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Research Article

Production and Characterization of a Mosquito Repellent Coil Using Neem (*AZADIRACHTA INDICA*): FTIR, UV-VIS Analysis and Bioassay Evaluation

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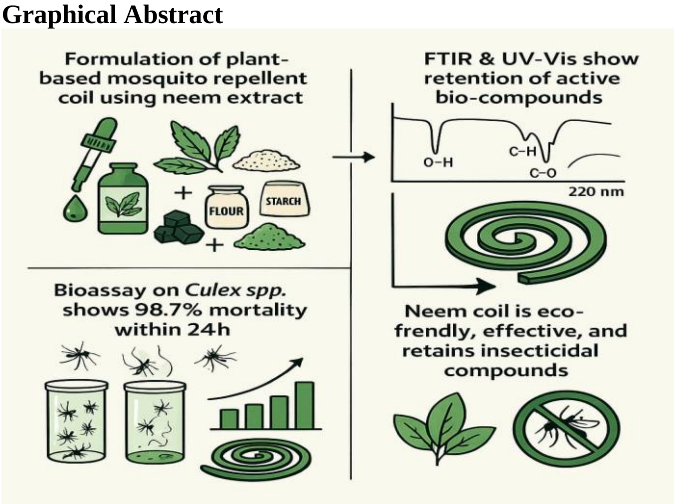
Abstract**—** This study explores the production and characterization of a mosquito repellent coil formulated using neem (*Azadirachta indica*) leaf extract. The coil was prepared using plant-based ingredients including starch, sawdust, flour, and charcoal, with neem extract serving as the active repellent agent. Fourier Transform Infrared (FTIR) spectroscopy was used to assess the phytochemical profile, revealing functional groups including O–H, C–H, C=O, and C–O, which are typically associated with bioactive neem compounds. These groups were also detected in the final coil, suggesting that the active constituents remained intact after formulation. UV-Visible spectrophotometric analysis showed a strong absorption peak at approximately 220 nm in both the neem extract and the coil, with absorbance values of 4.0 and 3.0, respectively. This indicates that key light-absorbing compounds such as azadirachtin were partially preserved during formulation. A laboratory bioassay was conducted on Culex mosquitoes to evaluate repellent efficacy. Seventy-five adult mosquitoes, divided into three replicates of 25, were exposed to the coil. Mortality increased progressively over time, reaching 24 to 25 dead mosquitoes per replicate at 24 hours. The mean mortality was 24.67 ± 0.58, representing a 98.7% mortality rate. Additionally, the median lethal dose (LD_{50}) calculated using Karber's method was 96.7%, further confirming the high potency of the coil formulation. The findings highlight neem's effectiveness as a natural insecticidal agent and support its application in environmentally friendly mosquito control solutions.

Keywords**—** Neem, FTIR analysis, UV-Vis spectroscopy, *Azadirachta indica*, Mosquito repellent coil, bioassay, LD_{50}.

Graphical Abstract



1. Introduction

Mosquito-borne diseases such as malaria continue to pose serious global health challenges, particularly in sub-Saharan Africa. According to the World Health Organization [1], over 240 million malaria cases and more than 600,000 deaths were reported globally in 2020, with Africa carrying the highest burden. Effective mosquito control remains a key strategy in reducing the spread of such diseases. Although chemical-based mosquito repellents and insecticides are widely used, they are associated with significant health and environmental concerns, including respiratory irritation, allergic reactions, and long-term toxicity from synthetic compounds such as allethrins and pyrethroids [2, 3].

As a safer and more sustainable alternative, plant-based repellents have gained increasing attention. Among these, Azadirachta indica (neem) has demonstrated strong insecticidal properties, attributed to its bioactive constituents like azadirachtin, salannin, and nimbin [4, 5]. These compounds disrupt insect hormonal systems, impair feeding, and cause mortality [6]. Neem is also widely available in Nigeria, making it an accessible raw material for mosquito control formulations. While neem has been incorporated into sprays and oils, fewer studies have focused on developing and scientifically validating neem-based mosquito coils using modern analytical techniques [7].

