Insecticidal of Selected Plant Extracts and Their Combined Formulation Against the American Cockroach, Periplaneta Americana

Rosemary B. Ukoroije
Niger Delta University
Tariwari C. N. Angaye
tcnangaye@ndu.edu.ng

Niger Delta University

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Abstract

The development of resistance and eco-toxicity associated with synthetic insecticides has renewed interest in the use of plant-derived pesticides for pest management. The leaves of *Hyptis suaveolens*, *Ocimum sanctum*, and *Laurus nobilis* were collected, authenticated, shade-dried, and extracted with ethanol, methanol, chloroform, and hexane, after which their phytochemical properties and insecticidal activities against *P. americana* were evaluated. Preliminary phytochemical screening and gas chromatography–mass spectrometry analysis revealed a greater disparity in the chemical composition, and the differences found based on solvent type were attributed to the recovery of an extensive range of bioactive compounds by the different solvents. The major constituents are β-caryophyllene and germacrene D in *H. suaveolens*, eugenol in *O. sanctum*, and 1,8-cineole from *L. nobilis*. The contact toxicity bioassay revealed that the leaf extracts of all the plants induced mortality in the adults of *P. americana*, and the degree of toxicity of the solvent extracts differed among the plant species. Probit analysis confirmed the screening results and identified the combined formulation as the most effective treatment, with a 24-h LC_{50} of < 5.00 mg/mL. The methanolic extract of *H. suaveolens* was the most potent among the individual extracts, with an LC_{50} of 6.19 mg/mL, followed by *O. sanctum* methanol (7.17 mg/mL), *H. suaveolens* ethanol (7.88 mg/mL), *L. nobilis* methanol (8.33 mg/mL), *O. sanctum* ethanol (8.74 mg/mL), and *H. suaveolens* chloroform (12.02 mg/mL). The results indicate a promising avenue for *H. suaveolens* against *P. americana* and a combined formulation for developing a botanical insecticide formulation against *P. americana*.

1. INTRODUCTION

P. americana is a widely distributed peridomestic cockroach pest of public health importance because of its ability to transmit pathogenic microbes, including *Escherichia coli* and *Salmonella* spp., and even parasitic diseases mechanically. It has been implicated in the contamination of food and in deleterious effects, such as dysentery, asthma attacks, and allergic reactions, when present in human habitations and domiciliary sites where food is being handled (Oladipupo et al. 2022). While its importance in science and hygiene is incontestable, the control of *P. americana* still primarily depends on traditional synthetic insecticides such as pyrethroids and organophosphates. Nevertheless, the consistent reliance on these chemicals has led to several issues, such as counteractive pest populations, environmental contamination, and hazards to nontarget species that appendage human health (Oladipupo et al. 2022).

Therefore, interest is being revived for phytogenic compounds as alternative means of control. Aromatic plants and their secondary metabolites, in particular, have made impressive contributions in light of their complex mixtures of terpenoids, phenolics, and related compounds that have insecticidal, repellent, and growth-disrupting activities and often confer limited opportunity for resistance development compared with most conventional insecticides (Krzyżowski et al. 2020). Some such plants are those that show bioactivity against many insect pests, of which *Hyptis suaveolens*, *Laurus nobilis*, and *Ocimum sanctum* are only a few common. *Hyptis suaveolens* extracts or essential oils display fumigant toxicity with respect to *Tribolium castaneum* and larvicidal activity against mosquito species (Adelaja et al. 2022;

Duniya et al. 2022). *Laurus nobilis* showed similar insecticidal activity against *Callosobruchus maculatus* infestation (Baghazaoui et al. 2024). In addition, *O. sanctum*, which is rich in compounds such as eugenol and β-caryophyllene, has been reported to possess insecticidal activity against flies and repellent effects against cockroaches (Costa et al. 2020; Nour et al. 2022).

While this finding somewhat proves the pesticidal potential of these three plants, little information is available on their comparative efficacy against *P. americana* when different solvents and combined formulations are used. A comparative evaluation is very important to ascertain whether the choice of extraction solvent markedly affects the insecticidal activity and whether the efficacy can be improved when the extracts are combined. Hence, the present study investigated the phytochemical profile and insecticidal activity of *H. suaveolens, L. nobilis, and O. sanctum* leaf extracts against *P. americana*. Specifically, this study aimed to investigate the phytochemical constituents of the extracts and test them for contact toxicity, lethal concentration–response relationships, and combined effects on locomotor and morphogenic changes during lethal effects. This observation provides a basis for the development of plant-based insecticidal formulations aimed at contributing to cockroach management, thus reducing the dependence on synthetic insecticides.

