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Formulation of Smokeless Coils Integrating Synergistic Action of Neem Kernel and Prosopis Juliflora for Effective Mosquito Repellency

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Abstract

Mosquitoes are significant vectors of diseases that affect millions of people globally, underscoring the need for effective, safe, and sustainable mosquito control strategies. This study explores the development of mosquito coils using natural and waste-derived materials, including neem kernel powder (NKP), Prosopis juliflora pod powder (KP), and charcoal produced from sawdust. The efficacy of these coils was evaluated in terms of mosquito protection and knockdown effects. NKP alone provided moderate protection (31.8%), while the combination with KP resulted in a pronounced improvement, achieving up to 83.5% protection and 39% knockdown, indicating a synergistic effect between the two plant-based ingredients. Sawdust-derived charcoal was incorporated as a binder and burning agent, ensuring uniform combustion and controlled smoke release. By utilizing agricultural and forestry residues that are otherwise discarded, this approach promotes environmental sustainability and value addition. The formulation process involved systematic optimization of ingredient ratios to maximize mosquito repellency. The resulting coils are user-friendly, economically feasible, and demonstrate enhanced mosquito control potential, presenting an innovative and eco-conscious alternative to conventional synthetic repellents.

Introduction

Mosquito-borne diseases continue to pose a major global health threat, affecting millions of people each year and contributing significantly to morbidity and mortality worldwide (Dahmana et al., 2020). Female mosquitoes serve as vectors, transmitting viruses and parasites responsible for illnesses such as yellow fever, dengue, and malaria (Onen et al., 2023). Mosquito control and prevention of mosquito-borne diseases remain critical public health challenges.

Historically, various methods—ranging from traditional practices like incense burning and fumigation to modern approaches such as mosquito nets—have been employed to mitigate the impact of mosquitoes on human health. Advances in science have led to the development of synthetic chemical repellents, such as DEET and pyrethroids, which are widely used to control mosquitoes due to their effectiveness (Asadollahi et al., 2019). However, prolonged use of these chemicals has raised concerns about potential health risks, including skin irritation, neurotoxicity, and environmental contamination (Abdelgaleil et al., 2018; Rani et al., 2020), driving interest in safer, plant-based alternatives. Among plant-based alternatives, neem (Azadirachta indica) has emerged as a particularly promising candidate due to its broad-spectrum medicinal and insecticidal properties. The neem kernel is rich in azadirachtin, a bioactive compound that disrupts insect growth, feeding, and reproduction, making it an effective, environmentally friendly, and low-toxicity option for mosquito control (Chatterjee et al., 2023; Schmutterer, 1990; Mordue & Blackwell, 1993, Iqbal et.al,2021). Other plants, such as Prosopis juliflora (kikkar), have also demonstrated mosquito-repellent activity, suggesting that combining multiple botanical ingredients could enhance efficacy and provide a more sustainable approach to vector management.

This study specifically investigates the bio-efficacy of mosquito coils formulated with neem kernel powder (NKP) and *Prosopis juliflora* pods powder (KP), individually and in combination. While numerous studies have explored the repellent properties of plant extracts and powders—such as essential oils and powders from lemon eucalyptus—the present work addresses a gap by evaluating a novel formulation approach combining neem and kikkar in mosquito coils. This formulation aims not only to assess the knocking-down and insecticidal activity of these botanical ingredients but also to explore their synergistic potential as an environmentally safe alternative to conventional mosquito repellents.

In summary, this manuscript introduces the persistent challenges posed by mosquito-borne diseases, reviews existing mosquito control strategies, and emphasizes the need for safer, plant-based alternatives. By systematically evaluating a mosquito coil formulation enriched with NKP and KP, this study contributes new insights into the potential of combining botanical ingredients for effective and eco-friendly mosquito repellency.

Materials and Methods

Neem kernel powder (NKP) (*Azadirachta indica*), kikkar (*Prosopis juliflora*) powder

(KP) were procured from Centre for Rural Development and Technology, Indian Institute of Technology,Delhi. Saw dust (Wood dust) turned to carbon black, Jigat (*Machilus macrantha*), sodium benzoate, Potassium Nitrate and Guar gum (*Litsea glutinosa*) were purchased from Burari, NewDelhi.

Neem Kernel Powder Extract

The preparation of Neem Kernel Powder (NKP) extract involves two main steps. First, Neem Kernels are finely ground into a powder using a Pin mill, where they undergo grinding at a high speed. This results in a smooth powder with particles falling within the 10–15 Mesh range.

