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ORIGINAL ARTICLE

Comparative Toxicity of Synthetic and Botanical Gel Baits against *Periplaneta americana* (Blattodea: Blattidea)

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ABSTRACT

Cockroaches (*Periplaneta americana* L.) are ubiquitous pests implicated in disease transmission and allergies, making their control a public health priority. Synthetic gel baits are effective but raise environmental concerns, while botanical gels remain underexplored. This study compared the toxicity of two synthetic baits: fipronil and imidacloprid, and two botanical gel baits: sodom apple and neem-ginger gel baits against *P. americana*. Oils were extracted via hydrodistillation (ginger) and soxhlet procedures (neem and sodom apple), characterized by GC–MS, and formulated into peanut-based gels. Baits were tested at dosages of 0.5 g, 1.0 g, 1.5 g, and 2.0 g per treatment, with controls consisting of peanut gel and bait matrix, replicated four times with 10 cockroaches per container without active ingredients. Mortality data were analyzed using a one-way ANOVA regression analysis. Extracted oils showed neem's dominance in fatty acids, ginger's richness in terpenoids and phenolics, and sodom apple's diverse ester composition. Laboratory assays demonstrated that imidacloprid (2%) and fipronil (0.05%) achieved 100% and 93.75% mortality in *P. americana* at 18 h, respectively, while the neem–ginger gel (20%) produced progressive, dose-dependent mortality up to 81.25% at 24 h. In contrast, sodom apple gel (20%) showed limited efficacy at 16.25% mortality. Probit analysis confirmed potency differences, with LC_{50} at 24 h values of 0.028 g (fipronil), 0.836 g (neem–ginger), and 2.13 g (sodom apple). These findings provide the first evidence that neem–ginger gels can serve as ingestion-based, ecofriendly alternatives to synthetic cockroach baits, supporting their potential integration into sustainable pest management programs.

Keywords: Fipronil; Imidacloprid; Neem–ginger; Sodom apple oil; *Periplaneta americana*; Gel bait formulation; GC–MS.

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1.0 INTRODUCTION

The American cockroach (*Periplaneta americana*) is among the most significant urban pests worldwide, infesting homes, hospitals, food industries, residential buildings, and sewer systems. They are strongly associated with filth and act as mechanical transmitters of numerous microorganisms, including bacteria and fungi, while also triggering allergies and asthma (Arruda, 2001; Arruda et al., 2005; Davari et al., 2018; Padonou et al., 2023; Rahayu et al., 2025; Wannigama et al., 2014). For decades, control strategies have relied heavily on spray formulations of pyrethroids, carbamates, and organophosphates. However, widespread resistance and growing concerns about human exposure and environmental contamination have raised questions about the continued use of these liquid formulations (Gondhalekar et al., 2011; DeVries et al., 2019; Hu et al., 2020; Lee et al., 2022). Pesticide formulations remain an essential component of Integrated Pest Management (IPM), which incorporates knowledge of insect behaviour into control strategies while prioritizing safety and compatibility. Gel bait formulations, in particular, have become vital tools in advanced cockroach control (Miller & Smith, 2020). These baits combine an attractive food matrix with a toxic active ingredient and are typically applied in small spots or thin lines within cracks and crevices where cockroaches forage. Gel insecticides have been widely used against *Blattella germanica* and *Periplaneta americana*. Common active ingredients include fipronil, hydramethylnon, indoxacarb, imidacloprid, clothianidin, boric acid, abamectin, and dinotefuran (Hamilton et al., 2023). Laboratory and field studies consistently report that commercial gel baits produce rapid and high mortality (>80–95%) in German and American cockroach populations, with effects lasting several weeks to months in kitchens, residential structures, and sewer systems. Gel baits offer targeted control, significantly reducing pesticide residues on indoor surfaces, making them suitable for do-it-yourself applications and crucial in sensitive environments such as affordable housing and healthcare facilities (Neupane & Kafle, 2019; Gordon et al., 2025). The success of gel baits among insect populations lies in ensuring voluntary ingestion even in the presence of alternative food sources, while formulations can be tailored or rotated to maintain acceptance and avoid behavioural avoidance. Many gels contain slow-acting insecticides that allow cockroaches to return to harborages before dying, facilitating the transfer of toxicants via coprophagy and necrophagy, thereby generating secondary and tertiary mortality within aggregations (Hamilton et al., 2023; Lucero & DeVries, 2025). Recent studies have highlighted the potential of essential oils and plant-derived compounds as potent, biodegradable, and eco-friendly alternatives to synthetic pesticides (Gupta et al., 2023). Botanical insecticides, though rarely formulated into gels, represent a promising alternative for sustainable cockroach control. *Calotropis procera* (sodom

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apple), a medicinal plant distributed across tropical regions, contains bioactive compounds such as cardenolides, alkaloids, and flavonoids with insecticidal and growth-disrupting properties (Arya et al., 2010; Ahmad et al., 2023; Ranjan et al., 2025). All parts of the plant have been reported to be toxic, with the stem and root more toxic than the leaves (Wadhwani et al., 2021;Kilani-Morakchi, 2021). The laticifer proteins in the plant have been confirmed to contain biopesticide properties after being assayed against pests of different crops; likewise, they have larvicidal activities against some vector species, such as mosquitoes and houseflies (Wadhwani, et al., 2021). Similarly, neem (*Azadirachta indica*) is well recognized for its pesticidal activity, with azadirachtin and related limonoids exerting insecticidal, antifeedant, nematicidal, and growth-regulating effects (Ogbonna and Uchenna, 2023 ; Sambo et al., 2024; Amadou et al., 2025; Ogbinaka et al., 2025). At 100 ppm, neem gum nano-plan has been demonstrated to have 100% insecticidal, larvicidal, antifeedant, and pupicidal effects against *Helicoverpa armigera* (Hub.) and *Spodoptera litura* (Fab.) (Dimetry, 2020). Ginger (*Zingiber officinale*), rich in phenolic compounds such as gingerol and shogaol, may enhance insecticidal efficacy through synergistic action when combined with other botanicals (Al-Rowaily et al., 2020; Vigad et al., 2025). The studies by Liu et al. (2022) found that the ginger shoot extract significantly inhibited the longevity and molting of aphids, thereby increasing their mortality.

Gel deposits can remain effective for weeks to months under typical indoor humidity conditions; however, aging, contamination, and mold growth may alter consumption and performance (DeVries et al., 2019; Lee et al., 2022). Increasing reports of reduced susceptibility and cross-resistance to bait active ingredients underscore the need for resistance monitoring, product rotation, and the integration of baits with non-chemical botanical tactics to sustain long-term control (Wang et al., 2022). Hence, this study investigates the comparative effectiveness of synthetic insecticides, fipronil and imidacloprid, against botanical gels, evaluating their potential to serve as eco-friendly alternatives.

