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Research Article

Production and evaluation of mosquito repellent coil using orange (*Citrus sinensis*) peel extract

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ABSTRACT

Mosquito-borne diseases remain a major public health concern, and continued reliance on synthetic mosquito coils raises issues of cost, insecticide resistance, and indoor air quality. This study produced and evaluated a plant-based mosquito repellent coil formulated from orange peel (Citrus *sinensis*) extract. Dried orange peels were extracted using ethanol and the extract was incorporated into a combustible base with starch solution as the binder. Gas Chromatography-Mass Spectrometry (GC-MS) analysis confirmed limonene (87.3%) as the major constituent, with linalool (2.1%), citral (1.8%), and α-pinene (1.2%) as minor components. Turmeric and camphor were included as botanical repellent enhancers, while activated charcoal was added to support steady combustion and improve smoke characteristics. Dose-response studies were conducted at 5%, 10%, 15%, and 20% extract concentrations, with 15% showing optimal repellency (91.2%) and burning characteristics. Performance was assessed using standardized WHO cone bioassay with Aedes aegypti, physical properties, burning time, mosquito repellency effectiveness, air quality emissions (PM2.5, CO, formaldehyde), stability over 3 months storage, and thermal degradation analysis. From 100 g of dried orange peel, 8.5 g of extract was obtained, giving a percentage yield of 8.5%. The formulated coils showed good structural integrity, produced moderate smoke, and had a characteristic, pleasant citrus odour. Statistical analysis (ANOVA) showed significant differences in repellency between concentrations ($F = 24.36$, $p < 0.001$), and t-test confirmed comparable burning time to commercial coils ($t = 2.14$, $p = 0.067$, 95% CI: -1.65 to 0.05). The average burning time of the 15% orange peel-based coil was 6.4 hours, compared with 7.0 hours for a commercial mosquito coil. Standardized bioassay revealed knockdown rates of 45% at 30 min and 78% at 60 min, with 82% mortality after 24h. Stability studies showed 94% essential oil retention after 3 months, and thermal analysis indicated 23% limonene degradation during combustion. Emission analysis demonstrated significantly lower PM2.5 ($p < 0.01$) compared to commercial coils. Overall, the orange peel-based coil demonstrated appreciable repellency, acceptable burning performance, improved safety profile, and satisfactory stability, suggesting potential for an affordable, eco-friendly household mosquito control product.

Keywords: *Citrus sinensis*; essential oil; limonene; mosquito repellent; plant-based insecticide, waste valorization; GC-MS; standardized bioassay; dose-response; stability

Introduction

Mosquitoes are among the most dangerous insects to human health because of their ability to transmit a wide range of infectious diseases, including malaria, dengue fever, yellow fever, chikungunya, lymphatic filariasis, and Zika virus infection [1]. These diseases continue to pose serious public health challenges, particularly in tropical and subtropical regions where climatic conditions favor mosquito breeding and survival [1,2]. Malaria alone accounts for hundreds of thousands of deaths annually, with sub-Saharan Africa bearing the highest burden due to persistent transmission and limited access to effective vector control infrastructure [1,2].

Mosquito control remains a cornerstone of disease prevention strategies worldwide. Common control measures include environmental management, larval source reduction, insecticide-treated bed nets, indoor residual spraying, and the use of household insecticidal products such as sprays, vaporizers, mats, and coils [3,4]. Among these methods, mosquito repellent coils are widely used at the household level, especially in developing countries, due to their low cost, ease of use, and widespread availability in local markets [4].

Conventional mosquito coils are typically formulated with synthetic insecticides, particularly pyrethroids such as allethrin and transfluthrin, which act on the mosquito nervous system to induce knockdown and mortality [4]. While these coils are effective in reducing mosquito bites, increasing scientific evidence has raised concerns regarding their safety for human health. Prolonged exposure to mosquito coil smoke has been associated with respiratory irritation, headaches, allergic reactions, and potential long-term toxicological effects [5,6]. Studies investigating mosquito coil emissions have reported that burning a single mosquito coil can release substantial quantities of fine particulate matter ($PM_{2.5}$), aldehydes, and other toxic pollutants at levels comparable to or exceeding those produced by multiple cigarettes [5,7].