This study aims to fill that gap by producing a mosquito repellent coil using neem extract and evaluating its phytochemical composition through FTIR and UV-Visible spectroscopy. The biological efficacy of the coil was assessed through a mosquito bioassay, providing a holistic view of both chemical and functional performance. This approach not only addresses the need for safer mosquito control strategies but also supports the utilization of indigenous plant resources for public health applications.

2. Related Work

The use of botanical insecticides and natural mosquito repellents has received considerable attention due to increasing concerns over the environmental and health risks associated with synthetic products. Among plant-based alternatives, neem (*Azadirachta indica*) has been extensively studied for its wide range of bioactive compounds, particularly azadirachtin, salannin, and nimbin, which exhibit insecticidal, antimicrobial, and antifeedant properties [2, 6].

Neem oil has been incorporated into sprays, ointments, and larvicidal formulations to control mosquitoes and other insect vectors [7]. For instance a comparative study of neem extract and citronella oil found neem to be more effective against *Aedes aegypti* [4]. Another study showed that neem seed oil caused high mortality in *Ephestia cautella*, validating its repellent and toxic effects on insects [5].

A phytochemical screening of neem leaf extract confirmed the presence of terpenoids, flavonoids, and alkaloids, compounds known for their insect repellent and antimicrobial activities. However, most of these studies focus on neem used in sprays or oils rather than in coil formulations, which are more accessible and commonly used in rural and semi-urban households.

Moreover, while neem-based mosquito coils have been produced in some studies [9], limited work has characterized their chemical profile using modern spectroscopic techniques. FTIR and UV-Visible spectroscopy are powerful tools for identifying functional groups and detecting bioactive constituents in plant-based materials [6], yet are rarely applied to repellent coil studies.

This present study not only formulates a mosquito repellent coil using neem leaf and seed components but also characterizes the chemical profile using FTIR and UV-Vis spectroscopy, alongside conducting a mosquito bioassay evaluation. By integrating analytical chemistry with bioefficacy testing, this work aims to fill an important gap in the literature and provide a more complete scientific validation of neem-based mosquito control strategies.

3. Experimental Methods

3.1 Materials and Equipment

The materials employed in this work included n-hexane (CDH, India), distilled water, starch, flour (Dangote brand), sawdust, and charcoal powder. All reagents were of analytical reagent (AR) grade to ensure experimental reliability. Laboratory glassware and tools used comprised conical flasks, beakers, measuring cylinders, stirring rods, aluminum foil, filter paper, Petri dishes, mortar and pestle, and a precision digital balance. Spectroscopic analyses were conducted using a Euro-FTIR spectrometer (UK) and a Shimadzu UV-1650 UV-Visible spectrophotometer supplied by Labstock Nigeria Ltd.

3.2 Sample Collection and Authentication

Seeds and leaves of *Azadirachta indica* (neem) were obtained from the campus environment of Usmanu Danfodiyo University, located in Wamakko Local Government Area of Sokoto State, Nigeria. A certified botanist from the Department of Biological Sciences at the university authenticated the plant materials.

3.3 Sample Preparation

The collected neem seeds and leaves were washed thoroughly with clean water to remove dust and other impurities. The seeds were oven-dried at 60°C for four days, de-shelled manually using a mortar and pestle, and ground into fine powder. The neem leaves were shade-dried for seven days and similarly pulverized to a fine consistency. Both powders were sieved to ensure uniform particle size [6]. Sawdust and charcoal powder were also obtained by grinding using mortar and pestle into fine powder.