2.0 MATERIALS AND METHODS

2.1 Collection of *Periplaneta americana*

Wild *P. americana* were collected from septic tanks, drainages, and waste disposal areas in the Yaba environs of Lagos State, Nigeria. This area experiences a high influx of people with a high presence of human activities, generating a lot of waste. After capture, cockroaches were maintained in 4 L transparent plastic containers with pinhole-perforated lids to allow aeration. Experimental boxes consisted of clear plastic containers perforated with heated needles to ensure adequate ventilation and prevent asphyxiation, while the sides had Vaseline smeared on the wall of the containers to also restrict the roaches from running out of the container. Newspapers were used to line the floor of each container, providing a suitable environment for the cockroaches. They were fed with soft coaster biscuits and peanut butter. Water was provided via wet cotton wool.

2.2 Synthetic insecticides used

Fipronil gel was purchased from the open market in Lagos State, while imidacloprid was obtained as a solution concentrate due to the absence of a commercial gel formulation.

2.3 Plant material collection and preparation

Leaves of *Calotropis procera* (commonly known as Sodom apple) were plucked from trees located within the premises of Yaba College of Technology, Yaba, Lagos State (6.5165° N, 3.3752° E). Mature seeds of *Azadirachta indica* (neem) were collected directly from neem trees along the Lekki corridor in Lagos State (6.43° N, 3.48° E). Fresh rhizomes of *Zingiber officinale* (ginger) were obtained from a local market in Yaba, Lagos State. Leaves of *Calotropis procera* (sodom apple) and seeds of *Azadirachta indica* (neem) were collected and subsequently identified and authenticated by the curator at the Herbarium, Department of Botany, University of Lagos. Voucher specimens were deposited at the herbarium with the following accession numbers: *Azadirachta indica*-LUH 100781; *Calotropis procera*-LUH 100762. They were rinsed with distilled water to eliminate surface debris, and oven-dried at 40ºC till constant weight was obtained. The dried samples were ground into fine powder using a Ninja blending device. Powders were stored in clean one-litre containers until further processing. Subsequently, oil extraction and chemical characterization using GC-MS analysis were carried out at the Department of Pharmacognosy, Faculty of Pharmacy, University of Lagos, Idi-Araba, Lagos State, Nigeria.

2.4 Soxhlet extraction of *Azadirachta indica* (Neem) and *Calotropis procera* (Sodom Apple) oils

Oil extraction of the seeds of *A. indica* and leaves of *C. procera* was carried out using *n-hexane* as a solvent in a Soxhlet apparatus, respectively. Approximately 250 mL of analytical-grade n-hexane was placed in the distillation flask, and the ground neem seed sample was loaded into the thimble. The extraction was allowed to proceed for 6–8 h under reflux conditions until the solvent in the siphon tube became clear, indicating exhaustive extraction. The solvent-oil mixture was concentrated by rotary evaporation at 40 to 45°C to remove n-hexane. The crude neem oil obtained was weighed, and the extracted oil was stored in amber glass bottles at 4°C until further analysis to prevent oxidation and degradation. The yield was calculated as:

$$\text{Oil yield (\%)} \frac{weight\ of\ extract\ oil}{weight\ of\ seed\ sample} \times 100 \quad (1)$$

2.4.1 Hydro-steam distillation

Ginger oil was extracted via hydro-steam distillation using the Clevenger apparatus. The dried sample of ginger (500 g) was taken in a 2 L round-bottom flask. Then distilled water was added according to the ratio 2:1 (1000 mL distilled water for 500 g sample) and subjected to steam distillation for 3 h using a modified Clevenger-type glass apparatus. The volatile distillate was collected and stored in an airtight amber bottle container at 2 to 10ºC before usage (Fitriady et al., 2017).

2.4.2 GC-MS analysis of Sodom apple oil, neem and ginger oil

GC-MS analyses of the oils of *C. procera, A. indica,* and *Z. officinale* extracts were performed using an Agilent 5977B GC/MSD system coupled with an Agilent 88 60 auto-sampler, a gas chromatograph interfaced to a mass spectrometer (GC-MS) equipped with an Elite-5MS (5% diphenyl/95% dimethyl polysiloxane) fused capillary column (30 × 0.25 µm ID × 0.25 µm df). For GC-MS detection, an electron ionisation system was operated in electron-impact mode with an ionisation energy of 70 eV. Helium gas (99.999%) was used as a carrier gas at a constant flow rate of 1 ml/min, and an injection volume of 1 µL was employed (a split ratio of 10:1). Five (5) point serial dilution calibration standards (1.25, 2.5, 5.0, 10.0 ppm) were prepared from the stock solution of 40 ppm and used to calibrate the GC-MS. The injector temperature was maintained at 300°C, the ion-source temperature was 250°C, and the oven temperature was programmed from 100°C (isothermal for 0.5 min.), with an increase of 20 °C/min to 280°C (2.5 min.), Mass. spectra were taken at 70 eV; a scanning interval of 0.5 s and fragments from 45 to 450 Da. The solvent delay was 0 to 3 min., and the total GC/MS running time was 21.33 min. (Loganathan et al., 2021).

2.4.3 Identification of photo components

Interpretation of the mass spectrum GC-MS was conducted using the database of the National Institute of Standard and Technology (NIST) having more than 62,000 patterns, and the Center for Biotechnology Information. The spectrum of the unknown components was compared with the spectrum of known components stored in the NIST library.

2.5 Gel bait formulation

2.5.1 Peanut butter processing

Fresh peanuts (3.0 kg) were sourced from the Oyingbo local market in Lagos and roasted until the flavour was perceived and the crunchiness observed. This was milled into a thick, oily paste and kept in a 2-litre container till needed.

2.5.2 Gel bait matrix formulation

Gel bait was prepared using peanut butter as the main bait owing to its strong attractant properties for cockroaches. Soft paste was produced by homogenising 280 g of peanut butter with 50 g of sorbitol, 8 g of sodium bicarbonate (Aboagye et al., 2025), 10 mL of dimethyl sulfoxide (DMSO), and 100 mL of distilled water until a uniform consistency was achieved. The gel bait matrix was carefully homogenised and kept in a 2-litre container until needed. Peanut butter served as the nutritive base and attractant (Khoobdel et al., 2022; Aboagye et al., 2025) while sorbitol acted as a humectant to retain moisture and maintain the gel texture. Sodium bicarbonate was included as a buffering agent to stabilise the formulation, and DMSO was added to enhance the solubility and dispersion of the active

ingredient. Distilled water provided the aqueous phase necessary for homogenization. Protective gloves and a fume hood were used for safety, especially while handling DMSO.

2.5.3 Synthetic chemicals

Fipronil gel bait was obtained commercially. Imidacloprid was sourced as a 200 g/L liquid formulation from a pest shop at Idumagbo, Lagos. 8.2 mL of imidacloprid was added to 80 g of bait matrix gel at a 2% v/w concentration. The mixture was homogenised thoroughly and dispensed into 50 mL syringes for easy dispensing. Prepared gels were stored under ambient laboratory conditions until further use.

