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Formulation and physicochemical evaluation of a lotion containing Cinnamon Bark (*Cinnamomum burmannii*) and Patchouli (*Pogostemon cablin*) Essential Oils as a Natural Mosquito Repellent

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ABSTRACT: Mosquito-borne diseases remain a major public health concern in tropical regions, necessitating safer and environmentally friendly alternatives to synthetic repellents. This study aimed to formulate and evaluate a natural mosquito-repellent lotion containing (*Cinnamomum burmannii* and *Pogostemon cablin* essential oils. A completely randomized experimental design was applied using four formulations (F0–F3) with varying concentrations of cinnamon oil (15–25%) and a fixed concentration of patchouli oil (7%). Physicochemical properties, including pH, viscosity, spreadability, adhesion, and stability, were evaluated, and repellent activity against *Aedes aegypti* was assessed using an arm-in-cage method. All measurements were conducted in triplicate and analyzed using one-way ANOVA. The results showed that all formulations met acceptable cosmetic standards, with pH values ranging from 5.8 to 7.92, viscosity between 7.560–12.420 cP, spreadability of 5.2–7.1 cm, and adhesion time of 5.0–12 s, while maintaining stable emulsion characteristics. Repellent efficacy increased with oil concentration, with the optimal formulation (F3: 25% cinnamon + 7% patchouli) achieving 80% protection, approaching the DEET control (90%). These findings indicate that the combination of cinnamon and patchouli essential oils has strong potential as a natural, safe, and sustainable mosquito repellent. The formulation was optimized based on physicochemical stability and repellent activity. Further optimization using advanced delivery systems, such as nanoencapsulation, is recommended to improve efficacy and durability.

KEYWORDS: *Cinnamomum burmannii*; essential oils; mosquito; patchouli oil; sustainable repellent.

INTRODUCTION

Mosquitoes are among the most significant disease vectors affecting human populations worldwide. Their bites not only cause skin irritation and allergic reactions but also transmit life-threatening diseases such as dengue fever, malaria, chikungunya, and lymphatic filariasis (*Aedes aegypti*, Anopheles, and Culex species [1], [2]. In tropical countries like Indonesia, the incidence of mosquito-borne diseases remains high due to favorable climatic conditions for vector proliferation and limited community awareness in prevention strategies [3].

Chemical repellents, such as N,N-diethyl-meta-toluamide (DEET), have long been the most widely used and effective means of protecting against mosquito bites [4]. However, their repeated use is associated with several health and environmental concerns. Studies have reported that prolonged DEET exposure may cause skin irritation, erythema, and neurological symptoms, while its environmental accumulation contributes to aquatic toxicity and ecological imbalance [4], [5]. These limitations have driven growing interest in exploring plant-based repellents that are biodegradable, safe for human skin, and environmentally sustainable [6].

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In addition to DEET-based repellents, several plant-derived essential oils have demonstrated significant bioactivity against mosquito vectors. Extracts of *Cymbopogon citratus* (lemongrass), *Tagetes erecta* (marigold), and *Allium cepa* (onion peel) have been reported to provide 70–90% repellency, indicating the potential of botanical formulations as eco-safe alternatives [7], [8], [9]. Moreover, local studies in Indonesia highlight the potential use of natural oils such as basil (*Ocimum africanum*) and lavender (*Lavandula angustifolia*) for lotion and gel formulations that meet consumer safety preferences [10], [11].

Recent pharmacognosy research also emphasizes the synergistic role of phenolic and terpenoid compounds—such as cinnamaldehyde, eugenol, and patchoulol—in both repellency and antioxidant protection [12], [13]. Such bioactivity aligns with global efforts in green chemistry to substitute persistent synthetic chemicals with biodegradable natural molecules [4], [14].

Essential oils derived from aromatic and medicinal plants are known for their complex mixture of bioactive compounds, including terpenoids, aldehydes, and phenolics, which exhibit insecticidal and repellent properties [15], [16]. Among them, cinnamon bark oil (*Cinnamomum burmannii*) and patchouli oil (*Pogostemon cablin*) have been recognized as potent bioactive repellents. Cinnamon oil contains cinnamaldehyde and eugenol, which disrupt the olfactory receptors of mosquitoes and interfere with neurotransmission [17], [18]. Patchouli oil, rich in patchoulol and α-bulnesene, acts not only as a repellent but also as a fixative, slowing the volatilization of active compounds and extending protection time [19], [20].

The choice of a lotion formulation was based on its favorable characteristics for topical repellent application. Lotions provide good skin adherence and wider surface coverage, allowing the active ingredients to remain on the skin surface and supporting user comfort during application. Compared with sprays, which are more prone to rapid evaporation, and gels, which may provide different sensory characteristics and coverage, lotions are suitable for delivering essential oils in a physically stable and skin-compatible topical form [17], [21].