In addition to health concerns, the effectiveness of synthetic insecticide-based mosquito control methods is increasingly threatened by the emergence and spread of insecticide resistance in mosquito populations [2,8]. These challenges have stimulated growing interest in the development of plant-based mosquito repellents as safer and more environmentally friendly alternatives [9]. Botanical repellents are generally biodegradable, exhibit lower toxicity to humans, and are derived from renewable natural resources [9]. Many medicinal and aromatic plants contain essential oils rich in volatile compounds such as terpenes, aldehydes, and phenolics, which have been shown to interfere with mosquito host-seeking behavior [10].

Citrus fruits, particularly orange (Citrus *sinensis*), have attracted attention due to their high essential oil content and wide availability. Orange peel contains large amounts of bioactive compounds such as limonene, linalool, and citral, which have demonstrated mosquito repellent and insecticidal properties [11,12]. Despite this potential, orange peels are often discarded as agricultural and household waste. The utilization of orange peel for mosquito repellent production therefore represents a sustainable approach that combines vector control, waste management, and environmental protection. This study focuses on the production and evaluation of a mosquito repellent coil using orange peel, with the aim of developing an effective, affordable, and eco-friendly household mosquito control.

Materials and Methods

Apparatus and Equipment

The following apparatus and equipment were used: analytical balance, mortar and pestle, hot plate, beakers and conical flasks, measuring cylinders, sieve (1 mm mesh), glass rods, mould for mosquito coil shaping, drying oven, desiccator, filter paper, stopwatch, Gas Chromatography-Mass Spectrometer (GC-MS, Agilent 7890A/5975C), WHO cone bioassay kit, air quality monitor (PM2.5, CO, formaldehyde), and protective gloves and nose mask.

Chemicals and Reagents

All chemicals used were of analytical grade. The reagents included: ethanol (95%) as extraction solvent, distilled water, starch (as binder), turmeric powder (botanical additive), camphor (volatile repellent additive), activated charcoal (combustion aid and smoke modifier), n-hexane (GC-MS grade), limonene standard (≥97% purity, Sigma-Aldrich).

Test Organisms

Laboratory-reared *Aedes aegypti* mosquitoes (3-5 days old, non-blood-fed females) were obtained from the insectary of the Department of Biological Sciences, Umaru Musa Yar'adua University, Katsina. Mosquitoes were maintained at 27 ± 2°C and 70-80% relative humidity with 12:12 light:dark cycle.

Methodology

Collection and Preparation of Orange Peels

Fresh orange (Citrus *sinensis*) fruits were obtained from a local market. The fruits were washed thoroughly with clean water, and the peels were carefully removed using a stainless-steel knife. The collected peels were rinsed with distilled water to remove surface contaminants. The peels were air-dried under shade for several days to reduce moisture content and prevent degradation of volatile compounds. After air-drying, the peels were oven-dried at 60°C until a constant weight was achieved. The dried peels were ground into fine powder using a mortar and pestle and sieved through a 1 mm mesh to obtain uniform particle size. The powdered samples were stored in airtight containers until extraction.

Extraction of Bioactive Compounds from Orange Peel

The powdered orange peel was subjected to solvent extraction using ethanol. A measured quantity of the powder (100 g) was placed in a clean conical flask, and ethanol was added in sufficient volume to completely immerse the sample. The mixture was allowed to stand for 48 hours with intermittent shaking to enhance extraction efficiency. After extraction, the

mixture was filtered using filter paper to separate the liquid extract from the residue. The filtrate was concentrated by evaporating excess solvent on a hot plate at low temperature to obtain a crude orange peel extract.

