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ORIGINAL ARTICLE

Spectroscopic Analysis and Performance Evaluation in Eco-Friendly Neem Candle Formulation

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Abstract

Neem (*Azadirachta indica*) is one of India's most valued traditional medicinal herbs, with each part of the tree holding distinct medicinal properties. Mosquito-borne diseases pose a significant global health threat and require developing alternative mosquito-repellent solutions. This research explores the potential of neem-scented candles as a natural repellent due to neem's insect-repelling compounds, such as azadirachtin. In the beginning, the percentage of yield of neem oil extract, Fourier Transform Infrared Spectroscopy (FTIR), and Ultraviolet-Visible (UV-Vis) Spectroscopy were conducted to evaluate the neem oil. Additionally, tests on the candles' melting point, burning rate, scent stability, and candle compression were performed, along with a structured survey to assess consumer perception. After 28 hours of extraction, the highest yield of neem oil 35.0% was achieved. The FTIR and UV-Vis peaks confirmed the neem oil. In the flammability test, all the candle types had the same amount of flame height; the commercial and beeswax candles had a slightly higher flame height of 15 mm, while the 5% Neem and 2% wax candles had a flame height of 14 mm. In the burning rate test, neem-infused candles demonstrated higher burn rates than beeswax candles. All candle samples exhibited remarkable stability. There were no significant changes in their physical or sensory characteristics, indicating that the candles could withstand the test conditions without degrading. The neem candles, especially the 2% Neem candle, show higher compressive strength and structural integrity, according to the results of the compression tests. The formulated neem-scented candles exhibited moderate effectiveness in repelling mosquitoes, offering a potential alternative to chemical-based repellents. The consumer survey indicated a positive reception towards the neem-infused candles, appreciating their dual functionality as decorative items and mosquito repellents. Neem-scented candles demonstrate potential as an eco-friendly mosquito-repellent solution. The research supports using neem oil as a natural repellent, highlighting its biodegradability and minimal impact on beneficial insects. Future work could focus on optimizing the formulation for enhanced efficacy and exploring other natural additives to improve the candles' performance.

Keywords: *Azadirachta indica;* neem oil; neem candle properties; mosquito repellent; eco-friendly candles

Introduction

Mosquito-borne diseases, including malaria, dengue fever, Zika virus, and West Nile virus, pose significant public health threats, particularly in tropical and subtropical regions. These diseases not only affect human health but also impose substantial financial burdens and strain on healthcare systems globally (Torresi et al., 2019). Conventional mosquito control methods often rely on chemical insecticides, which, although effective, raise concerns due to their potential environmental and health impacts. Prolonged use of these substances can lead to resistance in mosquito populations and cause harm to non-target species, thereby disrupting ecosystems (Şengül Demirak et al., 2022).

Given these challenges, there is an increasing need for safe and environmentally friendly mosquito control methods. Neem oil (*Azadirachta indica*), extracted from the neem tree, has been identified as a promising natural alternative. Neem has been utilized for centuries in traditional medicine and agriculture, particularly in the Indian subcontinent, due to its numerous health benefits (Macchioni et al., 2019; Hashim et al., 2023a). The bioactive compounds in neem oil, especially azadirachtin, and limonoids, possess insecticidal properties that disrupt insect growth and development, making neem oil an effective natural mosquito repellent (Sarkar et al., 2021). Neem oil is not only known for its insect-repelling properties but also for its versatility and environmental benefits. Its use in candle-making adds aesthetic value while serving as an effective mosquito deterrent without the harmful effects associated with chemical repellents (Aidoo et al., 2021). In addition to its repellent qualities, neem oil exhibits anti-bacterial and anti-inflammatory properties, offering a multifaceted solution to mosquito-related issues. Additionally, it helps to maintain healthy hair and encourage hair growth. In the cosmetics and skincare sector, neem-based soaps and shampoos are typical (Baby et al., 2022).

Historically, neem has been valued in traditional medicine across Asia and Africa for its antiviral, antifungal, antibacterial, and anti-inflammatory properties. Various parts of the neem tree, such as leaves, seeds, and bark, have been used to treat illnesses including malaria, diabetes, and skin conditions. Scientific studies have supported many of these traditional uses, highlighting neem's therapeutic potential (Wylie et al., 2022).