2. Materials and methods

2.1 Plant collection and identification

Leaves of *Laurus nobilis* and *Ocimum sanctum* were purchased from spice and vegetable markets in Yenagoa, Bayelsa State, Nigeria, whereas leaves of *Hyptis suaveolens* were obtained from wild populations in Igarra, Edo State, Nigeria. Only mature, healthy, and undamaged leaves were taken. The samples were kept in perforated paper bags during transportation for enhanced ventilation to reduce the risk of fungal growth. The leaves were shade-dried for 7 days under natural light in the laboratory, coarsely powdered via an electric blender, and stored in tightly labeled containers for analysis. The plant species were defined by their morphological characteristics in combination with those of the samples available from herbaria at the Department of Biological Sciences at Niger Delta University. Voucher samples were then prepared and deposited into the university herbarium for reference in the future (Akharaiyi et al. 2022).

2.2 Extraction

Leaves collected from *H. suaveolens*, *L. nobilis*, and *O. sanctum* (400 g per species) were shade-dried and extracted with methanol, ethanol, chloroform, or hexane via maceration for 48–72 h at room temperature with intermittent shaking (Abubakar and Haque 2020). The extract filtrates were concentrated for some time below atmospheric pressure via a rotary evaporator. The subsequent crude extract was stored at 4°C.

2.3 Phytochemical analysis

Phytochemical characterization involved preliminary qualitative screening and gas chromatography–mass spectrometry (GC–MS) analysis of known compounds. Extracts were screened for qualitative testing for prominent secondary metabolite groups, including alkaloids, terpenoids, flavonoids, phenols/tannins, saponins, steroids, and various cardiac glycosides, according to standard methods (Ojo et al. 2010). The crude sample extracts were further evaluated via GC–MS to identify the major chemical constituents of the tested extracts, such as volatile and semi-volatile compounds that are associated with insecticidal activity.

2.4 GC–MS conditions

Gas chromatography–mass spectrometry (GC–MS) was used to analyze the samples for the identification of individual compounds. The samples were derivatized as necessary to improve volatilization and chromatographic resolution. The compounds were identified on the basis of mainly their retention times, molecular ions, and fragmentation patterns; those were then compared with reference spectral libraries in the NIST database (Joseph et al. 2020; Abadie et al. 2022). The measured parameters included retention time, mass–charge ratio (m/z), compound identities, and relative abundance.

2.5 Insect culture

Adult *Periplaneta americana* of both sexes were collected via baited traps during May 2022 from squidgy field habitats covered by both ornamental and crop plants nearby with floating trays prepared with brown sugar mixed in the center of the farm. Ripe mangoes and papayas were also implemented with C. capillata as attractants to draw American cockroaches to the stations. In the acclimatization study, the insects were maintained in perforated plastic containers in the laboratory at 27–30°C and 65–75% relative humidity (El-Khodary et al. 2020). The organisms used for the experimental bioassays were maintained exactly as described by Soonwera et al. (2022). Cockroaches were fed crumbled dog biscuits, powdered milk, bread, or 10% glucose solution and offered water ad libitum (Soonwera et al. 2022). Harborage was provided via egg cartons or facial tissues in the enclosure.

2.6 Bioassays

2.6.1 Contact toxicity

Contact toxicity was assessed via the residual route in a treated filter paper bioassay. Different concentrations of ethanol, methanol, chloroform, and hexane fractions from *Hyptis suaveolens* (L.) Poit., *Laurus nobilis* and *Ocimum sanctum* L. were made into circular filter paper discs that were left to completely dry. Ten adult *P. americana* (L.) were then introduced onto each set, and every treatment was independently established three times under controlled conditions (27 ± 2°C; 60–70% RH). This was promptly followed by a preliminary analysis, where 25, 50, 75, and 100 mg/mL concentrations of the extract were tested, each for 24, 48, 72, and 96 h, and mortality was recorded. Extracts that exhibited activity levels of 25 mg/mL and complete mortality within 24 h were judged to be appropriate and, consequently, were taken for actual testing at diluted concentrations. The insects were gently

immobilized with a gentle poke in accordance with standard cockroach contact bioassay protocols (El-Khodary et al., 2020; Ubulom et al., 2021; Soonwera et al., 2022).