GC-MS Analysis of Orange Peel Extract

The crude orange peel extract was analyzed using GC-MS to identify and quantify chemical constituents. One microliter of extract diluted in n-hexane (1:100 v/v) was injected into an Agilent 7890A gas chromatograph equipped with a 5975C mass selective detector. Separation was achieved on an HP-5MS capillary column (30 m × 0.25 mm × 0.25 µm). The oven temperature program was: initial 60°C (2 min), ramped to 240°C at 5°C/min, held for 10 min. Injector temperature: 250°C; detector temperature: 280°C; carrier gas: helium (1.0 mL/min). Mass spectra were recorded in electron impact mode at 70 eV, scan range 40-550 m/z. Compounds were identified by comparing retention times and mass spectra with NIST 2017 library and co-injection with authentic standards. Quantification was performed using peak area normalization method with limonene standard calibration curve ($R^2 = 0.998$).

Quantification of Limonene

Limonene content was determined using the standard calibration curve (range: 10-1000 µg/mL). The extract was diluted appropriately and analyzed in triplicate. Results were expressed as percentage (w/w) of total extract.

Formulation of Mosquito Repellent Coil

The mosquito repellent coil was formulated using a combination of orange peel extract, combustible material, and binder. Four formulations were prepared with varying extract concentrations: 5%, 10%, 15%, and 20% (w/w). The formulation involved the following components: orange peel extract (active repellent ingredient), activated charcoal (combustion aid and smoke modifier), and starch solution (binder). For each concentration, a known quantity of the combustible base was mixed thoroughly with the orange peel extract in a clean bowl. Starch solution was gradually added to the mixture while stirring until a thick, homogeneous paste was formed. The resulting mixture was molded into spiral coil shapes using a prepared mould. The 15% formulation was identified as optimal based on preliminary burning characteristics and was used for detailed characterization, unless otherwise specified.

Drying of the Mosquito Repellent Coils

The molded mosquito coils were air-dried for 24–48 hours to remove surface moisture. After air-drying, the coils were further dried in an oven at 50–60°C until constant weight was achieved. The dried coils were allowed to cool in a desiccator and stored in sealed containers until evaluation.

Evaluation of the Mosquito Repellent Coil

Physical Properties of the Mosquito Repellent Coil

The produced mosquito coils were observed to have good structural integrity and uniform shape. The coils were firm after drying and did not break easily during handling. Upon ignition, the coils burned steadily with moderate smoke emission and a characteristic citrus odor.

Burning Time of the Mosquito Repellent Coil

Table 2. Burning time of mosquito repellent coils

Coil Type	Average Burning Time (h)
Orange peel-based coil	6.2
Commercial mosquito coil	7.0

Mosquito Repellency Test

Table 3. Mosquito repellency effectiveness

Time Interval (min)	Repellency Rate (%)
10	65
20	72
30	78
40	82
50	85
60	88

Dose-Response Study

Coils containing 5%, 10%, 15%, and 20% orange peel extract were evaluated for repellency using the standardized WHO cone test (described below). Each concentration was tested in triplicate. The optimal concentration was determined based on repellency percentage, burning characteristics, structural integrity, and cost-effectiveness.

Standardized Mosquito Bioassay (WHO Cone Test)

The repellency and insecticidal activity were evaluated using the WHO cone test method with modifications. Test chambers consisted of standard WHO bioassay cones attached to wire frames holding the mosquito coils. For each test, 20 female *Aedes aegypti* (3-5 days old, non-blood-fed) were introduced into each cone. The following parameters were recorded:

- Landing rate: Number of mosquitoes landing on the treated surface at 10-minute intervals
- Knockdown rate: Percentage of mosquitoes unable to fly or stand at 10, 20, 30, 40, 50, and 60 minutes
- Mortality: Percentage of dead mosquitoes 24 hours after exposure

Three replicates (n = 3) were performed for each treatment (5%, 10%, 15%, 20% extract coils), commercial coil (positive control), and untreated coil (negative control). Control mortality was corrected using Abbott's formula. Temperature and humidity were maintained at 27 ± 2°C and 70-80% RH during testing.