3.4 Oil Extraction Procedure

Soxhlet extraction was used to obtain neem oil from the seed powder. Approximately 100 g of powdered neem seed was placed in a thimble and extracted using 300 mL of n-hexane as solvent. The process was maintained for six hours at the boiling temperature of n-hexane. Upon completion, the extract was passed through Whatman No. 1 filter paper and concentrated using a water bath set to 45°C. The obtained oil was then transferred into a clean amber bottle and stored at room temperature for further use. [8].

3.5 Preparation of coil Mixture and sample

The mosquito coil was formulated using neem oil extracted from seeds, powdered neem leaves, charcoal, sawdust, flour, and starch. Specifically, 7 g of neem oil, 5 g of powdered neem leaves, 2 g each of charcoal and sawdust, 25 g of flour, and 4 g of starch were measured and transferred into a clean beaker. Hot water (50 mL at approximately 85°C) was added gradually while stirring continuously with a glass rod until a consistent, pliable paste was formed.

Before molding, the inner surface of the coil mold was lightly coated with neem oil to prevent adhesion. The prepared paste was packed into the mold and compressed evenly. Once shaped, the coil was demolded and left to dry at ambient temperature for about 21 hours to harden and maintain structural integrity. This method was developed through preliminary formulation trials to achieve an optimal and functional mosquito coil.

Plate 1: Diagram of the coil formation

3.6 Fourier Transform Infrared (FTIR) Spectroscopic Analysis

Fourier Transform Infrared (FTIR) spectroscopy was employed to identify the functional groups present in both the crude neem oil and the formulated mosquito coil. A small portion of each dried sample was ground and pressed into a thin film using potassium bromide (KBr) as a background reference.

Spectral data were collected using a Euro-FTIR spectrometer (UK) in the range of 4000–400 cm⁻¹ under ambient conditions. The characteristic peaks corresponding to different functional groups were recorded and interpreted using standard infrared absorption ranges [10].

3.7 UV-Visible Spectrophotometric Analysis

Ultraviolet–Visible (UV-Vis) spectrophotometry was carried out to determine the absorption characteristics of the crude neem oil and assess the presence of bioactive compounds. A portion of the extract was diluted with n-hexane and scanned using a Shimadzu UV-1650 spectrophotometer (Labstock Nigeria Ltd) across a wavelength range of 200–800 nm.

The absorption peaks were recorded and compared to known UV spectra of phytochemical constituents such as azadirachtin and related terpenoids. UV-Vis analysis is widely used in the detection of chromophoric plant metabolites [11] and served as a confirmatory technique in this study.

3.8 Mosquito Mortality Test (Bioassay Evaluation)

The standard cage method was employed to assess the repellent efficacy of the formulated mosquito coil. Adult Culex mosquitoes were captured using an aspirator and introduced into a transparent holding cage. The ignited coil was placed near the cage, and the setup was observed for 24 hours. After the exposure period, the number of dead mosquitoes was counted manually [12].

3.9 Data Analysis

The mortality data obtained from the bioassay were analyzed using Karber's arithmetic method. The LD_{50} (lethal dose required to kill 50% of the mosquito population) was calculated using the formula:

$$LD_{50} = 100\% - \frac{(\text{dose differences} \times \text{mean death})}{\text{Number of Mosquitoes}}$$

Where:

Dose difference is the difference between successive dose levels

Mean death is the average number of deaths between two consecutive doses

Number of mosquitoes is the total per group

This statistical approach is widely used in entomological bioassays to estimate toxicity levels [13].

4. Results and Discussion

4.1 FTIR Spectroscopic Analysis

The FTIR spectrum of the crude neem oil displayed absorption bands at 2927 cm⁻¹ and 2856 cm⁻¹, indicating C–H stretching vibrations typical of alkanes. A sharp band at 1741 cm⁻¹ corresponds to C=O stretching, suggesting the presence of esters or aldehydes, while the peak at 1689 cm⁻¹ may indicate C=C stretching of alkenes. Additional peaks around 1238 cm⁻¹ and 1040 cm⁻¹ are attributed to C–O stretching vibrations of esters or ethers.