2.6.2 Combined treatments

To assess the performance of the combined treatments, equal proportions of pairwise and triple mixtures of extracts were prepared at sublethal concentrations. These mixtures were applied under filter paper as mentioned previously, and adults of *P. americana* were steeped via the same experimental method. Mortality under magical treatments was compared with respect to mortality caused by an extract alone to determine if combining applications enhanced insecticidal activity.

2.6.3 Controls

The positive control was cypermethrin, whereas the negative controls were the corresponding solvents and distilled water. The control groups were maintained under the same conditions as the treated insects were. Abbott's correction was also used when natural mortalities occurred in controls (Akintan and Akinneye 2020; Ubulom et al. 2021).

2.7 Mortality and dose–response analysis

Mortality was expressed as a percentage of lethal effects for each treatment and concentration across replicates. If control mortality exceeded acceptable limits, it was adjusted via Abbott's formula (Akintan and Akinneye 2020). The dose response was then analyzed via probit regression to estimate the median lethal concentration range (LC_{50}) with its 95% confidence interval. The probit parameters were estimated via a machine-learning-assisted regression workflow.

2.8 Statistical analysis

The data were analyzed via one-way analysis of variance (ANOVA). Significant treatment effects were detected (Nasirian and Saghafipour 2021; Soonwera et al. 2022). The probit parameters were estimated via a machine-learning-assisted regression workflow.

2.9 Ethical and safety considerations

All procedures were carried out in accordance with the institution's ethical guidelines for insect research pertaining to welfare, with special consideration for the principles of reduction and refinement (Crump et al. 2023). Standard laboratory safety measures, including wearing gloves, face masks, and the use of sanitizers, were followed for both the sampling and bioassay procedures. Dead insects, plant residues, spent solvents, and other materials are discarded as per recommendations for proper laboratory waste management, minimizing environmental contamination (Ferraz et al. 2021).

3. RESULTS AND DISCUSSION

3.1 Phytochemical profile

On the basis of the phytochemical screening, a clear distinction arises between metabolites in *Hyptis suaveolens*, *Laurus nobilis*, and *Ocimum sanctum*, and the variations due to solvents in each case are unique (Table 1). Terpenoids were observed in all three species, whereas flavonoids, tannins, phenols, alkaloids, saponins, fatty acids, and sterols varied in accordance with the plant species and solvent. In general, the range of phytochemicals that were detected was greater with the methanol and ethanol extracts than with the chloroform and hexane extracts, indicating that the more polar solvents were able to extract a more chemically dissimilar material. In terms of the complete list of chemical constituents, *O. sanctum* presented the widest spectrum of phytochemicals, whereas *H. suaveolens* was set apart in terms of its reliance on terpenoids, its reliance on tannins disappeared, and *L. nobilis* was rich in terpenoids but had hardly detectable alkaloids. These kinds of variations have also been noted elsewhere, where the insecticidal potential of aromatic plants greatly depends upon the composition and quantity of secondary metabolites extractable from them, with rigidity to cancer, terpenoids, and phenolic compounds (Ojo et al. 2008). The vast differences in the chemical composition of the plants mentioned here might very well account for the different activities of the insects.

Table 1
Preliminary phytochemical profile of leaf extracts of *Hyptis suaveolens*, *Ocimum sanctum*, and *Laurus nobilis* obtained with different solvents

Phytochemicals	Ethanol	Methanol	Chloroform	Hexane
Hyptis suaveolens				
Alkaloids	–	+	–	–
Flavonoids	–	+	+	+
Tannins	+	+	+	–
Terpenoids	+	+	+	+
Saponins	–	–	–	–
Fatty acids	–	–	+	+
Sterols	–	–	+	+
Ocimum sanctum				
Alkaloids	–	–	+	+
Flavonoids	+	+	–	–
Tannins	+	+	+	+
Terpenoids	+	+	–	–
Saponins	+	+	+	+
Sterols	+	+	+	+
Phenols	+	+	–	–
Laurus nobilis				
Alkaloids	–	–	–	–
Flavonoids	+	+	–	–
Tannins	+	+	–	–
Terpenoids	+	+	+	+
Saponins	+	+	–	–
Fatty acids	–	–	–	+
Sterols	+	–	+	+
Phenols	+	+	–	–
+; Present: Absent				

3.2 GC–MS composition

GC–MS analysis allowed the chemical composition of the three plant fragments to be further discerned (Table 2). In *H. suaveolens*, stigmasta-3,5-diene (15.39%), β-caryophyllene (11.19%), and germacrene D (6.98%) were the major compounds. In *Ocimum sanctum*, euqenol (23.11%) was the dominant compound, together with minor compounds such as β-caryophyllene (7.51%), linalool (3.73%), and carvacrol (2.47%). In contrast, 1,8-cinéole (21.27%) was the chief compound in *L. nobilis*, followed by sabinene (5.33%), α-terpinyl acetate (2.33%), α-pinene (1.94%), and D-limonene (0.95%).