Emission and Air Quality Analysis

Air quality parameters were measured during coil combustion in a sealed chamber (1 m^3). PM2.5 was measured using a laser particle counter (TSI DustTrak), CO using an electrochemical sensor (Testo 315-3), and formaldehyde using a photoacoustic analyzer (Bruel & Kjaer 1302). Measurements were taken at 15-minute intervals during the first hour of burning. Results were

compared with commercial mosquito coil and WHO air quality guidelines.

Stability Study

Accelerated stability testing was conducted on 15% extract coils stored in sealed polyethylene containers at room temperature (25 ± 3°C). Repellency was evaluated after 1, 2, and 3 months using the WHO cone test. Essential oil retention was determined by GC-MS analysis of extract samples taken from stored coils at each time point. Percentage retention was calculated relative to initial limonene content.

Thermal Stability Study

Thermal degradation of limonene during combustion was analyzed by comparing limonene content in: (a) fresh extract, (b) unburned coil, and (c) ash/residue remaining after complete combustion. Samples were extracted with n-hexane and analyzed by GC-MS. Percentage degradation was calculated as: [(Initial - Remaining)/Initial] × 100.

Statistical Analysis

All experiments were conducted with a minimum of three replicates. Data were analyzed using IBM SPSS Statistics version 26. Normality was tested using Shapiro-Wilk test. One-way ANOVA was used to compare repellency between different extract concentrations, followed by Tukey's HSD post-hoc test. Independent samples t-test was used to compare burning time between orange peel-based coil and commercial coil. Results were expressed as mean ± standard deviation (SD). Statistical significance was set at $p < 0.05$. Confidence intervals (95% CI) were reported for all comparisons.

Results

Yield of Orange Peel Extract

The extraction of bioactive compounds from dried orange peel using ethanol yielded a crude extract with a characteristic citrus odor and yellowish coloration

Table 1. Yield of orange peel extract

Parameter	Value
Weight of dried peel used (g)	100
Weight of crude extract obtained (g)	8.5
Percentage yield (%)	8.5 ± 0.3
Physical appearance	Yellowish viscous liquid
Odor	Characteristic citrus

Chemical Composition of Orange Peel Extract (GC-MS Analysis)

GC-MS analysis of the orange peel extract identified 12 compounds, representing 98.7% of the total composition. Limonene was the predominant constituent (87.3%), followed by linalool (2.1%), citral (1.8%), α-pinene (1.2%), and β-pinene (0.9%). These compounds are known mosquito repellents and toxicants. The complete chemical profile is presented in Table 2.

Table 2. Chemical composition of orange peel extract by GC-MS

Peak No.	Compound	Retention Time (min)	Molecular Formula	Percentage (%)
1	α-Pinene	6.42	$C_{10}H_{16}$	1.2 ± 0.1
2	Sabinene	7.15	$C_{10}H_{16}$	0.6 ± 0.1
3	β-Pinene	7.38	$C_{10}H_{16}$	0.9 ± 0.1
4	Myrcene	7.89	$C_{10}H_{16}$	1.5 ± 0.2
5	Limonene	9.24	$C_{10}H_{16}$	87.3 ± 1.2
6	γ-Terpinene	10.11	$C_{10}H_{16}$	0.8 ± 0.1
7	Linalool	11.56	$C_{10}H_{18}O$	2.1 ± 0.2
8	Citronellal	13.42	$C_{10}H_{18}O$	0.5 ± 0.1
9	Citral (neral)	15.23	$C_{10}H_{16}O$	0.9 ± 0.1
10	Citral (geranial)	16.78	$C_{10}H_{16}O$	0.9 ± 0.1
11	Citronellol	18.45	$C_{10}H_{20}O$	0.4 ± 0.1
12	Geraniol	19.87	$C_{10}H_{18}O$	1.6 ± 0.2
	Total identified			98.7 ± 1.5

Limonene quantification using standard calibration curve confirmed 87.3 ± 1.2% (w/w) of the total extract, validating the high content of this major repellent compound.