Moreover, neem oil's role in organic and sustainable agriculture as a natural insecticide underscores its importance in reducing reliance on chemical pesticides (Agbo et al., 2019). In traditional animal husbandry, neem leaves and seeds have been used to treat livestock diseases and repel insects. Neem is beneficial in preventing common diseases in cattle, poultry, and other livestock when used in animal care (Tembe-Fokunang et al., 2019). Timber and bark from neem trees have been used to make baskets, farm equipment, and furniture. Neem seed oil is an essential component used in the manufacturing of soaps, cosmetics, and biofuels. Neem leaves have also been employed as organic means of preservation and storage. The nitrogen-fixing qualities of neem trees aid in soil fertility and facilitate reforestation initiatives. Additionally, they contribute to the preservation of soil and water.

The use of neem in ethnomedicine dates back thousands of years, particularly in the treatment of infectious diseases. In ancient times, neem was used to combat smallpox and other ailments, reflecting its long-standing significance in traditional health practices (Hashim et al., 2023b & 2023c). Furthermore, neem's insecticidal properties have made it a preferred choice for agricultural use, with farmers employing neem in crop protection and pest control. Recent scientific interest has also focused on neem's anti-cancer properties, with studies showing promising results in using neem bark extract to inhibit the growth of cancer cells (Kumar et al., 2022). Neem oil's reputation as an effective mosquito repellent is well-established, with studies demonstrating its efficacy in both repelling adult mosquitoes and killing larvae.

These findings support the use of neem oil as a comprehensive tool in mosquito control programs. Additionally, neem oil is considered safe for human use, with minimal negative effects on health or the environment (Macchioni et al., 2019). According to Sharma and Ansari (1994), lamps burning indoors with neem oil-kerosene mixes (0.1% to 1%) not only lessen mosquito bites in human subjects, but also lower the number of indoor mosquitoes between 6 PM and 6 AM (the recording period). In comparison to *Culex sp*., the mixture was found to provide superior protection against *Anopheles sp.* These findings led to the recommendation of a 1% neem oil and kerosene mixture as an inexpensive home treatment for mosquito bites. In another experiment, three ovitraps were treated with a neem oil-water mixture (5 g/L), while three other ovitraps served as controls. Only a solution of water and emulsifier (used in the neem oil-water mixture) was applied to the control ovitraps. The blend produced the highest outcomes in June and July, per the research data (Macchioni et al., 2019). They explained their findings by claiming that over time, when exposed to high temperatures and precipitation, neem oil's effectiveness deteriorated (Macchioni et al., 2019).

The objectives of the current study were to prepare the formulated neem candles by using the extracted neem oil. The performances of the candles were examined including the flammability, burning test, stability at room temperature, and compression. Lastly, a structured survey was conducted regarding mosquito effectiveness repellent, scent, and texture. Despite extensive research on neem-based mosquito repellents, there is a noticeable gap in studies focusing on neem candles and their properties. Most existing research emphasizes neem oil or extracts in sprays and lotions, while the effectiveness of neem in solid candle form remains underexplored.

Additionally, limited data are available on the physical properties of neem candles, such as stability and compression strength, which are crucial for their durability and practical use. While candle-related studies often discuss wax composition and essential oil retention, they rarely address the mechanical properties of neem-infused formulations. Furthermore, there is minimal scientific investigation into the burning rate and flammability of neem candles, which are key factors influencing both safety and efficiency in repelling mosquitoes.

Materials and Methods

Materials

Neem leaf samples were collected from trees at University College TATI, Kemaman. The extraction of neem oil utilized 95% ethanol, supplied by HmbG Chemicals. Beeswax, sourced from TheGreenAttic, candle dyes, and neem extract were also used in the preparation of neem-scented candles.

Neem Oil Preparation

In the pre-treatment of neem leaves, the neem leaves were washed with double distilled water to remove dust and foreign materials. The samples were then dried in an oven at 109 °C for 24 hours. After drying, the leaves were ground into a fine powder using a cylindrical grinding machine with a particle size of 0.5 mm, preparing them for extraction.

Furthermore, neem oil was extracted using the Soxhlet extraction technique to assess total oil yield. 60 grams of the powdered neem leaves were placed in a thimble, and 300 ml of 95% ethanol was added as the solvent. The extraction was carried out for 24 hours at 80 °C. The solvent mixture was then concentrated using a rotary evaporator to obtain pure neem oil (Norazlina et al., 2024).