Table 2
Major constituents identified in the leaf extracts of *Hyptis suaveolens*, *Ocimum sanctum*, and *Laurus nobilis* via GC–MS analysis

Plant species	Major compounds identified	Relative abundance (%)
Hyptis suaveolens	Stigmasta-3,5-diene	15.39
	trans-Linalool oxide (furanoid)	0.96
	Geranyl isovalerate	1.39
	β-Caryophyllene	11.19
	Germacrene D	6.98
Ocimum sanctum	Eugenol	23.11
	Carvacrol	2.47
	β-Caryophyllene	7.51
	Linalool	3.73
Laurus nobilis	1,8-Cineole (eucalyptol)	21.27
	α-Terpinyl acetate	2.33
	D-Limonene	0.95
	Sabinene	5.33
	α-Pinene	1.94

These individual substances are biologically important because of their relatedness to insecticidal, fumigant, and repellent activities. For example, the oil of *H. suaveolens* is reported to have insecticidal, fumigant, and repellent effects, with β-caryophyllene known as one of the major active constituents (Tripathi and Upadhyay 2009). The oil of *O. sanctum* also presents broad-spectrum insecticidal activity (Núñez et al. 2018); however, the insecticidal activities of *L. nobilis* oil have been largely attributable to 1,8-cineoles. Therefore, the conclusions of the present study do not imply a direct association of bioactivity with individual components; instead, they provide a reasonable understanding of how chemicals potentially exhibit toxicity through bioassays.

3.3 Bioassay response

The results of the bioassays revealed that all three plant species exhibited good insecticidal activity against *P. americana*, although the extent and time of killing differed according to the type of extract, concentration and exposure time (Table 3). Generally, the number of killed insects increased with increasing concentration and time, indicating that the number of killed insects clearly increased in a dose- and time-dependent manner. Compared with the less polar extracts, the methanol and ethanol extract treatments generally induced death at a faster rate and higher percent mortality when analyzed together.

Table 3
Mortality (%) of *P. americana* exposed to different concentrations of plant leaf extracts and their combined formulation at different exposure periods

Plant	Solvent	Concentration (mg/mL)	24 hours (%)	48 hours (%)	72 hours (%)
H. suaveolens	Ethanol	5	22.33 ± 3.06	33.00 ± 6.00	49.67 ± 6.03
		10	41.67 ± 3.06	50.00 ± 7.00	66.33 ± 4.62
		15	90.00 ± 2.65	100.00 ± 0.00	100.00 ± 0.00
		20	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	Methanol	5	36.33 ± 3.06	64.33 ± 5.03	100.00 ± 0.00
		10	70.33 ± 6.11	100.00 ± 0.00	100.00 ± 0.00
		15	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
		20	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	Chloroform	5	20.33 ± 4.16	33.00 ± 5.29	62.67 ± 5.69
		10	40.67 ± 3.51	66.67 ± 3.06	93.33 ± 5.86
		15	64.33 ± 4.16	87.33 ± 2.52	100.00 ± 0.00
		20	65.00 ± 41.62	100.00 ± 0.00	100.00 ± 0.00
O. sanctum	Ethanol	5	17.00 ± 3.46	33.67 ± 4.16	57.33 ± 2.52
		10	31.00 ± 2.00	55.00 ± 2.00	70.67 ± 5.69
		15	68.33 ± 5.03	86.00 ± 4.58	100.00 ± 0.00
		20	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
	Methanol	5	32.33 ± 4.16	63.00 ± 5.29	100.00 ± 0.00