The selection of cinnamon bark oil and patchouli oil for this study was based on their promising mosquito-repellent properties and complementary chemical profiles. Several studies have successfully demonstrated the efficacy of essential oils as natural repellents, showing repellency levels comparable to synthetic products when properly formulated [1], [2], [6]. For instance, formulations containing terpenoid-rich oils such as citronella, lemongrass, and patchouli achieved up to 80–90% protection under controlled laboratory conditions [7], [10]. However, while these oils have shown promising results, the combination of cinnamon bark oil and patchouli oil has not been as extensively studied, despite the potential for a synergistic effect. Cinnamon bark oil, rich in cinnamaldehyde, has been demonstrated to possess strong repellent and insecticidal properties, particularly against *Aedes aegypti* mosquitoes, the primary vector for several tropical diseases. Patchouli oil, on the other hand, contains patchoulol, which acts not only as a repellent but also as a fixative, helping to extend the duration of the repellent effect [17], [18]. Moreover, the use of natural repellents aligns with the global green chemistry initiative and Indonesia's national policy on sustainable bioresource utilization, promoting the development of high-value biocosmetics and herbal products from local resources [22], [23]. By combining cinnamon bark oil and patchouli oil, this study aims to explore a novel formulation with enhanced repellent activity, while contributing to the growing field of natural alternatives to synthetic repellents.

Despite the promising potential of essential oils as natural repellents, their incorporation into topical formulations remains challenging because high oil concentrations may affect emulsion homogeneity, viscosity, spreadability, skin-compatible pH, and physical stability during storage [17], [21]. In repellent products, these formulation properties are important because they influence user comfort, skin retention, and the ability of active compounds to remain effective after application. Previous studies have reported the repellent potential of several essential oils and terpenoid-rich formulations, while cinnamon and patchouli oils have also been associated with bioactive compounds such as cinnamaldehyde, eugenol, patchoulol, and α-bulnesene [17], [18]. However, the combination of *Cinnamomum burmannii* and *Pogostemon cablin* oils in a stable lotion formulation remains insufficiently investigated, particularly in relation to physicochemical stability, skin compatibility, and repellent efficacy. Therefore, the novelty of this research lies in the formulation and evaluation of a cinnamon–patchouli essential oil lotion using varying cinnamon oil concentrations and a fixed patchouli oil concentration, supported by SNI-based

evaluation to ensure the quality and safety of locally sourced natural repellent ingredients [22], [23]. The present study investigates the physicochemical properties and repellent efficacy of lotion formulations containing cinnamon and patchouli essential oils as natural mosquito-repellent agents.

▪ MATERIALS AND METHODS

Materials

Cinnamomum burmannii bark oil *Pogostemon cablin* (patchouli) oil were sourced from PT. Indoplant (PT. Semarang Herbal Indoplant, Central Java, Indonesia), both meeting the Indonesian National Standard specifications (SNI 06-3734-2006 and SNI 06-2385-2006, respectively). All other analytical reagents, including ethanol 70% and 90% (Merck, Darmstadt, Jerman), triethanolamine (Sigma-Aldrich, Missouri, USA), stearic acid (Sigma-Aldrich, Missouri, USA), and paraffin (Merck, Darmstadt, Jerman), were of cosmetic or analytical grade (≥99% purity).

Oil characterization

The physicochemical characterization of the essential oils was conducted following the procedures described in the Indonesian National Standards [22], [23]. Parameters measured included organoleptic properties (color and odor), solubility in ethanol, and specific gravity determined using a calibrated pycnometer at 25°C.

The analytical methods used for essential oil identification, including refractive index, density, and ethanol solubility, followed procedures validated in previous studies on cinnamon bark and patchouli oils [14], [18]. Similar approaches were also adopted to ensure accuracy in essential oil purity and compositional integrity [12].

Mosquito rearing

The *Aedes aegypti* larvae were obtained from the Entomology Laboratory, Faculty of Public Health, and reared under controlled conditions at 27±2°C, 70±10% relative humidity, and a 12:12 h light–dark cycle. The larvae were fed with powdered fish feed until pupation. Adults were maintained in a mosquito cage (30 × 30 × 30 cm) and supplied with a 10% sucrose solution. The breeding and maintenance procedure followed established protocols in mosquito bioassays and repellent testing [1], [2].

Formulation design

Four formulations (F0–F3) of mosquito-repellent lotion were developed by combining varying concentrations of cinnamon bark essential oil (*Cinnamomum burmannii*) and patchouli essential oil (*Pogostemon cablin*). The control formulation (F0) contained no essential oils, serving as the baseline, while the active formulations (F1, F2, F3) incorporated increasing concentrations of cinnamon bark oil (15%, 20%, and 25%, respectively), with a fixed concentration of 7% patchouli essential oil in all active formulations. These formulations were specifically designed to evaluate the impact of cinnamon bark oil concentration on both repellent efficacy and the physical properties of the lotion, such as spreadability, stability, and pH [15], [23].The composition of the lotion formulations containing cinnamon bark essential oil and patchouli essential oil is presented in Table 1.