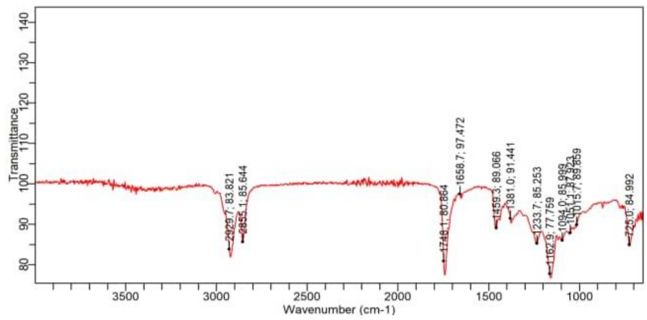


Plate 2: FTIR spectrum of the crude neem extract

The FTIR spectrum of the formulated mosquito coil also exhibited significant bands at 3276 cm⁻¹ (O–H C–H stretching), 1721 cm⁻¹ (C=O stretching), and 1635 cm⁻¹ (C=C or N–H bending).

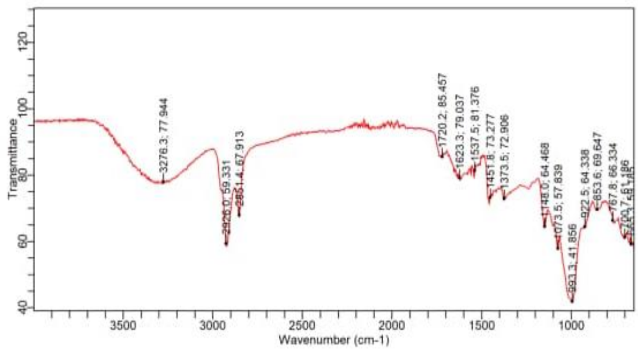


Plate 3: FTIR spectrum of the Mosquito coil

4.2 UV-Visible Spectrophotometric Analysis

The neem extract exhibited a prominent absorption peak at approximately 220 nm, with a maximum absorbance of 4.0 (Plate 4). The mosquito coil sample also showed a similar peak at approximately 220 nm, although with a reduced absorbance of 3.0 (Plate 5)

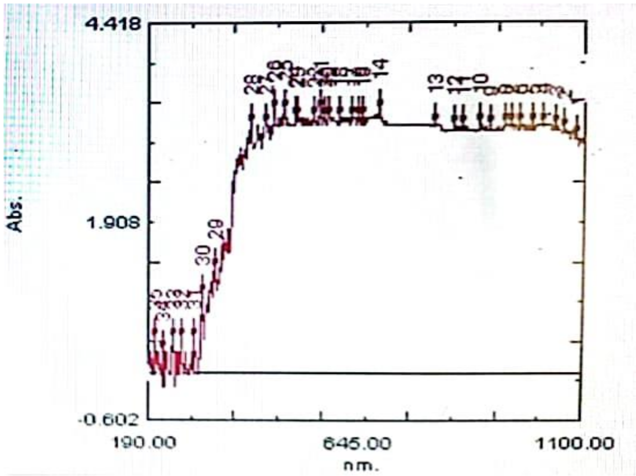


Plate 4: UV-Visible spectra of the neem extract

Both spectra displayed a shoulder between 250 and 300 nm. The baseline absorbance between 300 and 1100 nm was higher for the neem extract (ranging from 0.5 to 1.0 absorbance units) compared to the mosquito coil (ranging from 0.0 to 0.5 absorbance units.