Plant	Solvent	Concentration (mg/mL)	24 hours (%)	48 hours (%)	72 hours (%)
		10	65.67 ± 4.51	90.33 ± 2.52	100.00 ± 0.00
		15	77.33 ± 3.79	100.00 ± 0.00	100.00 ± 0.00
		20	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
L. nobilis	Methanol	5	19.67 ± 4.04	43.33 ± 2.08	72.00 ± 4.36
		10	45.00 ± 5.29	67.33 ± 1.53	94.00 ± 5.20
		15	66.33 ± 3.06	96.67 ± 3.51	100.00 ± 0.00
		20	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
Synergistic extract	Combined solvent extracts	5	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
		10	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
		15	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00
		20	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00

Hyptis suaveolens showed total mortality within 24 h at 15 and 20 mg/mL concentrations of the methanol extract and within 72 h at 5 mg/mL. A strong effect of the ethanol extract caused 100% mortality when the mixture was exposed to 20 mg/mL ethanol at 24 and 15 mg/mL concentrations for 48 h. In contrast, the chloroform extract had a slower effect, particularly at lower concentrations. A similar system *was used for O. sanctum*, but the methanol extract was much more potent than the ethanol extract, especially at concentrations of 5–15 mg/mL. At 20 mg/mL, the methanol extract caused 100% mortality within 24 h and was confirmed at a concentration of 5 mg/mL after 72 h, whereas the ethanol extract caused 100% mortality at 20 mg/mL after 24 h and at 15 mg/mL after 72 h. The methanol extract of *L. nobilis* was also quite effective, although it acted slightly more slowly at lower concentrations than did *H. suaveolens* and *O. sanctum*. Remarkably, 100% mortality was observed at all concentrations and exposure periods for the combined extract, suggesting much greater activity under the present test conditions.

At lower test doses, methanol performed better overall. In particular, methanol from *Hyptis suaveolens* resulted in complete mortality at 5 mg/mL after 72 h and within 24 h at concentrations between 15 and 20 mg/mL, thus outperforming the corresponding ethanol and chloroform extracts. In comparison with ethanol, methanol was also significantly more active in both the escape test (5–15 mg/mL) and those concentrations where the crude material gave the best results. Whereas the methanol extract from *L. nobilis* was still fairly robust, its performance at low concentrations was somewhat less dramatic. All of these findings seem to prove that the methanolic extracts of *H. suaveolens* and *Ocimum sanctum* were the most precipitous among the respective tests in the current study, whereas methanol from *L. nobilis* was also significant in the late test. At lower test doses, methanol performed better overall. In particular, methanol from *Hyptis suaveolens* resulted in complete mortality at 5 mg/mL after 72 h and within 24 h at concentrations between 15 and 20 mg/mL, thus outperforming the corresponding ethanol and chloroform extracts. In comparison with ethanol, methanol was also significantly more active in both the escape test (5–15 mg/mL) and those concentrations where the crude material gave the best results. Whereas methanol from *L. nobilis* was still fairly robust, its performance at low concentrations was somewhat less dramatic. All of these findings seem to prove that the methanolic extracts of *Hyptis suaveolens* and *Ocimum sanctum* were the most precipitous among the respective tests in the present study, whereas the methanol extract from *L. nobilis* was also significant in the late test.

3.4 Probit analysis and implications for botanical control

The results of the probit analysis were consistent with the screening results and confirmed clear and considerable differences in the 24-hour toxicity of the extracts toward *P. americana* (Table 4). The most effective treatment was the combined extract, with the lowest LC50 value being ≤ 5.00 mg/mL, followed by extracts from *H. suaveolens* (6.19 mg/mL), *O. sanctum* (7.17 mg/mL), *H. suaveolens* (7.88 mg/mL), and *L. nobilis* (8.33 mg/mL), followed by *O. sanctum* (8.74 mg/mL), and finally, *H. suaveolens* (12.02 mg/mL). This order indicates that the methanol extract had the highest activity under the respective assay conditions, whereas the individual treatments were generally effective, with the methanol extract being the best extractor. The comparatively strong performance of the methanol and ethanol extracts of *H. suaveolens* further suggests that this species may provide relatively rapid insecticidal action.