Analysis of Neem Oil

The obtained neem oil was characterized. The yield of neem oil was calculated using the formula:

$$Yield\ of\ oil\ (\%) = \frac{Mass\ of\ oil\ obtained\ (g)}{Mass\ of\ raw\ material\ (g)}\ x\ 100 \quad (1)$$

Fourier Transform Infrared Spectroscopy (FTIR) analysis was conducted using an alpha ATR-FTIR spectrophotometer. This method identified the characteristic functional groups present in the neem oil, confirming its composition. Ultraviolet-Visible Spectroscopy (UV-Vis) was performed to identify the functional groups of the neem oil by analyzing the absorbance spectrum. The neem oil samples were dissolved in 95% ethanol and analyzed to understand their chemical composition.

Formulation of Neem Candles

Three groups of candles were prepared; 1) without neem oil, 2) with 2% neem oil, and 3) with 5% neem oil. The beeswax was melted in a double boiler at 80 °C, and once melted, neem oil and candle dyes were added. The mixture was stirred continuously and poured into prepared candle containers with wicks. The candles were left to set for 2-3 hours and then cured for 10 days.

Analysis of Neem Candles

Several analyses were done to analyze the neem candles. In the flammability test, the candles' burning characteristics, including flame color, height, and stability, were observed and recorded. The stability of the flame was assessed in a controlled laboratory environment. In the burning rate test, the burning rate was calculated using the formula:

$$Burning\ rate = \frac{M2 - M1}{T2 - T1} \quad (2)$$

where M_1 is the initial mass of the candles (g), and T_1 is the time of lightning (h). Once the candles stop burning the time T_2 and mass M_2 were once against noted.

The stability of the neem-scented candles was tested by storing them in a cool, dark, and dry place for three months. The candles were regularly assessed for color, texture, weight loss, and fragrance changes. A universal testing machine from Mecomb Malaysia Sdn. Bhd. was used to perform compression tests on the candles to measure their resistance to mechanical stress and determine their compressive strength.

Customer Survey

Lastly, a structured survey was conducted with five consumers over two days to evaluate their satisfaction with the neem candles. The survey covered various aspects such as mosquito repellent effectiveness, scent, container design, and texture, using a 5-point Likert scale (Moore et al., 2018). The responses to these questions were analysed to identify trends in consumer preferences, which informed the formulation and design of the final product. This scale allows respondents to express their level of agreement with a series of statements, providing a nuanced understanding of consumer perceptions. The list of questions was as follows.

1. How effective do you find the mosquito repellent candle in repelling mosquitoes?
2. How would you rate the scent of the mosquito repellent candle?
3. How would you rate the candle container of the mosquito repellent candle?
4. How would you rate the design and appearance of the mosquito repellent candle?

Results and Discussions

Extracted Neem Oil

The extracted neem oil using 95% ethanol as a solvent at different time intervals was recorded. Fig. 1 displays the effects of neem extract over time. In this investigation, the sample weight has been kept constant. This graphic illustrates how the length of time after the 28 hours of the Soxhlet extraction process affected the amount of neem oil recovered. Nearly no neem oil was extracted within the first 4 hours. After 12 hours, the majority of the neem oil is distilled. The amount of neem oil recovered increased consistently as the extraction time was extended. After 28 hours of extraction, the highest yield of neem oil 35.0% was achieved.

The extraction time was proven to affect oil recovery. According to Tesfaye et al., essential neem oil was extracted from neem seeds utilizing a straightforward distillation process and a variety of solvent types and parameters, including hexane, methanol, and ethanol (Tesfaye et al., 2020). A mixture of ethanol and hexane with volume proportions of 60:40% produced the highest yield in Soxhlet extraction, 43.71%. The outcomes of a simple distillation procedure demonstrated that using hexane might produce up to 42.35% neem oil. All solvent types have a particle size of 355 µm, and they can be applied at both constant and variable temperatures. The extraction periods range from 1 to 3 hours.