2.5.4 Botanical mix

Two botanical gels were formulated: Sodom apple gel and Neem-ginger gel matrix. Oil of *C. procera* was incorporated into bait formulations by adding 16 mL of oil to 80 g of food bait matrix, yielding approximately 20% v/w concentration. Neem ginger oil was achieved by mixing 60 mL of neem oil with 40 mL of ginger oil. Sixteen milliL (16 mL) of this neem-ginger mixture was incorporated into 80 g of bait matrix, producing 20% v/w. The mixture was homogenised thoroughly with a hand-held mixer to achieve uniform consistency and dispensed into labelled and calibrated 50 ml syringes for accurate delivery during assays, respectively.

2.5.5 Control

A formulated bait matrix without any insecticides was used as the negative control, while peanut butter bait was also evaluated for possible toxicity to *P. americana,* respectively.

2.6 Laboratory toxicity assays

2.6.1 Experimental setup

Laboratory toxicity assays were conducted under standardised conditions. Rectangular plastic containers (4 L) were used, lids were perforated to allow aeration. Paper sheets were placed inside each box to line the containers, while filter papers were cut into smaller units and used as bait stations within the container. Baits were weighed and placed at the corners of the rectangular boxes, with each concentration of 0.5 g, 1.0 g, 1.5 g and 2.0 g weighed and replicated three times across containers. Ten adult *P. americana* were introduced per box after a 24 h starvation period (water provided ad libitum). Experimental treatments included two synthetic baits: fipronil and imidacloprid, and two botanical gel baits: *C. procera* (Sodom apple) and neem-ginger gel bait. Peanut gel alone and the bait gel matrix (control) without any of the synthetic and botanical insecticides. These were also evaluated for toxicity response in *P. americana* populations.

2.6.2 Observation and monitoring

Observations were made every three h to track toxic responses within 24 h. Mortality was confirmed by a lack of movement and no response when touched.

$$Mortality\ (\%)\ \frac{Total\ number\ of\ cockroaches\ exposed}{Number\ of\ dead\ cockroaches} \times 100 \quad (2)$$

Corrected mortality was calculated using Abbott's formula (Abbott, 1925):

$$C.Mort\ (\%) = \frac{Observed\ mortality\ in\ treatment - observed\ in\ control}{100 - observed\ mortality\ in\ control} \times 100 \quad (3)$$

2.6.3 Statistical analysis

Mortality data were analyzed using one-way analysis of variance (ANOVA), and significant differences across means were separated at $p < 0.05$ using Tukey's post hoc test. Linear regression analysis was performed to estimate the rate of mortality progression, with regression equations and coefficients of determination (R^2) calculated for each dose. Mortality data were log-transformed and subjected to probit analysis to estimate lethal concentration values (LC_{50}) and compare relative potency among treatments. Regression slopes and probit parameters were used to quantify dose-dependent efficacy. Statistical analyses were performed using GraphPad Prism version 10.6.1 (GraphPad Software, San Diego, CA, USA).

3.0 RESULTS

3.1 Chemical characterization of neem seed oil, ginger oil and sodom apple oil

Chemical characterization of neem seed oil (NSO) showed seven major peaks between 13.7 and 15.4 minutes, consistent with long-chain fatty acids. The major constituents were oleic acid (26.21%), linoleic acid (18.05%), palmitic acid (20.45% combined from two peaks), and stearic acid (14.12%). Together, these four fatty acids accounted for over 78% of the total composition, indicating that NSO is rich in both saturated and unsaturated fatty acids (Table 1). In contrast, the chemical profile of ginger oil was dominated by terpenoids and phenolic compounds. Cyclohexadiene derivatives (20.63%), β-farnesene (9.51%), α-farnesene (7.62%), and eugenol (6.92%) were the most abundant constituents (Table 2). Sodom apple oil exhibited a diverse composition of terpenes, fatty acids, and esters. The major compounds were ethyl 9, 12, 15-octadecatrienoate (29.71%), oleic acid (22.28%), n-hexadecanoic acid (17.67%), and linoleic acid ethyl ester (12.33%), which together accounted for more than 80% of the total composition (Table 3).

Table **1.** Chemical characterization of neem seed oil *Azadirachta indica*

Peak No.	Retention Time (min)	Compound Identified	CAS No.	Area %	Match Quality (%)
1	13.742	n-Hexadecanoic acid (Palmitic acid)	57-10-3	12.66	98–99
2	13.793	n-Hexadecanoic acid (Palmitic acid)	57-10-3	7.79	98–99
3	15.098	9,12-Octadecadienoic acid (Linoleic acid); cis-13-Octadecenoic acid; cis-Vaccenic acid	60-33-3;13126-39-1; 506-17-2	12.65	96-97
4	15.195	9,12-Octadecadienoic acid (Linoleic acid); cis-13-Octadecenoic acid	60-33-3 / 13126-39-1	18.05	96–97
5	15.292	Oleic acid; 9-Octadecenoic acid (E)	112-80-1 / 112-79-8	26.21	98–99
6	15.327	Oleic acid; cis-Vaccenic acid	112-80-1 / 506-17-2	8.52	99
7	15.435	Octadecanoic acid (Stearic acid)	57-11-4	14.12	90–99

Table **2.** Chemical composition of ginger oil *Zingiber officinale* Roscoe

Peak No.	Retention Time (min)	Compound Identified	CAS No.	Area %	Match Quality (%)
1	3.711	Eucalyptol	470-82-6	2.08	98
2	5.525	endo-Borneol	507-70-0	1.33	97
3	5.828	α-Terpineol	98-55-5	0.69	91
4	5.931	Decanal	112-31-2	0.81	98
5	6.274	Citronellol	106-22-9	1.68	96
6	7.939	Eugenol	97-53-0	6.92	98
7	8.18	Germacrene a	28387-44-2	0.76	99
8	8.529	Caryophyllene	87-44-5	2.31	99

9	8.866	Humulene	6753-98-6	0.81	78
10	9.17	Benzene derivatives	644-30-4	4.06	97
11	9.444	Cyclohexadiene derivatives	495-60-3	20.63	94
12	9.519	α-Farnesene	502-61-4	7.62	87
13	9.725	(E)-β-Farnesene	18794-84-8	9.51	98
14	9.94	Cyclohexanemethanol derivatives	—	4.06	95

Table **3.** Chemical composition of sodom apple oil *Calotropis procera*

Peak No.	Retention Time (min)	Compound Identified	CAS No.	Area %	Match Quality (%)
1	3.894	D-Limonene	5989-2-5	1.26	94
2	12.683	Neophytadiene	504-96-1	0.74	91
3	12.735	2-Pentadecanone, 6,10,14-trimethyl-	502-69-2	0.93	91
4	13.799	n-Hexadecanoic acid (Palmitic acid)	57-10-3	17.67	99
5	14.005	Hexadecanoic acid, ethyl ester	628-97-7	7.02	98
6	14.806	9,12-Octadecadienoic acid (Z,Z) methyl ester	112-63-0	0.95	99
7	14.858	9,12,15-Octadecatrienoic acid methyl ester (Z,Z,Z)	301-00-8	1.76	98
8	14.938	Neophytadiene / epoxy derivatives	504-96-1	0.94	86
9	15.207	Oleic acid	112-80-1	22.28	97
10	15.321	Linoleic acid ethyl ester	544-35-4	12.33	99
11	15.373	Ethyl 9,12,15-octadecatrienoate	1191-41-9	29.71	99
12	15.573	Octadecanoic acid ethyl ester (Stearic acid ester)	111-61-5	1	95
13	17.524	Squalene	111-02-4	3.39	90

