a cylindrical glass chamber was coated with petroleum jelly emulsion and allowed to dry for 2 h to prevent the beetles from climbing to the top cover and moving away from the test area. Half filter paper disks (Whatman No. 1) were used as test areas. Test solutions of essential oils were prepared by dissolving 2.5 ml of each essential oil in 0.5 ml of acetone.

Test concentration from each oil was applied individually to a half-filter paper disc to obtain concentrations of 0.1 μl/cm^2. The other half filter paper disc was treated with acetone only and served as a control. The treated and control discs were air-dried for 5 min at room temperature. Treated and control discs were attached to their opposite sides using adhesive tape and then placed in the bottom of a cylindrical glass jar of diameter 12.5 and height of 17 cm. Ten adults of unspecified sex were released separately at the center of each filter paper disc. Three replicates were used, and the entire experiment was repeated three times for 30 adults per concentration. Observations on the number of insects on both the treated and untreated halves were recorded after, 2, 4, 6, and 8 h from the beginning of the test. The percentage repellence (PR) was calculated using,

$$PR = \frac{C - T}{C + T} \times 100$$

C is the number of beetles in the untreated area, and T is the number of beetles in the treated area.

2.5. Fumigant toxicity test

The essential oils were screened for the sample with the highest toxicity against *P. fuscipes* and *L. tristis* using the method described by Zhang et al. (2016). The concentration of 0.1 μl/ml of air was selected for the experiment. Whatman filter paper (1 cm length by 1 cm width) was prepared by adding 5 μl of oil. The paper was placed on the underside of a screw cap of 50 mL plastic bottles providing a concentration of 0.1 μl/ml of air. The inner wall of each glass vial bottleneck was coated with petroleum jelly emulsion and allowed to dry for two hr, to prevent the beetles from coming in contact with the treated filter paper. After 1, 2, 4, 6, and 8 hr of exposure, the beetles were transferred into new rearing containers containing the culture media (the artificial diet and water) and incubated at 27.5 ± 0.5C and 65 ± 5 % RH for 24 h. The mortality rate (%) of the beetles was determined. Each vial contained 5 adults (undefined sex), and each experiment with treatment and blank control was replicated three times. When no signs of the leg or antennal movement were observed, beetles were considered dead. Five different concentrations (0.04 μl/ml, 0.06 μl/ml,0.08 μl/ml, 0.1 μl/ml and 1.2 μl/ml) were used for determining the Lc_{50} of cinnamon oil against *Paederus fuscipes* (Zapata & Smagghe, 2010).

2.6. Statistical analysis

The repellence and fumigant toxicity assay effects were recorded as percentages. Since the data obtained in the assays were non-normal, for data analysis non-parametric tests were employed. Multivariate comparisons were done using Kruskal-Wallis followed by the Mann-Whitney *U* test at $P < 0.05$ for testing the significance between the repellence and fumigant activities of oils. And individual oils were tested using the Wilcoxon test at $P < 0.05$ separately for their repellence and fumigant toxicity. All mentioned statistical analysis was carried out using PAST free software. For the calculation of lethal concentration 50 (Lc_{50}) probit analysis was performed using SPSS 22.0 software (SPSS Inc., Chicago, US), and the graphs were made using R 3.2.2 software.

3. Results

3.1. Analysis of constituents

The composition of plant essential oils was evaluated by GC–MS analysis (Table1). 68 chemical components were identified from the analysis using RSI. From cinnamon oil 17 compounds were identified. The primary component in Cinnamon oil was found to be (E)-Cinnamaldehyde (40.3 %), a large amount of β-Caryophyllene (12.45 %), and Eugenol (10.8 %). Although 17 compounds were identified in Turmeric oil, they were different from that in cinnamon oil. The principal constituent of Turmeric oil includes *ar*-Turmerone (34.9 %), β-Turmerone (25.8 %), and α-Turmerone (20.5 %). The largest number of chemical components was found in Neem oil, where 46 constituents were identified. Most of these compounds were found in very low concentrations, only β-Thujone (32.5 %) and trans-Sabinene hydrate (20.5 %) were found in larger quantities.