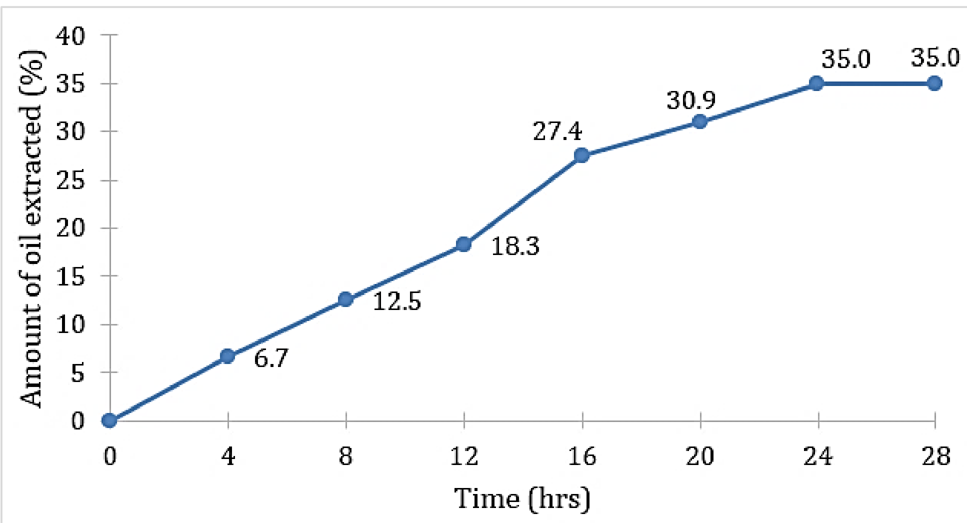

Figure 1. Effect of extracted neem oil for various time

Fourier Transform Infrared Spectroscopy

The successful synthesis of neem oil was verified through FT-IR, as depicted in Fig. 2. The FT-IR analysis indicates the presence of peaks corresponding to OH stretch, C=H bend, C=C stretch, and C=O stretch. Fig. 2 shows the peak analyzed by FT-IR from neem extract and is similar to another study (Patel et al., 2018). The broad absorbance peak at 3457 cm^{-1} corresponded to O-H stretching. Meanwhile, the peak at 2954 cm^{-1} was referred to as C-H stretching. The peak at 1645 cm^{-1} corresponds to the C-C stretching vibration. Further analysis shows a peak at 1459 cm^{-1} is indicative of C-H bending vibrations, which are associated with the bending of hydrogen atoms attached to carbon atoms. Lastly, the peak at 1112 cm^{-1} corresponds to the C=O stretching vibration.

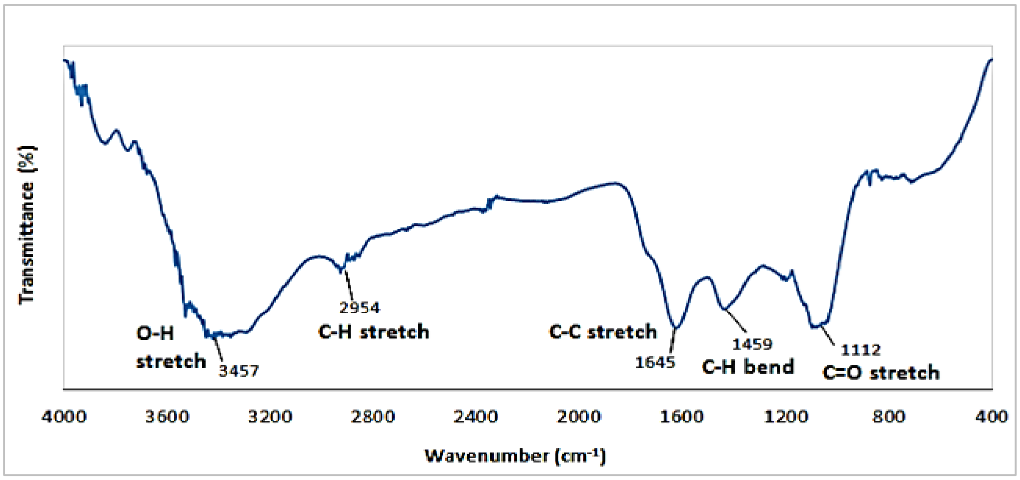

Figure 2. Neem extract peak analyzed by FT-IR

Ultraviolet-Visible Spectroscopy

The UV-vis spectrum of neem leaf extract is displayed in Fig. 3. The simplest method to gain information on the extract is this analysis. Three peaks were found, the first peak had an optical density of 0.250 at λ_{max} = 296 nm, the second peak had an optical density of 0.253 at λ_{max} = 377 nm, and the third peak had an optical density of 0.260 at λ_{max} = 380 nm. The peak is similar to another research (Kumari et al., 2023). The combination of these peaks with those observed in the UV-Vis spectrum provides a more comprehensive understanding of the chemical composition of the neem leaf extract.