3.2 Mortality rates of *P. americana* exposed to synthetic and botanical insecticides

Figure 1 shows the rates of mortality in populations of *P. americana* exposed to four treatments over time. Synthetic gels (fipronil and imidacloprid) were significantly more effective, as indicated by the rapid mortality observed in the cockroach populations exposed. Fipronil gel (0.05%) produced rapid and sustained mortality, attaining 81.25% and 93.75% after 12 and 18 h, respectively. At the early onset (3–9 h), fipronil and imidacloprid produced significantly higher mortality compared to neem-ginger, Sodom apple, and controls. By 12 h, fipronil (81.25 ± 7.48%) and imidacloprid (68.75 ± 8.27%) were significantly more effective than neem-ginger (42.50 ± 9.79%) and Sodom apple (6.88 ± 3.66%) at $p < 0.05$. At 15–24 hr, imidacloprid and fipronil were statistically different, both producing 95–100 % mortality of *P. americana*, while neem-ginger remained moderately effective (81.25 ± 8.35% at 24 h). Sodom apple gel showed consistently low mortality (16.25% ± 3.45% at 24 h) (Figure 1). Botanical formulations acted more slowly and were less potent. The neem-ginger gel produced a gradual, dose-dependent mortality, while the gel base matrix alone caused negligible effects among *P. americana* populations fed with the gel base matrix after 24 h. Peanut butter paste (food attractant) showed no mortality, confirming the toxicity of the synthetic and botanical mix (Figure 1). Similarly, Table 4 shows the mean mortality among *P. americana* populations exposed to different gel baits at 24 h.

Table **4**. Mean mortality percentages and standard errors at 24 h of *Periplaneta americana* populations exposed to each treatment

Gel bait matrix	Mean mortality (%)	Standard error
Fipronil gel (0.05%)	93.75	6.25
Imidacloprid (20%)	100a	0
Neem–ginger mix gel (20%)	81.25ab	8.35
Sodom apple gel	16.25c	3.45
Gel base matrx only	3.75d	3.75
Peanut butter paste only	0	0

Different superscript letter a,b,c,d indicate statistically significant differences among treatments at p < *0.05 (Tukey's post hoc test)*

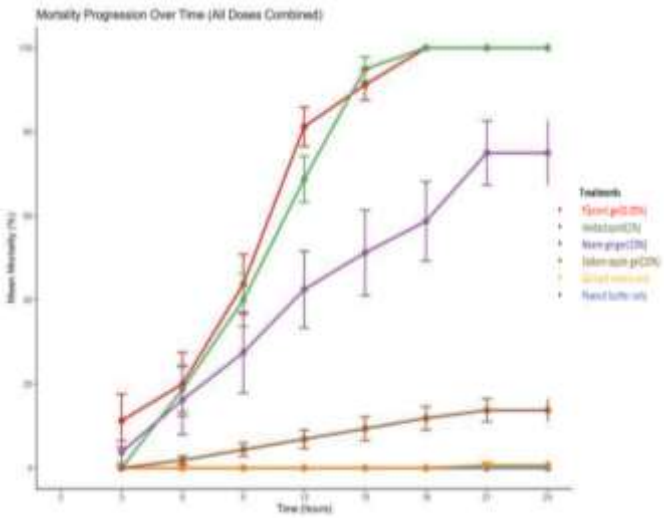


Figure 1. Mortality progression of cockroaches exposed to synthetic and botanical gel formulations at 24 h

3.3 Dose–response dynamics in fipronil, imidacloprid, neem–ginger, and sodom apple gels

Figure 2 shows the distinct differences in the mortality of populations of *P. americana* observed across treatments and doses. Mortality increased rapidly with time among populations exposed to fipronil (0.05 %), as indicated by the steep regression slopes (1.54–1.89) and moderately high coefficients of determination (R^2 = *0.53–0.86*). Similarly, imidacloprid (2 %) produced steep slopes (1.54–1.83) with high R^2 values (0.84–0.94), demonstrating a better fit and rapid mortality progression. In contrast, Sodom apple gel exhibited much lower slopes (0.16–0.19), while the regression models maintained high R^2 values (0.87–0.92). This suggests that while Sodom apple produced weak toxicity, its effects were consistent and predictable across doses. The neem-ginger mix gel (20%) showed slopes comparable to synthetic insecticides (1.54–1.83) with R^2 values ranging from 0.84–0.94. Mortality increased steadily, with variability observed at higher doses, reflecting the combined bioactivity of neem and

ginger extracts. The gel base matrix produced minimal slopes (0.14–0.16) with moderate R^2 values (0.89–0.93), confirming its inert nature and validating its role as a negative control. Similarly, peanut butter paste showed no measurable regression parameters, indicating negligible toxicity (Figure 2).