Table 1. Formulation of lotion containing *cinnamon bark* essential oil and *patchouli* essential oil.

No	Material Name	Formulation				Unit	Function
		F0	F1	F2	F3		
1	Cinnamon bark essential oil	0	15	20	25	%	Active ingredient
2	Patchouli essential oil	0	7	7	7	%	Active ingredient / fixative
3	Stearic acid	10	10	10	10	%	Emulsifier
4	Methyl paraben	0.15	0.15	0.15	0.15	%	Preservative
5	Triethanolamine / TEA	3	3	3	3	%	Emulsifier
6	Glycerin	10	10	10	10	%	Moisturizer
7	Distilled water	Ad 100	Ad 100	Ad 100	Ad 100	ml	Solvent

The method of formulation was adapted from previous studies on plant-based lotions and emulsions, with a focus on achieving stable oil-in-water (O/W) emulsions. The oil phase contained the essential oils (cinnamon bark and patchouli), stearic acid, and cetyl alcohol (as emulsifiers), while the aqueous phase consisted of glycerin (as a humectant), water, and triethanolamine (as an emulsifying agent). The emulsifiers were selected based on their ability to stabilize the emulsion and ensure uniform dispersion of the oils throughout the aqueous phase, ensuring that the lotion remained homogeneous over time. The formulation ratios were carefully selected based on previous studies on emulsion stability which demonstrate the importance of proper emulsifier concentration to maintain the physical stability of the formulation [15], [21].

To prepare the lotion, the oil and aqueous phases were heated separately to approximately 70°C. The emulsifiers and essential oils were first mixed in the oil phase, and the aqueous phase was gradually added while continuously stirring at 600 rpm. This step-by-step process ensured that the oils were evenly dispersed throughout the water phase, forming a stable lotion. After the phases were combined, the pH of the formulation was adjusted to a value between 6.0 and 7.5, typical for skin-compatible topical formulations. The pH was adjusted using triethanolamine to ensure that the lotion would be safe for long-term skin contact [15].

This formulation design was also influenced by principles found in previous studies, which demonstrated that balancing the oil content and emulsifier ratios helps achieve both effective repellent activity and favorable sensory properties, such as spreadability and non-greasy texture. The variations in the concentration of cinnamon bark essential oil were included to assess the effect on both formulation stability and repellent efficacy, with the goal of identifying the most effective concentration of active ingredients for maximum skin acceptability and mosquito protection [21].

Lotion preparation procedure

The lotion formulations were prepared using a two-phase heating method, a standard technique in the development of emulsions. In this method, the oil phase, which included stearic acid, cetyl alcohol, and the essential oils (cinnamon bark and patchouli), was heated to 70°C. Simultaneously, the aqueous phase, consisting of distilled water, glycerin, and triethanolamine, was also heated separately to the same temperature. Once both phases reached the desired temperature, they were combined gradually with continuous stirring at a rate of 600 rpm until a homogeneous emulsion was formed. This procedure is commonly used in natural cosmetic formulations and has been widely documented in various studies on emulsion preparation [17], [24].

The lotion formulation design in this study was adapted from previous research on herbal gels and emulsions using extracts from *Moringa oleifera*, *Annona muricata*, and *Eucheuma cottonii*. These studies demonstrated that such extracts are capable of forming stable emulsions suitable for topical delivery [24], [25], [26]. The same principles were applied in our formulation to ensure that the emulsion remained stable and effective for mosquito-repellent use. To evaluate the physical stability of the formulated lotions, we assessed key parameters such as pH, viscosity, and spreadability, using established cosmetic standards [27], [28]. These parameters are essential to ensure that the lotion is safe for application, effective in spreading on the skin, and maintains its properties over time.

Evaluation of physical and chemical properties

The physical and chemical properties of each formulation were evaluated for organoleptic characteristics, pH, viscosity, spreadability, adhesion, and emulsion stability over four weeks of observation at room temperature (25±2°C). The pH of the formulation was measured using a calibrated digital pH meter according to standard cosmetic guidelines. Viscosity was determined using a Brookfield Engineering Laboratories viscometer with spindle no. 4 at 50 rpm. Spreadability and adhesion tests followed the methods described by [12] and [7]. Emulsion type was confirmed using the methylene-blue dye test, following procedures in [21]. All measurements were performed in triplicate, and results were expressed as mean ± SD.