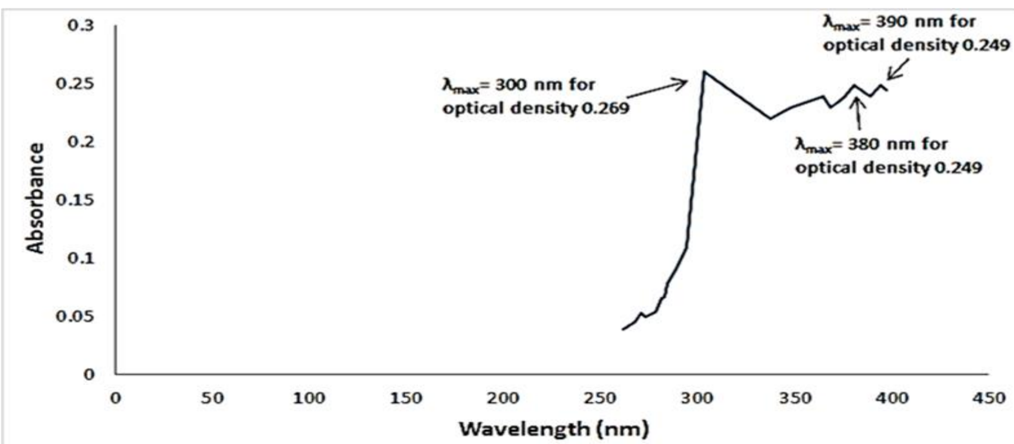

Figure 3. Neem extract peak analyzed by UV-Vis

Flammability Test

The prepared candles were observed while burning and the results are shown in Table 1. They were seen to emit a long, steady flame that was vivid orange in color. This type of flame indicates efficient burning because it implies that the candles were completely burned. To further enhance the sensory experience, the candles' smell started to diffuse about 10 minutes after they were lit. The stability and brightness of the flame also reflect the high quality of the candle composition, ensuring that the flame remains steady and does not flicker excessively, which is often a sign of impurities or poor-quality wax.

Table 1. Determine the flame of candles

Candle Types	Flame Colour	Flame Height (mm)	Melt Pool Depth (mm)
Beeswax Candle	Bright orange with blue ball base	14	10
2% Neem Candle		15	6
5% Neem Candle		14	5
Commercial Candle		15	2

The findings of the melting point test provided significant information on the burn efficiency and possible durability of candles infused with neem. Every examined candle had a blue ball at the base of a bright orange flame, signifying full combustion and a high temperature. All the candle types had the same amount of flame height; the commercial and beeswax candles had a slightly higher flame height of 15 mm, while the 5% Neem and 2% wax candles had a flame height of 14 mm. This constancy in flame height indicates that the addition of neem oil did not adversely affect the candles' ability to burn.

Burning Rate Testing

Results in Table 2 show that the burning time ranged from 3 hours to 4 hours. Among the tested candles, the beeswax candle exhibited the lowest burn rate, suggesting it lasts longer compared to the other candles. This finding highlights the durability of beeswax candles, making them a preferred choice for consumers seeking longer-lasting candles. Conversely, Neem-infused candles, specifically those with 2% and 5% Neem oil, demonstrated higher burn rates, with the 2% Neem candle burning the fastest. This phenomenon could be attributed to the presence of Neem oil, which may enhance the combustion process, thereby increasing the burn rate. Additionally, the commercial candle also exhibited a high burn rate, comparable to the Neem-infused candles, though it was still faster than the beeswax candle. These variations in burn rates are significant as they could impact the effectiveness and duration of the mosquito-repellent properties of the candles.