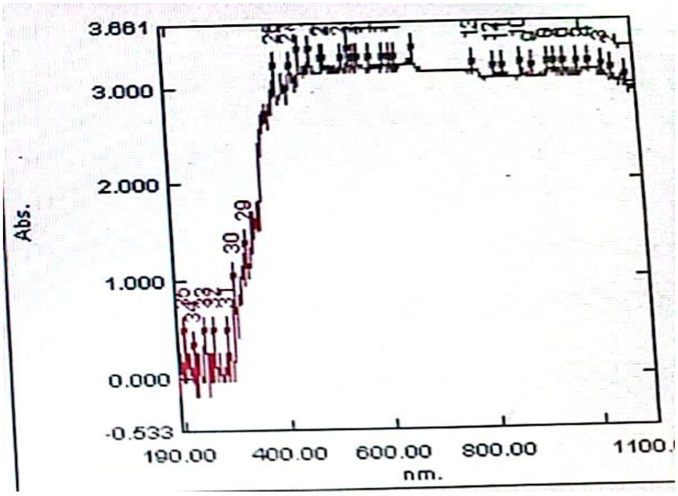


Plate 5: UV-Visible spectra of the mosquito coil

4.3 Mosquito Mortality Result

A total of 75 adult Culex mosquitoes were used across three replicates (25 per group). After 24 hours of exposure to the neem-based mosquito coil, Replicate 1 recorded 24 deaths, while Replicates 2 and 3 both recorded 25 deaths. The control group, which was not exposed to the coil, recorded only one mortality (Table 1).

The trend in mortality over time is presented in Table 1 and illustrated in the bar chart (Plate 6). Mortality gradually increased at intervals from 5 to 45 minutes, followed by a marked increase by the 24-hour mark.

Table 1: Mortality of Culex Mosquitoes After 24-Hour Exposure to Neem Coil

	Mortality Rate			
Time (mins)	**Replicate 1**	**Replicate 2**	**Replicate 3**	**Control Group**
5	0	0	0	0
10	2	2	2	0
15	4	4	3	0
20	4	4	4	0
25	5	4	4	0
30	5	5	5	0
35	6	6	6	0
40	6	6	6	0
45	7	6	6	0
1440 (24 hours)	24	25	25	1

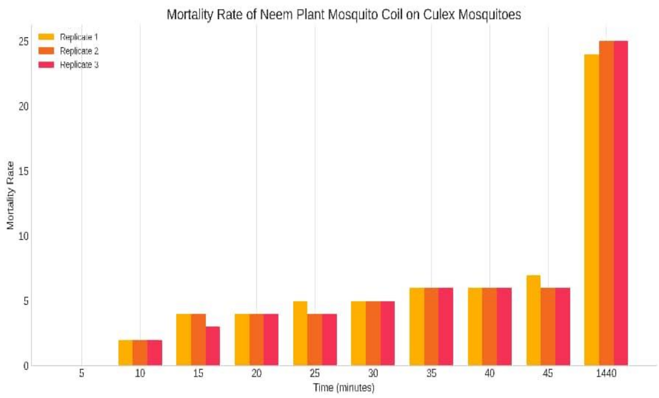


Plate 6: Bar Chart Showing 24-hours Mortality Across Replicates

4.4 Data Analysis

The final 24-hour mortality data across the three replicates yielded a mean of 24.67 ± 0.58 (mean ± SD) dead mosquitoes. Using Karber's arithmetic method, the LD_{50} value of the neem-based mosquito coil was calculated as 96.7%.

Discussion

The UV-Vis spectroscopic analysis provides insights into the retention of neem's bioactive compounds in the mosquito repellent coil, a key aspect of its characterization as an insect-repellent product. The absorbance peak at 220 nm in both the neem oil and the mosquito coil is attributed to $\pi \rightarrow \pi^*$ transitions from conjugated systems in terpenoids (e.g., azadirachtin) and phenolic compounds (e.g., flavonoids, tannins), which contribute to neem's insect-repellent properties [14]. The reduction in absorbance from 4.0 in the neem extract to 3.0 in the coil (approximately 25% decrease) reflects a dilution effect due to the formulation, as well as potential degradation of heat-sensitive compounds like azadirachtin during processing.