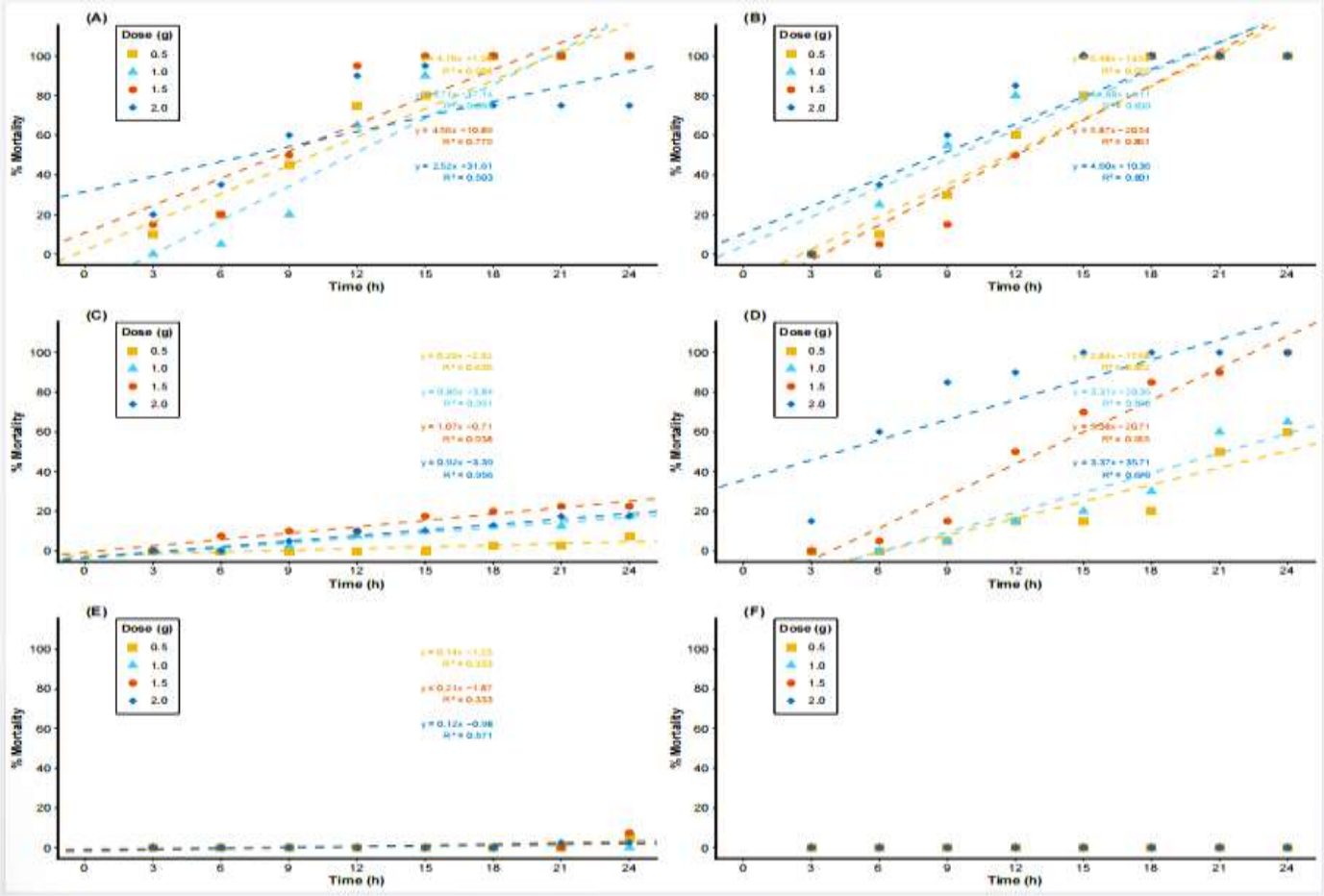


*Figure **2**. Dose–Time Mortality Relationships in Cockroach Populations Exposed to Synthetic and Botanical Gel Formulations. Plots : a: fipronil gel b: imidacloprid gel c: Sodom apple based gel d: neem-ginger based gel e: bait matrix only e: peanut butter only*

he tested dose range.

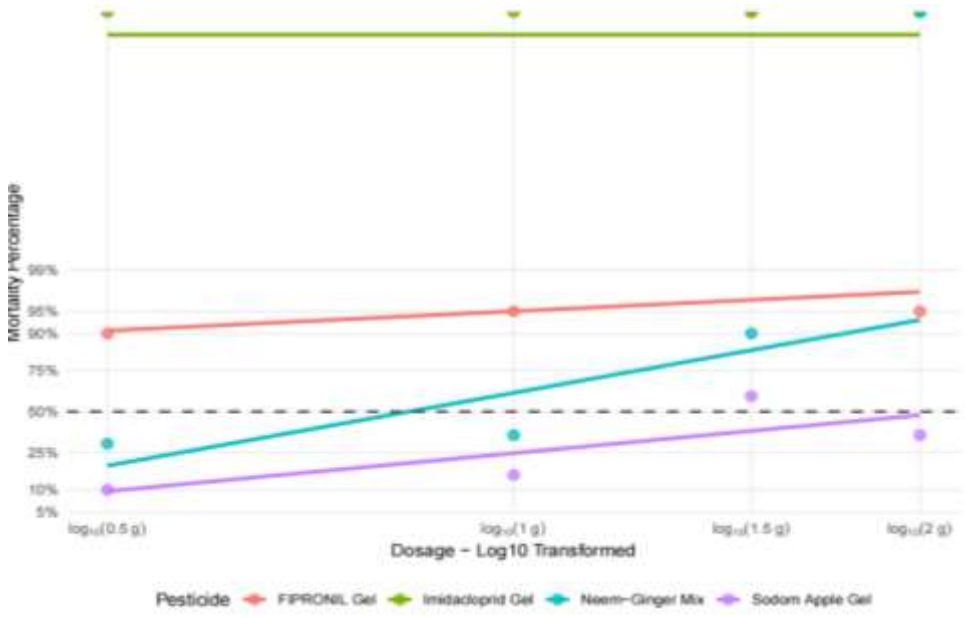


*Figure **3**. Comparative probit analysis of pesticide potency at 24 h. Mortality (%) is plotted against log10-transformed dosage. Confidence intervals are shown as shaded bands. Dashed line indicates LC_{50} threshold.*

3.3 Comparative potency of synthetic and botanical gel baits based on LC_{50} estimates

The probit analysis showed distinct differences in the lethal concentrations (LC_{50}) of the tested gel baits against *P. americana* (Figure 3). Fipronil gel exhibited the highest potency, with the lowest LC_{50} value of 0.028 g (95% CI: 0.018–0.037), indicating rapid and effective toxicity. The neem–ginger mix gel demonstrated moderate efficacy, with an LC_{50} of 0.836 g (95% CI: 0.60–1.10), and showed a strong dose-dependent increase in mortality across the exposed populations. In contrast, sodom apple gel was the least effective, with an LC_{50} of 2.13 g (95% CI: 1.55–2.70), reflecting limited insecticidal potential. The imidacloprid gel produced inconsistent results, and its LC_{50} could not be conclusively determined within time