The burn rate test results demonstrated that while Neem-infused candles burn faster than pure beeswax candles, they still maintain a significant burn time that can be effective for mosquito-repellent purposes. Specifically, the 2% Neem candle had the highest burn rate at 2.96 g/hr, followed by the commercial candle at 2.66 g/hr, and the 5% Neem candle at 2.17 g/hr. The beeswax candle, with the lowest burn rate of 1.20 g/hr, exhibited the longest burn time. These findings suggest that the inclusion of Neem oil in the candle formulation increases the burn rate, possibly due to the oil's properties that enhance combustion.

Table 2. Result of burning time test on candles

Candle Types	Initial Weight (g)	Final Weight (g)	Total Burning Time (hr)	Burning Rate (g/hr)
Beeswax Candle	12.98	8.20	4	1.20
2% Neem Candle	13.47	4.58	3	2.96
5% Neem Candle	12.64	3.97	4	2.17
Commercial Candle	13.19	2.55	4	2.66

Stability Test

A comprehensive stability test was conducted to assess the shelf life of neem candles under controlled conditions. The test was performed over three months in a cool and dry environment, simulating accelerated aging to predict the long-term stability and durability of the candles. The objective was to determine whether the neem candles could maintain their quality and performance over an extended period.

The observations made during the stability test were promising as shown in Table 3 and the physical appearance is shown in Fig. 4. All candle samples, including those containing neem oil, exhibited remarkable stability. There were no significant changes in their physical or sensory characteristics, indicating that the candles could withstand the test conditions without degrading. The candles retained their original color throughout the test period. There were no signs of discoloration or fading. The fragrance of the candles remained consistent and potent during the three months. The essential oils and fragrance compounds used in the candles did not volatilize or degrade significantly, ensuring they maintained their intended scent profile.

Based on the stability test results, it can be confidently concluded that neem candles possess a promising shelf life of at least 12 months. The absence of significant changes in color, fragrance, and moisture content under the accelerated conditions of the stability test indicates that the candles are likely to remain in their original state for a year or more when stored in similar cool and dry environments.

Table 3. Result of stability test on candles

Candle Types	**Parameters**	**Properties of Wax**
Beeswax Candle	The color is evenly distributed, with no cracks, no defects, and no breaks	The wax color is even, does not crack, and has a distinctive smell
2% Neem Candle		
5% Neem Candle		
Commercial Candle		

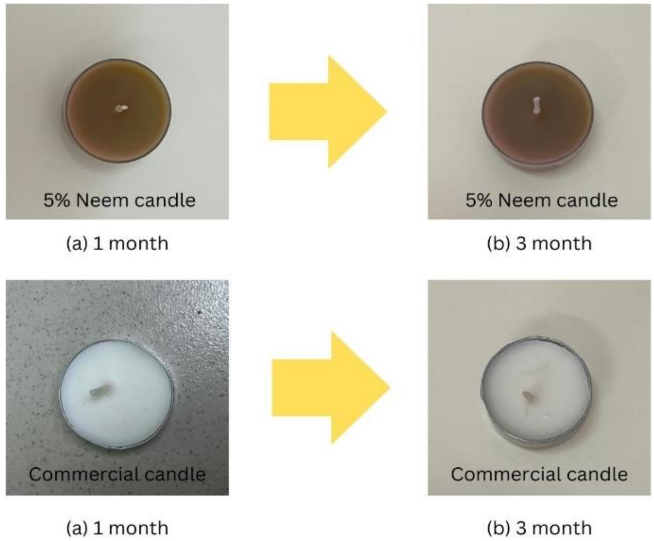

Figure 4. Neem candle conditions before and after three months at a cool and dry place

Compression Test of Candles

Fig. 5 illustrates the relationship between the applied load (kN) and the resulting displacement (mm) for four types of candles: Beeswax, 2% Neem, 5% Neem, and Commercial candles. The load-displacement curves provide information on these candles' mechanical characteristics and compressive strength.

In comparison to the other types of candles tested, the neem candles, especially the 2% Neem candle, show higher compressive strength and structural integrity, according to the results of the compression tests. With a maximum load of about 1.5 kN, the 2% Neem candle performs best, showing that adding 2% Neem greatly increases the mechanical strength of the candle. With a maximum load of 0.8 kN, the 5% Neem candle outperforms the Commercial candle even though it is not as robust as the 2% Neem candle. This implies that increasing the mechanical qualities of candles is mostly dependent on the amount of neem oil present.