3.2. Repellence activity of essential oils against Paederus fuscipes

All three plant essential oils (Cinnamon, Turmeric and Neem) have exhibited a significant repellent activity ($P < 0.05$) against *Paederus fuscipes* at a concentration of 0.1 μl/cm^2 after different periods of exposure (Table 2; Fig. 1). Similarly, between oils, a significant difference in activity was noted between Neem-Cinnamon ($P < 0.001$) and Neem-Turmeric ($P < 0.0005$), but no significant difference was observed between Cinnamon-Turmeric ($P = 0.8498$). Of the tested oils, Turmeric oil has exhibited excellent repellence as high as 73 % against the beetle for 6 hr. Cinnamon oil also showed good repellence of up to 66 % for 6 h. Neem oil also exhibited a significant level of repellence of 40 % after a 6-hour exposure period.

3.3. Repellence activity of essential oils against Luprops tristis

All three plant essential oils have exhibited significant levels of repellence activity ($P < 0.05$) against *L. tristis* at a concentration of 0.1 μl/cm^2 after different periods of exposure (Table 3; Fig. 1). But in the case of activity between the oil samples, no significant difference ($P = 0.7449$) was observed. Cinnamon oil has exhibited the highest percentage of repellence on *Luprops tristis* with 49.6 % after over 8 h of exposure. Turmeric oils had a rapid action activity since they showed a repellence of 40 % after 1-hour exposure, but the values significantly decreased with the time of exposure. The activity of Neem oil was lower than other oils and only up to 26.6 % was noted after 6 h of exposure.

3.4. Fumigant toxicity

3.4.1. Fumigant toxicity of essential oils against Paederus fuscipes

All the three oils tested have exhibited significant fumigant activity against *P. fuscipes* ($P < 0.05$), and a significant difference was noted between the activity of Neem-Cinnamon and Neem-Turmeric ($P < 0.05$) however in the case of Cinnamon-Turmeric oils no difference was observed ($P = 0.1992$). Cinnamon oil exhibited excellent activity against *Paederus fuscipes*, and 100 % mortality was recorded after 4 h of exposure (Table 4). Similarly, Turmeric oil also proved to have good fumigant activity, and a mortality rate of 40 % was noted after a 4-hour exposure period. However, Neem oil, even though showed significant activity (13 %) against the beetles the values recorded very much lower than that of cinnamon and Turmeric oils (Fig. 2).

3.4.2. Fumigant toxicity of essential oils against Luprops tristis

Three essential oils- Neem, Turmeric and Cinnamon oils, when tested against *L. tristis*, showed significant levels ($p < 0.05$) of fumigant toxicity as given in Table 5. A significant difference in fumigant activity was observed between Neem-Cinnamon oils ($P < 0.05$), but no significant difference was found between Cinnamon-Turmeric ($P = 0.06266$) and Turmeric-Neem ($P = 0.3985$). Of the three oils tested Cinnamon oil in this case also proved to be the most effective with up to 73.3 % mortality

Table 1
Chemical composition of essential oils (in percentage).

Sl. No	Constituents	Percentage composition		
		Cinnamon oil	Turmeric oil	Neem oil
1	α-Pinene	1.3	0.5	0.1
2	Benzaldehyde	0.3		
3	p-Cymene	1.9	1.1	0.05
4	Limonene	1.2		0.2
5	Eucalyptol	7.8		
6	γ-Terpinene	0.6		0.04
7	Linalool	7.1		4.1
8	Isoborneol	0.8		
9	(E)-cinnamaldehyde	40.3		
10	Eugenol	10.8		
11	β-Caryophyllene	12.45	0.6	
12	Acetic acid-cinnamyl ester	0.5		
13	α-Humulene	5.9		0.1
14	δ-Cadinene	6.3		
15	trans-Calamenene	0.1		
16	Caryophyllene oxide	1		
17	Benzyl benzoate	0.5		
18	Vinyl propionate		2.7	
19	1.8-Cineole		0.9	0.01
20	Camphor		0.1	0.1
21	α-Terpineol		0.1	0.1
22	γ-Curcumene		0.4	0.7
23	ar-Curcumene		2.6	
24	α-Zingiberene		1	
25	β-Sesquiphellandrene		2.1	
26	ar-Turmerol		1.1	
27	α-Cadinol		1.7	
28	ar-Turmerone		34.9	
29	α-Turmerone		20.5	
30	β-Turmerone		25.8	
31	Bisabolone		1.8	0.6
32	(E)–Atlantone		1.2	
33	Tricyclene			1
34	α-Thujene			0.05
35	Camphene			0.06
36	β-Pinene			4.5
37	Sabinene			0.28
38	Myrcene			0.5
39	α-Terpinene			0.2
40	β-Phellandrene			0.2
41	Z-β-Ocimene			0.1
42	E-β-Ocimene			0.1
43	Terpinolene			0.1
44	β-Thujone			32.5
45	α-Thujone			0.1
46	trans-Linalool oxide			0.02
47	trans-Sabinene hydrate			20.5
48	cis-Linalool oxide			0.03
49	α-Copaene			1
50	Linalool			4.1
51	cis-Sabinene hydrate			0.4
52	Linalyl acetate			0.5
53	Bornyl acetate			0.5
54	Terpinene-4-ol			7.8
55	cis-Dihydrocarvone			0.3
56	cis-Verbenol			2
57	Sabinyl acetate			0.2
58	trans-Sabinol			0.5
59	Lavandulol			8.2
60	Neral			0.1
61	γ-Muurolene			0.2
62	α-Terpinyl acetate			0.1
63	Borneol			0.4
64	Germacrene D			0.1
65	Neryl acetate			0.1
66	β-Selinene			5.5
67	Carvone			1.5
68	Geranyl acetate			0.1