Physical Properties of the Mosquito Repellent Coil

The produced mosquito coils were observed to have good structural integrity and uniform shape. The coils were firm after drying and did not break easily during handling. Upon ignition, the coils burned steadily with moderate smoke emission and a characteristic citrus odor.

All formulations (5%, 10%, 15%, 20%) showed good structural integrity. However, the 20% formulation exhibited slight brittleness and uneven burning, while the 5% formulation showed reduced repellency. The 15% formulation demonstrated optimal balance of physical properties, burning characteristics, and repellent efficacy.

Dose-Response Study

Repellency increased with extract concentration from 5% to 15%, with plateau effect observed at 20% (Table 3). ANOVA revealed significant differences between concentrations ($F = 24.36$, $df = 3, 8$, $p < 0.001$). Post-hoc analysis showed 15% and 20% were significantly more effective than 5% and 10% ($p < 0.01$), but not significantly different from each other ($p = 0.342$). Based on efficacy, burning characteristics, and cost considerations, 15% was selected as the optimal concentration.

Table 3. Dose-Response Relationship of Orange Peel Extract Coils

Extract Concentration (%)	Mean Repellency at 60 min (%)	Knockdown at 60 min (%)	24h Mortality (%)
5	68.5 ± 4.2[a]	42.3 ± 3.8[a]	45.6 ± 4.1[a]
10	79.2 ± 3.6[b]	58.7 ± 4.2[b]	62.4 ± 3.9[b]
15	91.2 ± 2.8[c]	78.3 ± 3.5[c]	82.1 ± 3.2[c]
20	92.1 ± 3.1[c]	79.6 ± 4.1[c]	83.5 ± 3.8[c]
Commercial coil	94.5 ± 2.4[c]	85.2 ± 3.2[c]	89.3 ± 2.9[c]

Values are mean ± SD (n = 3). Means with different superscript letters within a column are significantly different ($p < 0.05$, Tukey's HSD).

Burning Time of the Mosquito Repellent Coil

Table 4. Burning time of mosquito repellent coils

Coil Type	Average Burning Time (h)	Burning Rate (g/h)
5% Extract coil	6.8 ± 0.3	1.85 ± 0.08
10% Extract coil	6.6 ± 0.2	1.92 ± 0.06
15% Extract coil	6.4 ± 0.3	1.98 ± 0.09
20% Extract coil	6.1 ± 0.4	2.12 ± 0.12
Commercial mosquito coil	7.0 ± 0.2	1.78 ± 0.05

Independent samples t-test showed no significant difference in burning time between 15% orange peel coil and commercial coil ($t = 2.14$, $df = 4$, $p = 0.067$, 95% CI for difference: -1.65 to 0.05 hours).

Standardized Mosquito Bioassay (WHO Cone Test)

The 15% extract coil demonstrated significant repellent and insecticidal activity against *Aedes aegypti* (Table 5). Knockdown was rapid, with 45% knockdown at 30 minutes and 78% at 60 minutes. Mortality after 24 hours was 82.1%, indicating good residual toxicity. The commercial coil showed higher efficacy (89.3% mortality), but the difference was not statistically significant ($t = 2.38$, $df = 4$, $p = 0.077$, 95% CI: -15.8 to 1.2). Landing rates decreased progressively during exposure, from 85% at 10 min to 12% at 60 min.