4.0 DISCUSSION

This study compared the toxic effects of synthetic gels and botanical gels against *Periplaneta americana.* While the effects of the synthetic gels fipronil and imidacloprid are well known, the impact of the neem-ginger gel, as well as the sodom apple oil-based gel when used as baits against *P. americana* are first presented. The neem ginger gel bait exhibited a comparable effect with the synthetic baits, though it was slower against *P. americana* which further strengthens ecofriendly options for cockroach control with an emphasis on an integrated approach. The effect observed from the GC–MS analysis confirmed that neem seed oil was dominated by long-chain fatty acids such as oleic, linoleic, palmitic, and stearic acids, which are known to disrupt insect cuticular lipids and interfere with feeding behavior. Although azadirachtin was not detected due to its thermolabile nature and the limitations of GC–MS, its presence in neem oil is well documented in the literature and contributes to neem's established role as an antifeedant and growth regulator (Schmutterer, 1990; Ismaila et al.,2022; Cabral et al., 2023; Michel et al., 2023). Ginger oil, in contrast, was rich in terpenoids and phenolic compounds, including eugenol, farnesene, and cyclohexadiene derivatives, consistent with earlier reports (Sharma et al., 2016; Nour et al., 2017; El-Khodary et al., 2020). These compounds are traditionally associated with repellency, but they also possess neurotoxic properties that enhance insecticidal activity when combined with neem. This is consistent with the findings of Hamada et al. (2018), who reported significant toxicity of ginger oil against the cotton leafworm (*Spodoptera littoralis*), emphasizing the broader evidence that ginger's phenolic and terpenoid compounds contribute to insecticidal activity. In contrast, sodom apple oil exhibited a diverse ester profile dominated by ethyl linolenate and oleic acid, in agreement with previous studies reported by Mettwally et al. (2022). However, its insecticidal potential as gel baits was comparatively weak in this study, though its effects were consistent and predictable across doses. Synthetic gels containing fipronil and imidacloprid produced rapid and near-complete mortality in *P. americana* populations within 24 h, consistent with previous reports attributing their effectiveness to high potency and fast action (Davari et al., 2018; Hamilton et al., 2023; Abdullah & Majid, 2023; Padonou et al., 2023). In contrast, botanical gels exhibited slower activity. The neem–ginger gel produced significant, dose-dependent mortality, with regression slopes comparable to synthetic gels, while sodom apple gel showed minimal efficacy. Probit analysis confirmed these differences, with fipronil exhibiting the lowest LC_{50}, neem–ginger demonstrating moderate potency, and sodom apple the least effective. The ingestion-based toxicity observed with neem–ginger gels is consistent with earlier reports of neem formulations disrupting digestive processes and interfering with molting hormones (Chinnaperumal et al., 2018; Madreseh-Ghahfarokhi et al., 2018; Michel et al., 2023). Hamada et al. (2018), Liu et al.(2022), Sinha & Ray, (2024), and Umohata et al., (2024) also confirmed the neurotoxic effects of ginger's terpenoids on insects, which may have played key roles in the mortality observed during this study. Together, these mechanisms explain the steady mortality progression observed during the bioassays. Importantly, the regression slopes of neem–ginger gels were comparable to synthetic gels, indicating strong dose–response dynamics despite a slower onset. Also, bait matrix composition plays crucial roles in acceptance, odour masking, and consumption. Roasted peanut butter is known as a strong attractant for cockroaches ensuring voluntary ingestion in *P. americana* (Khoobdel et al., 2022). Similarly, humectants such as sorbitol help maintain gel texture and moisture, prolonging bait palatability and effectiveness (Aboagye et al., 2025). To our knowledge, no published work has evaluated the combined use of neem and ginger oils in gel bait formulations.

This study therefore provides significant evidence that botanical gels can serve as eco-friendly alternatives to conventional synthetic baits. While synthetic gels remain superior in speed and potency, neem–ginger gels offers a sustainable option with reduced environmental risk. Future research should focus on bait consumption patterns, multispecies responses, horizontal transfers across populations, and field performance to validate laboratory findings and optimize botanical gel formulations for integrated pest management.

Conclusion

This study shows the comparative toxicity of two synthetic gels (fipronil and imidacloprid) and two botanical gels (neem–ginger and sodom apple) against *Periplaneta americana*. Synthetic gels caused almost 100% mortality at 24 h confirming their potency. The neem–ginger gel achieved progressive, dose-dependent mortality up to 81% at 24 h, supported by its LC_{50} value (0.836 g), highlighting its potential as an eco-friendly alternative. In contrast, the sodom apple gel exhibited limited efficacy, underscoring the variability of botanical formulations. While sodom apple was observed to possess a lower toxic effect within the cockroach populations, neem–ginger showed some level of toxicity that can be harnessed for further research. Leveraging the complementary insecticidal mechanisms of neem and ginger, alongside formulation adjuvants that enhanced palatability and delivery, more research is hereby necessary. The integration of neem–ginger gels into cockroach management programs offers a sustainable option that reduces total reliance on synthetic insecticides, minimizes environmental contamination, and aligns with integrated pest management principles. This work provides the first evidence that neem–ginger gels can serve as ingestion-based baits for urban cockroach control, providing direction for future development and application in sensitive environments such as homes, hospitals, and food industries.

Ethical approval and consent for publication

Not applicable

Conflict of Interest

The authors declare no conflict of interest regarding the publication of this article

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Authors contribution

BBA Conceptualization, Data curation, Methodology, formal analysis, writing, review(PAT) and editing.AAA:Data curation, investigation; KNE, Data curation and investigation; KDI and JCA investigation and Manuscript review.

REFERENCES

Abbott, W. S. (1925). A method of computing the effectiveness of an insecticide. *Journal of Economic Entomology,* 18(2): 265–267. https://doi.org/10.1093/jee/18.2.265.

Abdullah, N. & Majid, A. (2023). Efficacy and toxicity of cockroach gel bait (imidacloprid 2.5% and fipronil 0.05%) against American cockroach infestation in sewer system. *Heliyon*, 9:1, e12833. https://doi.org/10.1016/j.heliyon.2023.e12833.

Aboagye, I., Lartey, A., Anim, F. & Billah, M. (2025). Non-insecticidal control of domestic and peri-domestic species of cockroach. *The Journal of Basic and Applied Zoology,* 86:447. https://doi.org/10.1186/s41936-025-00447-4

Ahmad Nejhad, A., Alizadeh Behbahani, B., Hojjati, M., Vasiee, A. and Mehrnia, M. A. (2023). Identification of phytochemical, antioxidant, anticancer and antimicrobial potential of *Calotropis procera* leaf aqueous extract. *Scientific Reports*, 13(1): 14716. https://doi.org/10.1038/s41598-023-42086-1

Al-Rowaily, S. L., Abd-ElGawad, A. M., Assaeed, A. M., Elgamal, A. M., Gendy, A. E.-N. G. E., Mohamed, T. A., Dar, B. A., Mohamed, T. K. and Elshamy, A. I. (2020). Essential Oil of *Calotropis procera*: Comparative Chemical Profiles, Antimicrobial Activity, and

Allelopathic Potential on Weeds. *Molecules,* 25(21): 5203. https://doi.org/10.3390/molecules25215203

Amadou, L., Abdoulaye, O., Baoua, I. B., Souleymane, A. S., Oumarou, M. N., Yarifou, R., Ibrahim, L., Lamine, S., Aminou, A. M. and Kpindou, O. K. D. (2025). Effect of neem seed-based biopesticides and hygienized human urine (HHU) on the main insect pests of cowpea [*Vigna unguiculata* (L.) Walp.] in Niger. *American Journal of Plant Sciences,* 16(2): 195–215. https://www.scirp.org/journal/ajps

Arruda LK, Vailes LD, Ferriani VP, et al. 2001. Cockroach allergens and asthma. *J. Allergy Clin. Immunol.,* 107: 419–428. https://doi.org/10.1067/mai.2001.112854

Arruda LK. 2005. Cockroach allergens. *Curr. Allergy Asthma Rep.,* 5: 411–416. https://doi.org/10.1007/s11882-005-0015-y

Arya, H., Singh, B. R. and Singh, K. (2010). Aphidicidal activity of *Calotropis procera* leaves against mustard aphid *Lipaphis erysimi* (Kalt) and its natural predator *Coccinella septempunctata* (Linn). *World Applied Sciences Journal,* 8(8): 1001–1005