recorded after an exposure of 8 h (Fig. 2). Turmeric oil also proved to possess a significant level of fumigant toxicity comparable to that of cinnamon oil, after an exposure of 8 h 40 % mortality was reached. Neem oil showed negligible levels of activity initially but after 4 hrs effect was noted and after 8 h, 26.6 % mean mortality was recorded.

Table 2
Percentage repellence (mean ± SD) of *Paederus fuscipes* against plant essential oils.

Oil samples	1 h	2 h	4 h	6 h	8 h
Cinnamon oil	80 ± 20	73.33 ± 11.54	66.66 ± 11.54	66.66 ± 11.54	53.33 ± 11.54
Curcumin oil	86.66 ± 11.54	73.333 ± 23	73.33 ± 23	73.33 ± 23	46.66 ± 23
Neem oil	46.66 ± 11.54	46.66 ± 11.54	46.66 ± 30.55	40 ± 20	26 ± 11.54

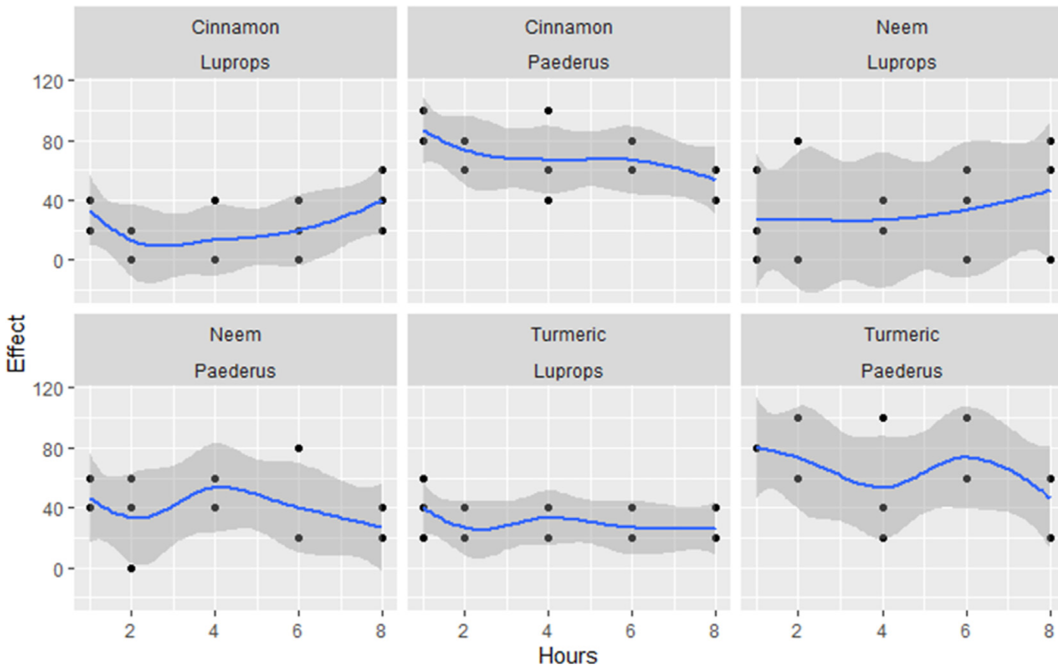

Fig. 1. Percentage repellence (mean ± SD) of *Luprops tristis* and *Paederus fuscipes* against three plant essential oils.

Table 3
Percentage repellence (mean ± SD) of *Luprops tristis* against plant essential oils.