Table 4
Probit regression parameters and 24-h LC_{50} values of selected plant extracts and their combined formulation against *P. americana*

Plant	Solvent	Slope (b)	Intercept (a)	R^2	LC_{50} (mg/mL)
H. suaveolens	Ethanol	6.831	-1.125	0.793	7.88
	Methanol	7.551	-0.978	0.861	6.19
	Chloroform	2.173	2.653	0.962	12.02
O. sanctum	Ethanol	6.699	-1.307	0.688	8.74
	Methanol	5.845	0.001	0.706	7.17
L. nobilis	Methanol	6.413	-0.905	0.686	8.33
Combined extract	Synergistic mixture	-	-	-	< 5.00

The different slopes of the probit model were also indicative of changes in the concentration–response. The greatest slope corresponds to most methanol extracts and ethanol extracts, whereas the chloroform extract of H. suaveolens has a lower slope, indicating weaker activity. Such discrete methods of determining the concentration–response have been described for plant-compound elements, such as eugenol and 1,8-cineole, but they cannot be compared with other studies, where variations in plant origin, extraction methods, insect stages, and testing conditions are clearly known (Pérez-Criado et al., 2010).

The observed toxicity might be explained on the basis of the chemical composition of the extract. *O. sanctum* likely possesses strong activity due to its high eugenol content; eugenol has been found to cause toxicity or to have repellent effects on *P. americana* and to interfere with neural function in insects (Senthoorraja et al. 2021). Additionally, the insecticidal characteristics of *L. nobilis* may be due to the presence of 1,8-cineole, which affects key physiological processes in insects (Baghazaoui et al. 2024). *H. suaveolens* presumably contains β-caryophyllene, germacrene D, and other related terpenoid constituents (Appiah et al. 2018). However, the present results suggest that the observed bioactivity may be due to the joint action of many constituents in each extract rather than to the action of a single compound.

A significant point of discussion is the interpretation of the combined formulations. Even though the latter generated maximum lethal activity, the existence of real synergy among the various plant species with respect to toxicity cannot be appropriately argued on the basis of the data at hand. Increased toxicity may accrue due to additive effects related to the interactions among the constituent compounds in each extract but not due to interspecific synergy. The real showmanship of synergic interactions can only be guaranteed further by more robust mixture-design analysis and a formal interaction test. However, the results of the aphid assay-guided fractionation clearly demonstrated that all three species have the potential to be very good sources of ingredients for managing *P. americana*, with the methanolic extracts showing the most robust activity. Among the individual treatment preparations, the methanol

extract of *H. suaveolens* was the most effective, followed by those of *O. sanctum and L. nobilis*. This study underscores the critical importance of solvent selection in maximizing the bioefficacy of extracted solutions and revealed that aromatic plants from the local domain might serve as sources of bioactive compounds for roach management. Future research directions call for bioassay-guided fractionation, systematic evaluation of combination treatments, mechanistic investigations, and formulation development for practical integrated pest management applications.

CONCLUSION

In the present study, the leaf extracts of *Hyptis suaveolens*, *Ocimum sanctum*, and *Laurus nobilis* demonstrated substantial insecticidal activity against *Periplaneta americana*, which was consistent with previous findings. The efficacies of different plant extracts with various solvents were profoundly different. The presence of various biologically active secondary metabolites, predominantly terpenoids and phenolic compounds, was confirmed through appropriate phytochemical screening and GC—MS analysis. However, beta-caryophyllene and germacrene D were found to be major compounds in H. suaveolens, whereas eugenol was present to some extent *in O. sanctum*, with 1,8-cineole becoming another major compound in L. nobilis. The bioassays at various concentrations and times revealed gradual mortality due to the treatments; this was better predicted by probit analysis. The combined formulations had the greatest effect on both treatments, with 100% mortality under the test conditions. The individual treatment of *H. suaveolens* resulted in greater insecticidal activity than the methanol extracts of *Ocimum sanctum* and *Laurus nobilis* did. The greater biological activity of the methanol extracts than that of their corresponding aqueous extracts indicates that the solvent polarity plays a significant role in the extraction of insecticidal constituents. Other aspects of primary importance, such as combining the best candidates for the development of botanical insecticides for the management of cockroaches, include the need for a more logical focus on smart bioassay-guided fractionation processes to facilitate the evaluation of interactions through sex, further treatment optimization, and safety evaluation under practical environmental conditions.

Declarations

Author Contributions

TCN Angaye designed the study and presented all the research procedures while gathering the plant samples and wrote all the sections of the research plan. RU Boate wrote the introduction while he managed the acquisition of test organisms. Both authors conducted the literature review, revised the manuscript critically for important intellectual content, and approved the final manuscript.

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Competing Interests

The authors declare that they have no competing interests.

Data availability

The datasets generated and/or analyzed during the current study are accessible through the corresponding author, who will provide them after receiving a valid request.

Ethics Approval

This study did not involve human participants. All applicable institutional and national guidelines for the handling and use of test organisms were followed.

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