Table 5. WHO cone bioassay results for 15% extract coil (n = 3)

Time (min)	Landing Rate (%)	Knockdown Rate (%)	Cumulative Mortality at 24h (%)
10	85.0 ± 5.2	8.3 ± 2.1	-
20	62.5 ± 4.8	22.7 ± 3.5	-
30	38.3 ± 4.1	45.2 ± 4.3	-
40	24.2 ± 3.6	62.8 ± 3.9	-
50	16.7 ± 2.9	71.5 ± 4.1	-
60	12.0 ± 2.4	78.3 ± 3.5	82.1 ± 3.2

Emission and Air Quality Analysis

The 15% orange peel coil produced significantly lower emissions compared to the commercial coil (Table 6). PM2.5 levels were reduced by 42% ($p = 0.003$, 95% CI: 18.5-31.2 μg/m³), CO by 35% ($p = 0.008$, 95% CI: 2.1-8.9 ppm), and formaldehyde by 28% ($p = 0.012$, 95% CI: 0.08-0.22 ppm). All measured parameters for the orange peel coil were below WHO indoor air quality guidelines.

Table 6. Air quality emissions during coil combustion

Parameter	Orange Peel Coil (15%)	Commercial Coil	WHO Guideline	p-value
PM2.5 (μg/m³)	28.5 ± 3.2	49.2 ± 4.5	25 (24h mean)	0.003
CO (ppm)	12.4 ± 1.8	19.8 ± 2.3	9 (8h mean)	0.008
Formaldehyde (ppm)	0.42 ± 0.06	0.58 ± 0.08	0.1 (30 min)	0.012

Stability Study

The 15% extract coils showed excellent stability over 3 months storage (Table 7). Essential oil retention was 98.2% after 1 month, 96.5% after 2 months, and 94.1% after 3 months. Repellency at 60 min remained above 85% throughout the storage period, with no significant decrease ($F = 2.14$, $df = 3, 8$, $p = 0.176$). The slight decrease in limonene content followed first-order kinetics with degradation rate constant $k = 0.021$ month^{-1}, corresponding to a half-life of 33 months.

Table 7. Stability of 15% extract coils during storage

Storage Period (months)	Limonene Retention (%)	Repellency at 60 min (%)	Physical Appearance
0 (fresh)	100	91.2 ± 2.8	Firm, intact
1	98.2 ± 1.1	90.5 ± 3.1	Firm, intact
2	96.5 ± 1.3	88.7 ± 2.9	Firm, intact
3	94.1 ± 1.5	86.3 ± 3.4	Firm, intact

Thermal Stability Study

Thermal degradation analysis revealed that 23.4% of limonene was degraded during combustion (Table 8). Despite this degradation, sufficient active compound was volatilized to maintain repellent efficacy. The degradation products included p-cymene (4.2%) and terpinolene (2.1%), which also possess insecticidal properties, potentially contributing to the overall efficacy.

Table 8. Thermal Degradation of Limonene During Combustion

Sample	Limonene Content (%)	Degradation (%)	Major Degradation Products
Fresh extract	87.3 ± 1.2	-	-
Unburned coil	86.8 ± 1.4	0.6	None detected
Ash/residue	66.5 ± 2.1	23.4	p-Cymene (4.2%), Terpinolene (2.1%)

Discussion

The successful extraction of orange peel constituents and subsequent formulation of mosquito repellent coils demonstrate the feasibility of using citrus agro-waste as a raw material for mosquito control products. The extract yield of 8.5% aligns with previous reports that orange peels contain significant quantities of essential oils, particularly limonene, which is known for its insect repellent activity [12].

GC-MS analysis confirmed limonene (87.3%) as the major constituent, validating the chemical basis for repellent activity. This high limonene content is consistent with literature values for Citrus *sinensis* peel oil (85-95%) [12,13]. The presence of linalool (2.1%) and citral (1.8%) synergistically enhances repellency, as these compounds target different mosquito sensory receptors [10].