Oil samples	1 h	2 h	4 h	6 h	8 h
Neem	26.62 ± 11.54	26.66 ± 11.54	26.66 ± 11.54	26 ± 11.54	13.33 ± 11.54
Cinnamon	33.33 ± 11.54	13.33 ± 11.54	26.66 ± 11.54	33.33 ± 11.54	46.66 ± 23.09
Curcumin	40 ± 20	26.66 ± 11.54	20 ± 14.14	26.66 ± 11.54	33.33 ± 11.54

Table 4
Fumigant toxicity (percentage) of essential oils on *Paederus fuscipes.*

Oils	1 h	2 h	4 h	6 h	8 h
Neem	0	6.66 ± 11	13.33 ± 11.54	13.33 ± 11.54	13.33 ± 11.54
Cinnamon	26.66 ± 11.54	86.66 ± 23.09	100	100	100
Curcumin	33.33 ± 11.54	46.66 ± 30.55	53.33 ± 41.63	53.33 ± 41.63	66.66 ± 41.633

3.5. LC_{50} of fumigant activity of cinnamon oil against P. Fuscipes

The fumigant activity of cinnamon oil was also found to be dose-dependent. The Lc_{50} values of cinnamon oil at 1,2,4,6 and 8 h of exposure are given in (Table 6). The Lc_{50} values of cinnamon oil against *Paederus fuscipes* decreased with prolonged periods of exposure. It exhibited the highest fumigant toxicity against *P. fuscipes*, with LC_{50} values of 15.5, 7.14, 6.801, 5.47, and 3.796 µl/L after 1, 2, 4, 6, and 8 h of exposure, respectively.

4. Discussion

Plant essential oils are known to contain an array of volatile organic components, in the present study our analysis of *Cinnamon* oil reveals *trans*-cinnamaldehyde (40.3 %) to be the dominant constituent which was found to be lower than the previously reported range of 44.2–97.7 % (Baratta et al., 1998; Michaelraj & Sharma, 2006; Shahverdi et al., 2007). Similarly analysis of Turmeric oil that *ar*-Turmerone (34.9 %) was the major component, this finding was in good agreement with the study on chemical profiling of Turmeric oil but differed from the values presented in place by Raina et al. (2002) and Jantan et al., (2008). The latter reported that Turmeric oil contained only 7.3 % *ar*-Turmerone. The composition of essential oils depends upon several factors including the growth stages, harvest time, edaphic and climatic factors, geographical region, extracted part of the plant, and extraction technology used (Nenaah, 2014; Zhang et al., 2014) which could explain the difference in the qualitative and quantitative differences in the constituents of essential oils even within the same species.

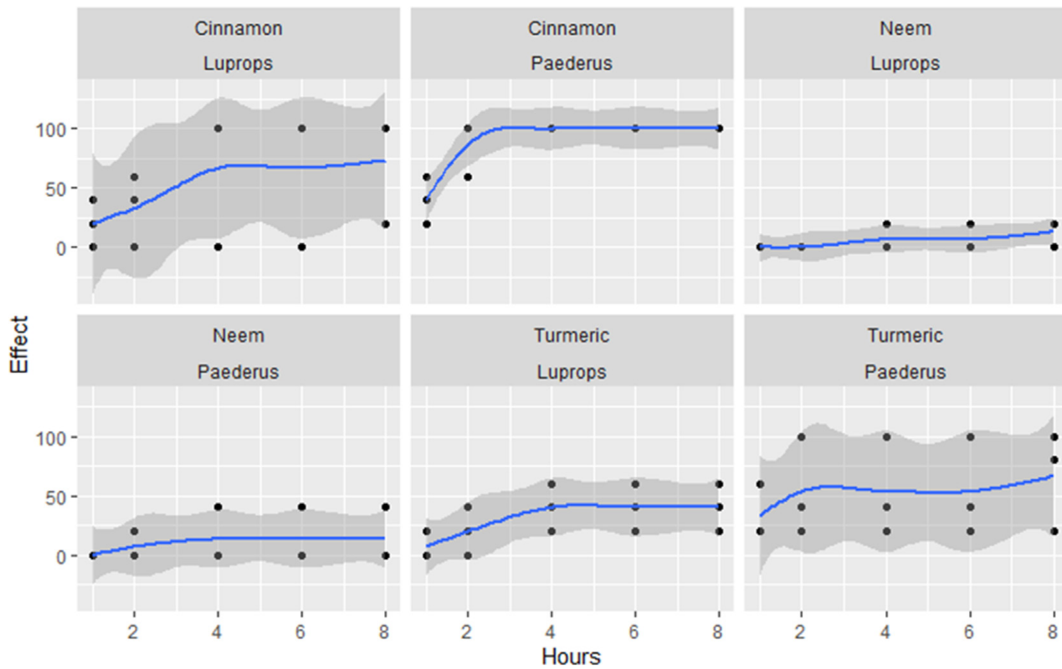

Fig. 2. Fumigant toxicity (percentage) of essential oils against *L. tristis*.