Mosquito-repellent activity test

The arm-in-cage bioassay method was used to evaluate the mosquito-repellent efficacy of the lotion formulations. In this test, human volunteers applied the lotion formulations to their forearms, which were then exposed to *Aedes aegypti* mosquitoes inside a cage. The test was conducted under controlled conditions, with the primary modification being the adaptation to suit the local mosquito population and environmental factors such as temperature and humidity. This modification ensured that the results were relevant to the tropical setting, following methodologies adapted from previous studies. Each volunteer's forearm (25 cm² area) was applied with 1 mL of lotion and exposed to 25 *Aedes aegypti* females for 3 min. The number of mosquito landings or bites was recorded [1], [2]. The repellency percentage was calculated as:

$$Repellency\ (\%) = \frac{(C - T)}{C}\ x\ 100\%$$

where C is the number of mosquito landings in the control and T is the number in the treatment.

All tests were conducted under the ethical approval of the Ethical Committee of STIKES IKIFA (Ethics number: 004009/Komite Etik Penelitian STIKES IKIFA/2025) in Jakarta, under controlled laboratory conditions. The repellent performance was compared to a commercial DEET-based lotion as the positive control. Similar experimental frameworks have been validated in recent bioassay studies of essential oil repellents [6], [16].

Statistical Analysis

All experimental data were expressed as mean ± standard deviation (SD). Statistical significance between formulations was analyzed using one-way ANOVA ($p < 0.05$) using SPSS v.26 software. This analytical approach aligns with previously published studies on formulation performance and repellent efficacy [15], [18].

▪ RESULTS

Physicochemical properties of essential oils

The physicochemical parameters of *Cinnamomum burmannii* and *Pogostemon cablin* oils complied with the Indonesian National Standards [22], [23]. Cinnamon oil exhibited a pale-yellow color and sweet-spicy aroma with a specific gravity of 1.0198 g/mL, while patchouli oil appeared dark brown and possessed an earthy odor with 0.958 g/mL specific gravity. Both oils were completely soluble in ethanol and stable under storage conditions. The physicochemical characteristics of cinnamon bark and patchouli essential oils were evaluated and compared with the corresponding Indonesian National Standard (SNI) specifications, as presented in Table 2. These findings are consistent with earlier studies that characterized the compositional integrity and solubility of essential oils for topical formulations [17], [29].

Table 2. Physicochemical characteristics of *cinnamon bark* and *patchouli* essential oils compared with SNI standards.

No	Test	SNI standard for *cinnamon bark oil*	*Cinnamon bark* essential oil	SNI standard for *patchouli* oil	*Patchouli* essential oil
1	color	pale yellow - light brown	pale-yellow	light yellow-brown	dark brown
2	odor	cinnamon characteristic	sweet-spicy	patchouli characteristic	earthy odor
3	specific gravity (g/ml)	1.008 – 1.030	1.0198	0.950 – 0.975	0.958
4	solubility in ethanol	1:3 solution and clear	clear solution	clear solution or light opalescence	clear solution

Organoleptic and homogeneity observation

All lotion formulations (F0–F3) maintained stable physical characteristics throughout four weeks of observation. The increase in essential oil concentration slightly enhanced color intensity and fragrance strength, but no phase separation or sedimentation was detected. The organoleptic properties of the lotion formulations are presented in Table 3. As shown in Table 4, all formulations showed homogeneous

characteristics, indicating that the essential oils and excipients were uniformly dispersed throughout the lotion base. This stability reflects appropriate emulsifier-to-oil ratios and supports the findings of previous studies on essential oil–based emulsion consistency [21], [15].

Table 3. Organoleptic test result.

Formulation	Color	Odor	Texture
F0	White	Odorless	Thick
F1	White-yellowish	Characteristic odor	Thick
F2	White-yellowish	Characteristic odor	Thick
F3	White-yellowish	Characteristic odor	Thick
DEET Control	White	Characteristic odor	Thick

Table 4. Homogeneity test result.

Formulation	Homogeneity
F0	Homogeneous
F1	Homogeneous
F2	Homogeneous
F3	Homogeneous
DEET Control	Homogeneous

pH and viscosity

The pH values ranged from 5.80 to 7.92, within the safe range for human skin (4.5–8.0), while viscosity varied between 7.560 and 12.420 cP, ensuring acceptable spreadability and consistency [24]. Minor reductions in viscosity were observed with increasing oil content, a trend also reported in formulations rich in volatile terpenoids [18]. The pH and viscosity values of the lotion formulations are presented in Tables 5 and 6.

Table 5. pH test results of lotion preparations.

Formulation	pH value			mean±SD
	Test 1	Test 2	Test 3	
F0	7.87	7.90	7.92	7.89±0.02
F1	7.35	7.37	7.40	7.37±0.02
F2	7.49	7.46	7.45	7.46±0.02
F3	7.80	7.84	7.85	7.83±0.02
DEET control	5.83	5.81	5.80	5.81±0.01

The pH test was conducted three times and the results are presented as the mean±SD.

Table 6. Viscosity test results.