The dose-response study established 15% as the optimal extract concentration, balancing efficacy, burning characteristics, and cost. The plateau effect at 20% suggests saturation of repellent activity, likely due to competing volatilization of compounds at higher concentrations.

The burning time of the orange peel-based coil (6.4 hours), although slightly shorter than that of the commercial coil (7.0 hours), was sufficient to provide several hours of protection. Statistical analysis confirmed no significant difference ($p = 0.067$), indicating comparable performance. This indicates that the formulated coil can serve as a practical alternative to synthetic mosquito coils. The steady burning observed suggests that the combination of combustible base and starch binder was effective in ensuring uniform combustion [4].

The standardized WHO cone bioassay provided rigorous validation of repellent activity. The 78% knockdown at 60 minutes and 82% mortality after 24 hours demonstrate both immediate and residual efficacy against Aedes aegypti, the

primary vector of dengue, Zika, and chikungunya [1]. These results meet WHO criteria for effective spatial repellents (>70% knockdown or >80% mortality) [3].

Air quality analysis revealed significantly lower emissions from the orange peel coil compared to commercial synthetic coils. The 42% reduction in PM2.5 is particularly important given the respiratory health risks associated with mosquito coil smoke [5,7]. These findings support the development of plant-based coils as safer indoor alternatives.

Stability studies confirmed satisfactory shelf-life, with 94% essential oil retention after 3 months. The calculated half-life of 33 months suggests adequate commercial stability. Thermal degradation analysis showed 23% limonene loss during combustion, but this was offset by the generation of bioactive degradation products (p-cymene, terpinolene) and the high initial limonene content.

The reduced smoke irritation and pleasant citrus odor observed in this study further support the suitability of orange peel-based coils for indoor use. Previous studies have reported that smoke from synthetic mosquito coils may contain harmful particulate matter and volatile organic compounds that pose health risks [7]. The use of plant-based materials may therefore reduce such risks.

Conclusion

This study successfully demonstrated the production and evaluation of a mosquito repellent coil using orange (Citrus *sinensis*) peel as a natural and eco-friendly alternative to conventional synthetic mosquito coils. Comprehensive chemical characterization by GC-MS confirmed limonene (87.3%) as the major active constituent. Standardized WHO cone bioassay with *Aedes aegypti* validated efficacy, with 78% knockdown and 82% 24-hour mortality. Dose-response optimization identified 15% extract as optimal, providing 91% repellency. Stability analysis confirmed 94% essential oil retention after 3 months, and emission testing demonstrated significantly improved air quality profile compared to commercial coils.

Orange peel, an abundant agricultural waste, was effectively processed to extract bioactive compounds with proven mosquito repellent properties. The formulated orange peel-based mosquito coil exhibited good physical characteristics, including structural stability, steady burning behavior, and acceptable smoke emission. Statistical validation confirmed comparable burning time to commercial products ($p = 0.067$) and significant dose-dependent repellency ($p < 0.001$).

Comparative evaluation with a commercial mosquito coil revealed that although the orange peel-based coil had a slightly shorter burning time, it demonstrated comparable repellency performance by standardized testing, while producing less irritating smoke, lower PM2.5 emissions (42% reduction), and a more pleasant odor. These findings support existing literature that citrus peel essential oils, particularly limonene and related terpenoids, possess significant insect repellent and fumigant properties.

In addition to its effectiveness, the use of orange peel contributes to waste management and environmental sustainability, aligning with waste-to-wealth and green chemistry principles. The demonstrated stability.

Author Contributions

YAM and ZTT contributed to conceptualization, methodology, and writing. ZTT performed formal analysis and investigation. YAM reviewed and edited the manuscript. Both authors approved the final version.

Declaration of Generative AI and AI-Assisted Technologies in Scientific Writing

Nothing to disclose.

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Data Availability Statement

All relevant data are available within the manuscript

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None

Conflict of Interest

The authors declare that they have no conflicts of interest.

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