These findings align with previous studies on neem-based products. A similar absorbance peak at 217 nm for neem extracts was reported, attributed to azadirachtin and phenolic compounds, though the study focused on unprocessed extracts [15]. Another study observed a more significant reduction in absorbance (up to 40%) in neem-based mosquito coils compared to the approximately 25% reduction observed in this study [16]. The relatively lower reduction here may be attributed to the formulation's composition, which includes a high proportion of flour and starch, potentially forming a protective matrix that minimizes thermal degradation of azadirachtin during coil production. The low charcoal content may also reduce combustion-related losses compared to formulations with higher charcoal ratios [16].

The shoulder at 250–300 nm in both spectra suggests overlapping n→π* transitions, likely from carbonyl groups in azadirachtin or phenolic compounds [17]. The higher baseline in the neem extract (Abs 0.5–1.0 beyond 300 nm) indicates scattering from impurities like chlorophyll, common in crude extracts [14]. The mosquito coil's cleaner baseline (Abs 0.0–0.5) reflects the dilution of such impurities by the formulation's non-absorbing components. The mosquito coil retains a significant portion of neem's bioactive compounds, as evidenced by the 220 nm peak, suggesting potential efficacy as an insect repellent. Azadirachtin is known to be effective against mosquitoes at low concentrations [15], and the coil's absorbance, though reduced, indicates that sufficient active compounds may remain for practical use.

Plates 4 and 5 present the UV-Visible spectra of the neem extract and the coil. A prominent absorbance peak near 220 nm is evident in both, though reduced in the coil. This indicates partial preservation of light-absorbing compounds, consistent with the presence of azadirachtin and other chromophoric constituents.

The FTIR analysis confirmed the presence of various functional groups in both the crude neem oil and the formulated coil. In the oil extract, peaks around 2927 and 2856 cm^{-1} were indicative of C–H stretching in alkanes, while the strong peak at 1741 cm^{-1} suggested ester or aldehyde groups. The peak at 1689 cm^{-1} indicated possible alkenes or unsaturated carbonyls, and those at 1238 and 1040 cm^{-1} were associated with C–O bonds of ethers or esters. FTIR spectral data for both neem oil and the formulated coil are shown in Plates 2 and 3, respectively. The coil retained major peaks observed in the oil, such as 3276 cm^{-1} (O–H), 2924 cm^{-1} (C–H), and 1721 cm^{-1} (C=O), suggesting the bioactive components remained stable post-formulation. These functional groups are commonly linked to phytochemicals with insecticidal or repellent properties [18]. These findings are consistent with previous FTIR studies of neem, which reported similar peaks associated with the functional groups of bioactive constituents such as azadirachtin, nimbin, and other triterpenoids and flavonoids [18–22].

The mosquito bioassay demonstrated a strong repellent effect, with 96.7% mortality after 24 hours of exposure. This aligns with earlier studies confirming neem's insecticidal potential [12]. The low mortality in the control group further validated the effectiveness of the coil. The results underscore the functional reliability of neem-based products for vector control, particularly in low-resource settings. The mortality rate of Culex mosquitoes increased steadily over time following exposure to the neem-based mosquito coil as shown in Plate 6. In all three replicates, mortality rose gradually within the first 15 minutes, reaching 4 to 5 mosquitoes per group. A more notable increase was recorded between 20 and 45 minutes, where mortality reached 6–7 mosquitoes, indicating increasing toxic activity of the neem smoke. By the 24-hour mark, mortality peaked with 24 to 25 mosquitoes dead in each replicate, resulting in a mean mortality rate of approximately 98.7%.