Cabral, S., Silva, F., Rodrigues, P., Rambo, M., Santos, J., Chaves, M., and Pinto, B. (2023). Extraction and chemical characterization of neem seed oil (*Azadirachta indica*). *Journal of Biotechnology and Biodiversity*,11(4),170-181
. https://doi.org/10.20873/jbb.uft.cemaf.v11n4.16258

Chinnaperumal, K., Pachiyappan, R. G., Elango, G., Karthi, S., Chung, I.-M. and Rajakumar, G. (2018). Novel and environmental friendly approach: Impact of Neem (Azadirachta indica) gum nano formulation (NGNF) on Helicoverpa armigera (Hub.) and Spodoptera litura (Fab.). *International Journal of Biological Macromolecules,* 107(Part A): 59–69. https://doi.org/10.1016/j.ijbiomac.2017.08.145

Davari, B., Kashani, S., Nasirian, H., Nazari, M. and Salehzadeh, A. (2018). Efficacy of Maxforce and Avion gel baits containing fipronil, clothianidin, and indoxacarb against the German cockroach (*Blattella germanica*). *Entomological Research,* 48: 459 - 465. https://doi.org/10.1111/1748-5967.12282.

DeVries, Z. C., Santangelo, R. G., Crissman, J. R., Mick, R. and Schal, C. (2019). Exposure risks and ineffectiveness of total release foggers (TRFs) used for cockroach control in residential settings. *BMC Public Health,* 19(1): 32. https://doi.org/10.1186/s12889-018-6371-z

Dimetry, N. Z. (2020). Toxic Effect of Different Neem Formulations against Pests and Mammals. *Journal of Botanical Research*, *2*(3), 6–19. https://doi.org/10.30564/jrb.v2i3.2032

El–khodary, S. & Ghanem, F. & Rakha, M. & Shoghy, Nourhan & Ueno, Takatoshi. (2020). Primary Screening of German Chamomile Oil as Insecticides, Baits, and Fumigants in Nanoformulations against the Health Pest Periplaneta americana (L.) (Dictyoptera: Blattidae). *Journal of the Faculty of Agriculture, Kyushu University*. 65. 103-112. https://doi.org/10.5109/2558902.

Fitriady, M., Sulaswatty, A., Agustian, E., S. and Aditama, D. (2017). Steam distillation extraction of ginger essential oil: *Study of the Effect of Steam Flow Rate and Time Process,* 1803: 020032. https://doi.org/10.1063/1.4973159.

Gondhalekar, A. D., Song, C., & Scharf, M. E. (2011). Development of strategies for monitoring indoxacarb and gel bait susceptibility in the German cockroach (Blattodea: Blattellidae). *Pest management science*, *67*(3), 262–270. https://doi.org/10.1002/ps.2057

Gordon, J. M., Sierras, A. J., Jackson, D. V., Principato, S. and DeVries, Z. C. (2025). Laboratory and in-home evaluations of consumer- and professional-grade cockroach baits. *Journal of Economic Entomology,* 118(2): 826–837. https://doi.org/10.1093/jee/toae291

Gupta, I., Singh, R., Muthusamy, S., Sharma, M., Grewal, K., Singh, H. P. and Batish, D. R. (2023). Plant Essential Oils as Biopesticides: Applications, Mechanisms, Innovations, and Constraints. *Plants (Basel, Switzerland):* 12(16): 2916. https://doi.org/10.3390/plants12162916

Hamada, H.M., Awad, M., El-Hefny, M. and Moustafa, M.A.M. (2018).Insecticidal Activity of Garlic (*Allium sativum*) and Ginger (*Zingiber officinale*) Oils on the Cotton Leafworm, *Spodoptera littoralis* (Boisd.) (Lepidoptera: Noctuidae). *African Entomology,* 26(1): 84–94. https://doi.org/10.4001/003.026.0084

Hamilton, J. A., Wada-Katsumata, A. and Schal, C. (2023). Cockroaches as Trojan Horses for Control of Cockroach Aggregations with Baits. *Journal of economic entomology*, 116(2): 529–537. https://doi.org/10.1093/jee/toad018

Hu, I. H., Chen, S. M., Lee, C. Y., & Neoh, K. B. (2020). Insecticide Resistance, and Its Effects on Bait Performance in Field-Collected German Cockroaches (Blattodea: Ectobiidae) From Taiwan. *Journal of economic entomology*, *113*(3), 1389–1398. https://doi.org/10.1093/jee/toaa053

Ismaila, S. S., Sani, Y., Sani, A. A., Yakasai, S. M., Momoh, H. and Mohammed, S. E. (2022). Determination of fatty acids and physicochemical properties of neem (*Azadirachta indica* L.) seed oil extracts. *Dutse Journal of Pure and Applied Sciences,* 8(1a): 149–160. https://doi.org/10.4314/dujopas.v8i1a.16

Khoobdel, M., Dehghan, H., Oshaghi, M., Saman, E., Asadi, A. and Yusuf, M. (2022). The different aspects of attractive toxic baits containing fipronil for control of the German cockroach (*Blattella germanica*). *Environmental Analysis, Health and Toxicology,* 37: Article e2022032. https://doi.org/10.5620/eaht.2022032

Kilani-Morakchi, S., Morakchi-Goudjil, H. and Sifi, K. (2021). Azadirachtin-based insecticide: Overview, risk assessments, and future directions. *Frontiers in Agronomy,* 3: 676208. https://doi.org/10.3389/fagro.2021.676208

Lee, S. H., Choe, D. H., Rust, M. K. and Lee, C. Y. (2022). Reduced Susceptibility Towards Commercial Bait Insecticides in Field German Cockroach (Blattodea: Ectobiidae) Populations From California. *Journal of Economic Entomology*, 115(1): 259–265. https://doi.org/10.1093/jee/toab244

Lee, Shao-Hung, Zhao, Man, Lee, Chow-Yang. (2025). Increase in insecticide susceptibility after sublethal exposure to deltamethrin in the German cockroach (Blattodea: Ectobiidae). *Journal of Economic Entomology*. 10.1093/jee/toaf124.