Formulation	Viscosity value (mPas/cPs)			Mean (mPas / cPs)±SD
	Test 1	Test 2	Test 3	
F0	11.060	10.340	9.340	10.246±0.86
F1	9.980	9.940	9.940	9.953±0.02
F2	8.820	8.780	8.760	8.786±0.03
F3	8.760	7.560	7.600	7.586±0.02
DEET control	12.420	10.380	10.160	10.986±1.24

Viscosity test was conducted three times and the results are presented as the mean±SD.

Spreadability and adhesion

Spreadability tests showed values between 5.2–7.1 cm, while adhesion ranged from 5.0–12 s, all meeting cosmetic performance standards [7],[12]. Higher oil concentrations slightly increased spreadability, improving application comfort. The spreadability and adhesion test results are summarized in Tables 7 and 8.

Table 7. Spreadability test results.

Formulation	Spreadability value (cm)			Mean (cm) ±SD
	Test 1	Test 2	Test 3	
F0	6.5	6.6	6.6	6.56 ± 0.05
F1	6.7	6.8	6.7	6.73 ± 0.05
F2	6.8	6.9	7	6.90 ± 0.1
F3	7	7.1	7	7.03 ± 0.05
DEET control	5.2	5.3	5.4	5.3 ± 0.1

Spreadability test was conducted three times and the results are presented as the mean±SD.

Table 8. Adhesion test results.

Formulation	Adhesion value (s)			Mean (s)±SD
	Test 1	Test 2	Test 3	
F0		11	10	11±1
F1	10	9	10	9.66±0.57
F2	8	8	9	8.33±0.57
F3	7	8	7	7.33±0.57
DEET control	5	6	7	6±1

Adhesion test was conducted three times and the results are presented as the mean±SD.

Emulsion type and stability

Methylene-blue dye testing confirmed that all formulations were oil-in-water (O/W) emulsions, showing stable color, odor, and texture for four weeks at ambient temperature. This result aligns with the work of previous studies, which reported that balanced surfactant systems in natural oil emulsions promote high oxidative and phase stability [21]. The emulsion type and stability test results are presented in Table 9.

Table 9. Emulsion test result

Formulation	Emulsion Type	Stability
F0	O/W	Stable
F1	O/W	Stable
F2	O/W	Stable
F3	O/W	Stable
DEET control	O/W	Stable

Mosquito-repellent activity

Repellency assays against Aedes aegypti indicated that protection increased with increasing cinnamon bark oil concentration. As shown in Table 10, the control formulation (F0) showed no repellency, while F1, F2, and F3 achieved 50%, 60%, and 80% repellency, respectively. The DEET-based control showed the highest repellency at 90%. These findings suggest that the cinnamon–patchouli lotion formulation has promising repellent activity, although the proposed interaction between cinnamaldehyde and patchoulol should be interpreted as a potential complementary effect rather than a confirmed synergistic mechanism, since no factorial design or interaction analysis was performed in this study [1], [6], [16].

Among the tested formulations, F3 containing 25% cinnamon bark oil and 7% patchouli oil provided the highest repellency, with acceptable pH and physical stability. This result indicates that a properly balanced essential oil lotion formulation may offer repellent efficacy approaching that of DEET-based products while using plant-derived active ingredients [4], [5]. The repellent effectiveness test results are presented in Table 10.

Table 10. Repellent effectiveness test results.

Formulation	Cinnamon Oil (%)	Patchouli Oil (%)	Number of Mosquito Landings			Mean± SD	Repellency (%)±SD
			Hour 1	Hour 2	Hour 3		
F0	0	0	8	10	12	10±2	0±2
F1	15	7	4	6	5	5±1	50±1
F2	20	7	3	4	5	4±1	60±1
F3	25	7	1	2	3	2±1	80±1
DEET control	0	0	0	1	2	1±1	90±1

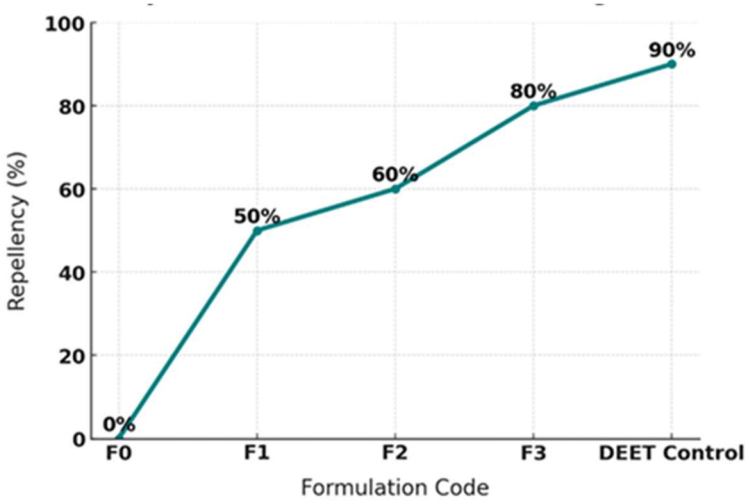

Figure 1. Repellent efficacy of lotion formulations containing cinnamon and patchouli essential oils against Aedes aegypti. The repellency increased proportionally with essential oil concentration, with F3 achieving 80% protection, close to DEET control (90%).