The increasing mosquito mortality over time indicates that *Azadirachta indica* exhibits strong insecticidal activity, particularly with prolonged exposure. These findings align with previous studies that have shown both larvicidal and adulticidal effects of neem-derived extracts on various mosquito species, including Culex [23, 24]. The plant's effectiveness is attributed to key phytochemicals like azadirachtin, salannin, and nimbin, which are known to disrupt insect development and reproduction through hormonal interference [25]. This study reinforces the potential of neem-based coils as a safer, plant-based solution for mosquito control, particularly in communities where chemical repellents raise environmental or health-related concerns.

5. Conclusion and Future Scope

This study successfully formulated a mosquito repellent coil using Azadirachta indica (neem) extract and evaluated its chemical and insecticidal properties. FTIR analysis confirmed the presence of bioactive functional groups, while UV-Vis spectroscopy demonstrated partial retention of key light-absorbing compounds such as azadirachtin. The bioassay results revealed a high repellent efficacy, with a mean mortality rate of 98.7% against adult Culex mosquitoes and an LD_{50} of 96.7%.

These findings validate the potential of neem-based coils as a natural, eco-friendly alternative to synthetic mosquito repellents, especially in settings where health or environmental concerns limit the use of chemical-based products.

Future research can focus on optimizing the coil formulation to further improve the retention of active compounds, possibly through encapsulation or alternative binders. Additionally, large-scale field trials and long-term safety evaluations are recommended to assess performance under real-world conditions. Expanding the scope to test against other mosquito species (e.g., *Aedes aegypti*) and exploring shelf-life stability will also enhance the practical value and commercial viability of neem-based mosquito coils.

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Authors' Contributions- The author **Ismail Muhammed**[1] and **Aleshinloye Rofiat**[2] carried out the research. **Ismail Muhammed**[1] drafted the manuscript. **Faisal Sanusi**[3] edited the manuscript. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

Conflict of Interest- The authors do not have any potential conflicts of interest to disclose.

Data Availability- Due to technological and time constraints, raw data required for an ongoing investigation cannot be shared.

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AUTHORS PROFILE

Mr. Ismail Muhammed Maizuna is a First-Class graduate and the best graduating student of the Department of Pure and Applied Chemistry, Usmanu Danfodiyo University, Sokoto, Nigeria in the year 2024. He was also awarded Best Student in Organic Chemistry, Inorganic Chemistry, and Analytical Chemistry. His academic foundation is rooted in core areas of chemistry, with particular interest in analytical and natural product chemistry, and he remains open to diverse research opportunities across the chemical sciences.

Mrs. Aleshinloye Rofiat Olanshile is a recent graduate of Usmanu Danfodiyo University, Sokoto, Nigeria, with a keen Interest in research and sustainable solutions. Her research, which focuses on the production of mosquito repellent (coil) using neem plants, highlights her dedication to using natural and locally available resources for practical applications. She is passionate about scientific research, environmental health, and contributing to innovative solutions in the field of chemistry.

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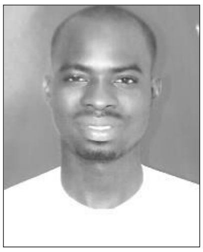

Mr. Faisal Sanusi Aliyu earned his B.Sc. in industrial chemistry with a first-class honor from Umaru Musa Yaradua University Katsina, Nigeria in the year 2021, During his undergraduate studies, he worked and gained experience with Ajiwa water treatment plant in the year 2019-2020 as a part of the Students Industrial Work Experience Scheme (SIWES). He did his 1-year National Youth Service Corps (NYSC) program in Kano of Nigeria, Served as a research/laboratory assistant at Yusuf Mai Tama Sule University. He is a member of Chemical Society of Nigeria (CSN) and a member of professional bodies which includes African Science frontier initiatives (ASFI), USA education fund Nigeria, and North-Elite Scholars' mentorship (NES). International Young chemist network (IYCN). He has 3 years of research experience, and has research interests in polymer chemistry, bio-based materials, Environmental chemistry, Renewable energy/Sustainable energy, materials materials, food chemistry.