Loganathan, T., Barathinivas, A., Soorya, C., Balamurugan, S., Nagajothi, T. G. and Jayakumararaj, R. (2021). GCMS Profile of Bioactive Secondary Metabolites with Therapeutic Potential in the Ethanolic Leaf Extracts of *Azadirachta indica*¬: A Sacred Traditional Medicinal Plant of INDIA. *Journal of Drug Delivery and Therapeutics*, 11(4-S): 119-126. https://doi.org/10.22270/jddt.v11i4-S.4967

Liu, X.; Xi, K.; Wang, Y.; Ma, J.; Huang, X.; Liu, R.; Cai, X.; Zhu, Y.; Yin, J.; Jia, Q.; et al. (2022). Evaluation of the Contact Toxicity and Physiological Mechanisms of Ginger (*Zingiber officinale*) Shoot Extract and Selected Major Constituent Compounds against *Melanaphis sorghi* Theobald. *Horticulturae*, 8, 944. https:// doi.org/10.3390/horticulturae8100944

Lucero, I. M., Gaire, S., & DeVries, Z. C. (2025). Effects of age and environmental conditions on cockroach gel bait performance. Journal of Economic Entomology, 118(4), 1850–1867. https://doi.org/10.1093/jee/toaf130

Madreseh-Ghahfarokhi, S., Pirali, Y., Dehghani-Samani, A. and Dehghani-Samani, A. (2018). *Annals of Parasitology,* 64(4): 351–360. https://doi.org/10.17420/ap6404.171

Mettwally, W. S. A., Zahran, H. A., Khayyal, A. E., Ahmed, M. M. E., Allam, R. M. and Saleh, D. O. (2022). *Calotropis procera* (Aiton) seeds fixed oil: Physicochemical analysis, GC–MS profiling and evaluation of its in-vivo anti-inflammatory and in-vitro antiparasitic activities. *Arabian Journal of Chemistry,* 15(9): 104085.

Michel, M. R., Aguilar-Zárate, M., Rojas Molina, R., Martínez-Ávila, G., and Aguilar-Zárate, P. (2023). The insecticidal activity of *Azadirachta indica* leaf extract: Optimization of the microencapsulation process by complex coacervation. Plants, 12(6), 1318. https://doi.org/10.3390/plants12061318

Miller, D. M., and E. P. Smith. 2020. Quantifying the efficacy of an assessment based pest management (APM) program for German cockroach (L.) (Blattodea: Blattellidae) control in low-income public housing units. *J. Econ. Entomol.,* 113: 375–384 https://doi.org/10.1093/jee/toz302 .

Neupane, A., & Kafle, L. (2019). Efficacy of gel baits against American cockroaches (Dictyoptera: Blattellidae) under laboratory conditions. *Journal of Entomological Research*, 43(3), 409–413. https://doi.org/10.5958/0974-4576.2019.00071.9

Nour, A. H., Yap, S. S. and Nour, A. H. (2017). Extraction and chemical compositions of ginger (*Zingiber officinale* Roscoe) essential oils as cockroach repellent. *Australian Journal of Basic and Applied Sciences*, 11(1): 1–7.

Ogbinaka, E. J. A., Edema, I. O., Ehijie, O. H. and Onakpoma, S. O. (2025).Evaluation of neem products for their efficacy in the management of some major insect pests associated with cowpea in Asaba, Delta State, Nigeria. *Journal of Entomology and Zoology Studies,* 13(1): 137–141. https://doi.org/10.22271/j.ento.2025.v13.i1b.9459

Ogbonna, U. F. S., and Uchenna, O. (2023). Mediators of arrested development as attractive malaria vector control tools: The *Azadirachta indica* and azadirachtin routes. *Journal of Biological Research and Biotechnology,* 21(1), 1805–1817. https://doi.org/10.4314/br.v21i1.4

Padonou, G., Kpanou, C., Ossè, R., Salako, A., Yovogan, B., Sagbohan, H., Konkon, A., Zoungbédji, D., Akinro, B., Sina, H., Baba-Moussa, L.

and Akogbéto, M. (2023). Evaluation of the efficacy of 2.15% imidacloprid (ROCO GEL) gel against *Periplaneta americana* under laboratory and field conditions in Benin. *Acta Entomology and Zoology*. 4(1):95-102 https://doi.org/10.33545/27080013.2023.v4.i1b.100.

Rahayu, R., Ahmad, I., Sinaga, M., Muslima, R. and Jannatan, R. (2025). Status and Mechanism of Insecticide Resistance in German Cockroach (Blatella germanica L.) Worldwide: A Literature Review. *Tropical Life Sciences Research*, 36:289-321. https://doi.org/10.21315/tlsr2025.36.3.15.

Ranjan, K., Shaikh, K., Pathan, T., Shaikh, W., & Shaikh, R. (2025). Evaluation of bio-efficacy of *Calotropis procer*a against juvenile stage of common household pest *Periplaneta americana* (American cockroach). *Asian Journal of Biological and Life Sciences,* 14(3), 1–6. https://doi.org/10.5530/ajbls.20250013

Sambo, D. L., Lucia, O. E., and Brains, O. O. (2024). Nematicidal effects of Azadirachta indica A. Juss (Neem) seeds on Meloidogyne species (root-knot nematodes). *Journal of Biological Research and Biotechnology*, 22(1), 2234–2241.

Schmutterer, H. (1990). Properties and potential of natural pesticides from the neem tree, *Azadirachta indica. Annual Review of Entomology,* 35(1): 271–297. https://doi.org/10.1146/annurev.en.35.010190.001415

Sharma, P.K., Singh, V. and Ali, M. (2016). Chemical composition and antimicrobial activity of fresh rhizome essential oil of *Zingiber officinale* Roscoe. *Pharmacognosy Journal* 8(3): 185–190

Sinha, N. and Ray, S. (2024). The potential of ginger (*Zingiber officinale* Rosc.) extracts as a bio-pesticide. *Journal of Entomology and Zoology Studies,* 12(3): 38–45. https://doi.org/10.22271/j.ento.2024.v12.i3a.9317

Umohata, I. A., Ubulom, P. M. E., Akpan, A. U., Thomas, P. S., & Eshiet, D. I. (2024).Knockdown and toxicity of essential oils from the rhizome of *Zingiber officinale* (L.) and the bud of *Syzygium aromaticum* (L.) to *Periplaneta americana* (L.).*Nigeria Journal of Entomology* 40(2), 15–29. https://doi.org/10.36108/NJE/4202/04.0220

Vigad, N., Tarachai, P., Chansakaow, S., Punyapornwithaya, V. and Chukiatsiri, K. (2025). Efficacy of citronella and ginger essential oil combinations against chicken lice (*Menopon gallinae*) and mites (*Ornithonyssus bursa*): Chemical characterization, contact toxicity, and in vivo validation. *Veterinary World,* 18: 1694-1702. https://doi.org/10.14202/vetworld.2025.1694-1702.

Wadhwani, B. D., Mali, D., Vyas, P., Nair, R., & Khandelwal, P. (2021). A review on phytochemical constituents and pharmacological potential of *Calotropis procera. Royal Society of Chemistry Advances*, 11(57), 35854–35878. https://doi.org/10.1039/D1RA06703F

Wang, C. and Scharf, M. E. (2022). Resistance to insecticidal baits in German cockroaches: Mechanisms, monitoring, and management. *Pest Management Science,* 78(12): 5071–5084. https://doi.org/10.1002/ps.6789

Wannigama, D. L., Dwivedi, R. and Zahraei-Ramazani, A. (2014). Prevalence and Antibiotic Resistance of Gram-Negative Pathogenic Bacteria Species Isolated from *Periplaneta americana* and *Blattella germanica* in Varanasi. *India Journal of Arthropod-Borne Diseases,* 8(1): 10–20