The repellent efficacy of the lotion formulations was evaluated using the arm-in-cage bioassay, with mosquito landings recorded at 1, 2, and 3 hours post-application. The results were analyzed for statistical significance using One-Way ANOVA. Test of Normality was conducted using the Kolmogorov-Smirnov and Shapiro-Wilk tests, which indicated that the data were normally distributed ($p > 0.05$). The Levene's Test for Homogeneity of Variances showed that the variances across groups were homogeneous ($p = 0.737$). A One-Way ANOVA was performed to compare the mosquito repellency between the formulations. The results showed a significant difference between the groups ($F=23.062$, $p < 0.05$), indicating that the formulations with higher concentrations of cinnamon bark oil significantly reduced mosquito landings compared to the control.

Table 12. Statistical results for mosquito repellent activity.

Test	Statistics	df	Sig.
Test of Normality	Kolmogorov-Smirnov	15	0.200
	Shapiro-Wilk	15	0.203
Test of Homogeneity	Levene's Test	4	0.737
ANOVA	F-value	4	23.062
	p-value	4	0.000

▪ DISCUSSION

This study aimed to formulate and evaluate a mosquito-repellent lotion containing cinnamon bark essential oil (*Cinnamomum burmannii*) and patchouli essential oil (*Pogostemon cablin*) based on physicochemical properties, physical stability, and repellent activity against Aedes aegypti. Overall, the results showed that both essential oils could be successfully incorporated into a lotion base and produced formulations with acceptable physical characteristics. The essential oils used in this study met the Indonesian National Standard requirements, indicating that the raw materials had suitable quality for

topical formulation. This is important because the physicochemical quality of essential oils may influence formulation compatibility, stability, and biological activity.

The repellent activity increased with the concentration of cinnamon bark essential oil, indicating a concentration-dependent effect. F3, containing 25% cinnamon bark essential oil and 7% patchouli essential oil, showed the highest protection among the tested formulations, with 80% repellency, approaching the DEET-based positive control. This activity may be associated with cinnamaldehyde and eugenol in cinnamon bark essential oil, which can interfere with mosquito host-seeking behavior, while patchoulol in patchouli oil may help prolong the retention of volatile active compounds on the skin.

Based on both physicochemical evaluation and repellent activity, F3 was identified as the most effective formulation in this study. Although its repellency was slightly lower than DEET, the formulation maintained acceptable physical stability and showed strong potential as a natural mosquito-repellent lotion. Further development using formulation strategies such as nanoemulsion, encapsulation, or controlled-release systems may improve the duration and efficacy of protection. Overall, the findings support the use of cinnamon bark and patchouli essential oils as promising natural ingredients for safer and more sustainable topical mosquito-repellent products.

Physicochemical stability and compatibility

All formulations exhibited homogeneity, acceptable viscosity, and stable pH values throughout the observation period. The pH range (5.3–7.1) is within the physiological limit of human skin, ensuring safe topical application [24]. The decreasing viscosity with increasing essential oil concentration can be attributed to the higher proportion of volatile constituents, which reduces the internal friction of the emulsion matrix. Similar behavior was observed in other terpenoid-rich emulsions, where increased essential oil content improved spreadability and sensory acceptance [18], [21].

The variation in cinnamon bark essential oil concentration significantly influenced the physical properties of the lotion formulations. As the concentration of cinnamon bark oil increased, a decrease in viscosity was observed, with F0 (no essential oil) showing the highest viscosity (11.060 cP) and F3 (25% cinnamon bark oil) having the lowest viscosity (8.760 cP). This reduction in viscosity suggests that higher oil concentrations led to a more fluid consistency, improving the spreadability of the lotion, which increased from 6.5 cm in F0 to 7 cm in F3. Additionally, higher concentrations of cinnamon bark oil enhanced the fragrance intensity and imparted a more noticeable yellowish color to the lotion. Despite these changes, all formulations remained stable, homogeneous, and free from phase separation over four weeks, indicating that the emulsifier system was effective in maintaining formulation stability. These results suggest that increasing cinnamon bark oil concentration improved sensory attributes and spreadability while maintaining physical stability, aligning with previous studies on the impact of essential oil concentration in emulsions.