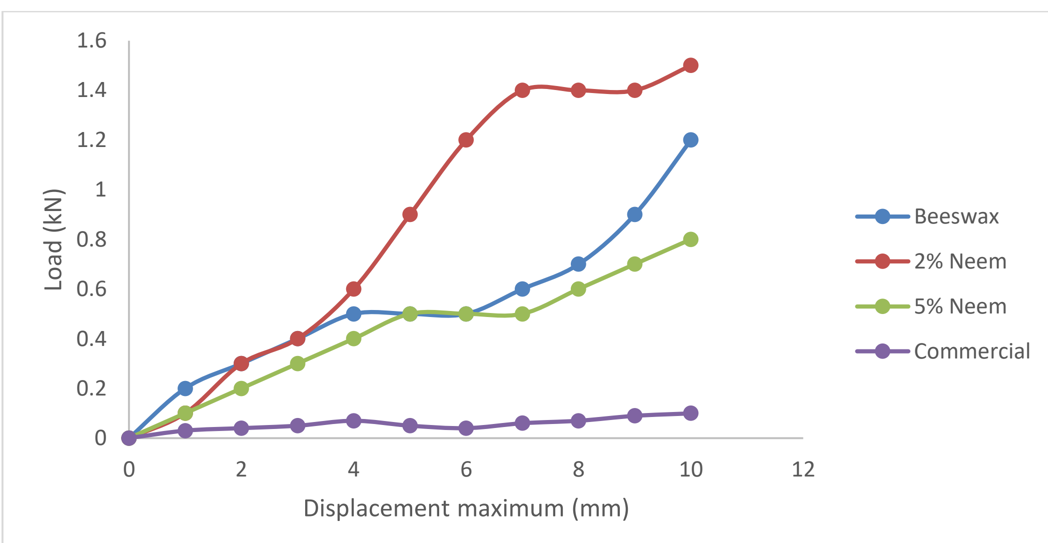

Figure 5. Compressive strength of candles

Structured Survey on Consumer

A structured survey was conducted to evaluate consumer responses to the neem-infused candles. Five consumers were asked to rate various attributes of the candles, including mosquito repellent effectiveness, scent, container design, and texture, using a 5-point Likert scale (1 = poor, 5 = excellent). The results are summarized in Table 4.

Table 4. Neem Candle Consumer Response

Candle Types	Mosquito Repellent Effectiveness	Scent	Container Design	Texture
2% Neem Candle	3	4	4	3
5% Neem Candle	4	5	5	5

The data showed that, in comparison to the 2% neem candles, the 5% neem candles were more likely to be evaluated as exceptional or excellent. The increased neem oil content played a crucial role in elevating the candles' performance, contributing to their higher scores in aroma, container, texture, and insect-repellent effectiveness. This comprehensive improvement underscores the benefits of incorporating a higher concentration of neem oil in candle formulations, resulting in a superior product that meets and exceeds user expectations. The comparative data analysis highlights the advantages of 5% neem candles over their 2% counterparts. The increased neem oil content in the 5% candles not only maintained high scores in aroma, container, and texture but also significantly improved the candles' insect-repellent effectiveness.

Conclusion

The successful formulation of neem-infused candles using the Soxhlet extraction method demonstrated the potential of neem oil as a natural mosquito repellent, with FTIR and UV-Vis analyses confirming the presence of key bioactive compounds. In comparison to beeswax candles, neem-infused candles showed greater burn rates in the burning rate test. Every sample of a candle showed exceptional stability. Their sensory and physical qualities did not significantly alter, suggesting that the candles could endure the test circumstances without deteriorating. As demonstrated by the results of the compression tests, the neem candles—particularly the 2% Neem candle—have greater compressive strength and structural integrity.

The candles, particularly those with 2% and 5% neem oil concentrations, exhibited moderate effectiveness in repelling mosquitoes and desirable physical properties and stability over three months, suggesting a shelf life of at least 12 months. Positive feedback from consumer surveys, especially for the 5% neem candles, further supports the viability of neem-infused candles as an eco-friendly alternative to chemical repellents, offering both functional and environmental benefits. Future research could enhance their effectiveness by optimizing neem oil concentration and exploring additional natural additives.

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