Table 5
Fumigant toxicity (percentage) of essential oils on *Luprops tristis*.

Oils	1 h	2 h	4 h	6 h	8 h
Neem	0	0	13.33 ± 11.54	20	26.66 ± 11.54
cinnamon	23 ± 13.33	40 ± 34.64	60 ± 52.91	66.66 ± 57.73	73.33 ± 46.18
curcumin	11.58 ± 6.66	20 ± 11.54	33.33 ± 11.54	33.33 ± 11.54	40 ± 20

Table 6
Data are given as 50% (LC50) lethal concentration values together with their 95% confidence interval (95%CI) (uL/L air).

Time of exposure	Lc50	Upper limit	Lower limit	Chi square
1 h	15.514	20.467	10.553	1.649
2 h	7.114	8.172	5.958	1.912
4 h	6.801	7.686	5.798	2.69
6 h	5.47	6.407	4.326	0.989
8 h	3.796	4.747	1.429	1.109

The presence of volatile components in plant essential oils have been linked to the strong repellent activities exhibited by many plant essential oils, including the ones tested in present study (Nerio et al., 2010). Of the tested oils, Cinnamon and Turmeric oils had the greatest repellence activities towards both *P. fuscipes* and *L. tristis*. Abtew et al. (2015) identified the repellence activity of *cinnamon* oil against legume flower thrips. The repellence of cinnamon oil could be from the high concentration of *trans*-cinnamaldehyde, which has previously been reported as a potent repellent against *Culex pipiens pallens*, *Tribolium castaneum* Herbst (Delong et al., 2016; Saad et al., 2019). Similarly, the repellence activity of Turmeric can be explained by the high levels of *ar*-Turmerone in it, de Souza Tavares et al. (2013) revealed that *ar*-Turmerone, is very effective as a repellent against pests *Sitophilus zeamais* and *Spodoptera frugiperda*. Due to the diffusion of volatile components of the oil with the atmosphere generally, the repellence activity exhibited by essential oils decreases with increased time of exposure, but in the present study, the repellence activity by *Cinnamon* and *Turmeric* oils in *L. tristis* the probable causes of it might be delayed response of beetles or the smaller sample size used in the study.

In the fumigant experiment, both *P. fuscipes* and *L. tristis* cinnamon oil showed the highest activity. Again, the high concentration of *trans*-aldehyde could explain the vapour phase toxicity shown by the oils. Studies by Coats et al. (1991) show that their neurotoxic mode of action can explain the fast knockout action of certain essential oils.

Cinnamon and Turmeric may potentially be used as repellents and fumigants against both *Paederus fuscipes* and *Luprops tristis*. Although some essential oil components are found to be skin irritants (Maia & Moore, 2011). The safe concentration for cinnamon was found to be 0.5 % (Zhang et al., 2016), the current study found that cinnamon oil exhibited strong repellence at 0.01 mL/cm^2 (0.05 %).

The incorporation of essential oils directly or indirectly- by isolation of its active components could prove effective as an Integrated Pest Management strategy. The use of essential oils can partially or completely replace the use of more toxic synthetic chemical pesticides, especially for indoor applications for the management of home-invading pests such as *P. fuscipes* and *L. tristis*.

5. Conclusion

The plant essential oils of Cinnamon, Turmeric, and Neem were found to possess bioactive properties which could be used for the effective pest management of *P. fuscipes* and *L. tristis.* The analysis of the oils revealed the presence of 68 different compounds in them. When tested as a repellent the activity of Turmeric > Cinnamon > Neem. While in the case of fumigant toxicity Cinnamon > Turmeric > Neem. To better understand the potency of the oil, we determined the LC_{50} of cinnamon oil, which was found to increase with the period of exposure. Further research on the evaluation of the particular chemical constituents which are responsible for the bioactive property exhibited holds scope for the formulation of safer and more effective pesticides for their control.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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