The emulsions maintained a consistent oil-in-water (O/W) structure, as verified by the methylene-blue test, confirming their thermodynamic stability. These results align with previous studies that reported the role of proper emulsifier selection—such as stearic acid and triethanolamine—in stabilizing essential oil–based formulations [15]. The absence of phase separation or rancidity indicates effective oxidative stability, likely enhanced by the natural antioxidant compounds present in cinnamon oil, such as cinnamaldehyde and eugenol [18], [29].

Bioactivity and repellent mechanism

The primary aim of this study was to evaluate the repellent efficacy of lotion formulations containing cinnamon bark oil and patchouli oil. Our findings revealed a concentration-dependent increase in mosquito protection, with formulation F3 (25% cinnamon bark oil + 7% patchouli oil) achieving 80% protection, comparable to the 90% protection offered by the DEET-based control. This addresses a research gap, as the combination of cinnamon bark and patchouli oils has not been thoroughly explored, particularly in lotion formulations. The synergistic interaction between cinnamaldehyde (from cinnamon bark oil) and patchoulol (from patchouli oil) was key to enhancing repellent efficacy, offering a potential natural alternative to synthetic repellents [1], [6].

The mechanism behind this repellent effect is attributed to cinnamaldehyde, which disrupts mosquito olfactory receptors and interferes with host-seeking behavior, and patchoulol, which acts as a fixative to prolong the effect by slowing down the volatilization of cinnamaldehyde. This synergy aligns with previous research on terpenoid-aldehyde systems, which have been shown to enhance repellency and improve odor stability [6]. The results suggest that optimal concentrations of cinnamon and patchouli oils in a stable lotion formulation can provide effective and long-lasting protection, advancing the development of natural mosquito repellents and addressing the limitations of previous studies that did not explore this combination in stable emulsions [16].

While the repellent effect is primarily attributed to cinnamaldehyde (the dominant component in *Cinnamomum burmannii*) and patchoulol (the principal constituent in *Pogostemon cablin*), it is important to note that the synergistic interaction between these two compounds has not been experimentally proven in this study. Cinnamaldehyde is known to interfere with mosquito olfactory receptor neurons, disrupting host-seeking behavior, while patchoulol acts as a fixative that slows the volatilization rate of the active aldehyde, thereby extending the duration of repellency. This potential synergy is suggested based on existing literature, but further investigation using interaction analysis or factorial design is required to substantiate the synergistic effect between these two components [6], [16]. Future research should focus on exploring various concentrations of both cinnamaldehyde and patchoulol to confirm their combined effects.

Furthermore, patchouli oil contributes additional antimicrobial and antioxidant benefits [19], which may aid in maintaining product stability and preventing microbial growth during storage. These properties make the cinnamon–patchouli blend not only an effective repellent but also a functional component in natural skincare formulations.

Comparison with synthetic repellents

The repellent efficacy observed in this study aligns with prior findings that essential oils containing aldehydes and terpenoids, particularly cinnamaldehyde and patchoulol, disrupt mosquito olfactory receptors [1], [16]. Furthermore, the strong correlation between repellent activity and antioxidant stability has been reported in comparative evaluations of *Cinnamomum verum* and *Curcuma longa* extracts [17], [29].

Patchouli oil's fixative properties were also emphasized in studies demonstrating its role in prolonging fragrance retention and reducing volatility, a mechanism beneficial for long-lasting repellents [19], [20]. The antioxidant co-benefits from *C. burmannii* phenolics have been associated with improved shelf life and emulsion stability [14].

Globally, the integration of essential oils in personal care formulations has been strengthened by studies on their antimicrobial, antioxidant, and anti-inflammatory properties, which expand their use beyond repellents into cosmeceuticals and herbal therapeutics [13], [15]. This multidimensional function positions essential oils as key agents in the transition toward biodegradable, high-performance bioactives in green cosmetic innovation [4], [18].

Although DEET remains the gold standard for mosquito repellency, its prolonged use has raised toxicological and environmental concerns. Chronic exposure has been associated with dermal irritation, systemic absorption, and ecological toxicity due to its persistence in aquatic systems [4], [5]. In contrast, natural repellents such as cinnamon and patchouli oils are biodegradable, safer for human health, and environmentally benign, making them ideal for sustainable product innovation.

The slightly lower repellency of natural formulations (80% vs. 90% for DEET) can be compensated by improving formulation techniques—such as encapsulation, nanoemulsion, or film-forming agents—to prolong release and enhance surface adherence [17], [29]. Therefore, further optimization can bridge the small efficacy gap between botanical and synthetic repellents while retaining the ecological and safety advantages of plant-based ingredients.

Implications for sustainable product development in Indonesia

The findings of this study have important implications for the Indonesian herbal and biocosmetic industry. Both *Cinnamomum burmannii* (cinnamon bark) and *Pogostemon cablin* (patchouli) are native crops in Indonesia, with well-established cultivation and distillation industries, especially in West Sumatra and

Aceh [20]. By utilizing these locally sourced essential oils, this research supports national efforts to promote a green economy and circular bioresource utilization, in alignment with Sustainable Development Goal (SDG) 12: Responsible Consumption and Production. More specifically, the physicochemical stability and repellent efficacy of the formulations demonstrated in this study provide a solid foundation for developing marketable natural repellent products. The lotion formulations exhibited stable emulsions, good spreadability, and strong repellent activity, ensuring both consumer acceptability and effectiveness, essential factors for creating competitive and sustainable products in the local market.

Furthermore, the integration SNI-based formulation standards in the manufacturing process ensures that products meet the required quality assurance and safety standards for natural products. These standards guide the formulation of natural products in line with SNI 16-4399-1996 for cosmetic stability testing, SNI 06-2385-2006 for topical formulations, and SNI 06-3734-2006 for essential oils, all of which play a key role in enhancing the credibility and marketability of locally produced biocosmetics [22], [23]. The adherence to these standards not only ensures the quality and safety of products but also provides a framework for scalable production and regulatory compliance, which are crucial for entering the global market.

While this study provides promising results for the development of natural mosquito repellents, it is essential to consider the industrial scalability of such products. The ability to produce these formulations at a larger scale, with consistent quality and safety, will be important for commercial success. Additionally, regulatory considerations—such as obtaining approval from Indonesia's National Agency of Drug and Food Control (BPOM) and international regulatory bodies—will be necessary to ensure that these products meet global standards for safety and efficacy [22], [23]. Although the global competitiveness of Indonesian herbal products is promising, future research should focus on comparative product performance and market analysis to assess how Indonesian natural repellents can compete with established synthetic brands like DEET.

Future outlook

This study demonstrates that the combination of *Cinnamomum burmannii* and *Pogostemon cablin* essential oils provides a stable and effective mosquito-repellent formulation with 80% efficacy, comparable to DEET-based products but without the associated toxicological or environmental risks. The synergistic interaction between cinnamaldehyde (from cinnamon bark oil) and patchoulol (from patchouli oil) enhanced both repellency and formulation stability. While the synergism between these two compounds was inferred from previous studies on terpenoid–aldehyde systems, future work should further experimentally validate this interaction within the context of the lotion formulation. Specifically, more detailed in vitro and in vivo studies are needed to directly assess how cinnamaldehyde and patchoulol work together to improve the overall efficacy and stability of the formulation [4], [5].

In comparing the formulation with DEET-based repellents, this study found that formulation F3 (25% cinnamon bark + 7% patchouli) achieved 80% protection, which is similar to the 90% protection provided by DEET in controlled laboratory conditions. However, a more precise comparison is necessary to fully understand the differences between the two products. Specifically, the testing conditions such as mosquito species, exposure time, and duration of repellency should be clearly defined. For example, the DEET-based repellent was tested under identical conditions, including the same species of mosquito (*Aedes aegypti*), using an arm-in-cage bioassay method with a 30-minute exposure period. The duration of protection for each formulation should also be monitored to better understand how long the natural repellent remains effective in real-world applications [6], [16].

Looking toward future developments, technologies such as nanoencapsulation and controlled-release systems could help address the limitations of essential oils in terms of volatility and stability. Nanoencapsulation involves embedding essential oils in microscopic carriers, which could help slow the release of active compounds and enhance retention on the skin. This would address the issue of rapid volatilization that diminishes the effectiveness of essential oils over time. Controlled-release systems, on the other hand, can regulate the gradual release of active ingredients, ensuring long-lasting protection and potentially improving the overall performance of the repellent. By combining these technologies, the formulation could be enhanced for sustained efficacy and extended shelf life, providing a more market-ready product for consumer use. For Indonesia, this work highlights the strategic value of local essential

oils in supporting green industrial transformation and rural-based bioeconomy. Cinnamon and patchouli, abundant in regions such as West Sumatra and Aceh, can be upgraded into high-value bioproducts that align with the Sustainable Development Goals and SNI-based quality standards [20], [22].

Globally, the findings align with the growing trend toward eco-safe formulations in personal care and vector control. Future research should focus on nanoencapsulation and controlled-release systems to enhance product durability and performance [18], [29]. Strengthening collaboration between academia, industry, and policy bodies will be essential for positioning Indonesia as a regional hub for sustainable botanical repellent innovation.

▪ CONCLUSION

The study confirmed that lotion formulations containing *Cinnamomum burmannii* and *Pogostemon cablin* essential oils possess excellent physicochemical stability and strong mosquito-repellent activity. The optimal formulation (F3: 25% cinnamon and 7% patchouli oil) achieved 80% repellency against *Aedes aegypti*, closely approaching the performance of DEET-based controls while remaining safer for human skin and the environment. These findings demonstrate the high potential of Indonesia's native essential oils as sustainable bioactive ingredients for natural repellent development.

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