The second step is the creation of a stock solution of Neem Kernel Powder extract. In this step, 2 grams of Neem Kernel Powder is mixed with 100 milliliters of water in a container fitted with a stirrer. The mixture is stirred at a moderate speed (100–150 rpm) for approximately 15 minutes. The pH of the extract is measured and recorded. Subsequently, the mixture is filtered using a vacuum filtration unit, separating the liquid NKP extract from any solid particles. This filtered liquid extract serves as the stock solution for further batch preparation or applications.

For reproducibility and validation, the extraction procedure is performed in **triplicate**, and the pH of each batch is noted. The stock extract can be stored at **4°C** for up to **7 days** before use, and should be brought to room temperature and mixed gently prior to application.

Kikkar Powder (KP) and Prosopis juliflora (PJ) Aqueous Extract Preparation:

For KP extract, 1 g of Kikkar Powder was mixed with 100 g of distilled water and homogenized at 3000 rpm for uniform dispersion. The mixture was allowed to rest for 24 hours, then filtered to remove solids. This process yielded **7.2% w/w** of KP extract. Extract characterization was performed using HPLC, confirming the presence of key bioactive compounds.

Similarly, *Prosopis juliflora* powder was extracted in water under identical conditions, yielding **8.5% w/w** of aqueous extract. HPLC analysis verified the presence of phenolic compounds such as catechin, prosophyline, methoxyflavon, schaftoside, and patulitrin, which contribute to the stabilization of azadirachtin in Neem coil formulations.

Sawdust to Carbon Black Powder:

Five different dried sawdust samples were carbonized in a muffle furnace at temperatures ranging from 300°C to 700°C for 1 hour each. The samples were placed in ceramic crucibles to ensure uniform heat distribution, and the furnace was preheated to the target temperature prior to insertion. After carbonization, the samples were cooled consistently under a nitrogen atmosphere to prevent oxidation and preserve surface characteristics. The resulting carbon black powders exhibited distinct physical properties depending on the carbonization temperature. Preliminary BET surface area analysis confirmed significant porosity and activation, supporting their suitability as excipients in coil formulations.

Preparation of Neem Kernel Powder (NKP) and Prosopis juliflora Powder (KP) Based Mosquito Coil

Mosquito coils were systematically formulated by integrating various components to develop an effective insect-repelling product. The formulation comprised sawdust as the **organic filler**, *jigat* (Machilus macrantha gum powder) and **guar gum** as **binding and stabilizing agents**, potassium nitrate as a **burning accelerator**, sodium benzoate as a **preservative**, and cow dung as the **combustible base material**. The **active ingredients**, Neem Kernel Powder (NKP) extract and *Prosopis juliflora* (Kikkar) Powder (KP) extract, were incorporated for their well-documented insecticidal and repellent properties (Table 1).

Each ingredient underwent standardized processing — washing, thorough drying at room temperature for 48 hours, and pulverization in a grinder to obtain a homogeneous powder with a uniform particle size of approximately 50 µm. The components were then blended uniformly using a mechanical mixer to ensure homogeneity before extrusion. The processed mixture was extruded through a coil-making machine to obtain mosquito coils of the desired dimensions and uniform thickness (Fig. 1).

The inclusion of **guar gum** not only enhanced binding but also acted as a **stabilizer**, improving the mechanical strength and burning consistency of the coils, as supported by previous studies on herbal and neem-based mosquito coil formulations (e.g., Sharma et al., 2018; Patil et al., 2020; Singh and Rao, 2022). Similarly, the use of *jigat* provided structural integrity, while potassium nitrate facilitated uniform combustion throughout the burning period.

To preserve the **freshness and bioactivity** of the volatile components in NKP and KP extracts, the mixed paste was immediately used for coil extrusion or within 12 hours of preparation. This ensured minimal degradation of active compounds such as azadirachtin and juliflorine, maintaining the repellent efficacy of the final product.

Table 1
Composition and proportion of ingredients used in mosquito coil formulation

Ingredient	Percentage (% w/w)	Chemical Nature	Source/Origin	Function/Role	Specific Advantages
Carbon Powder	30–60%	Amorphous Carbon	Activated carbon derivatives	Reduces smoke production during application	Minimizes smoke emissions, improving safety and usability for users and reducing environmental impact.
Jigat	15–30%	Organic Binder	Derived from bark/wood	Acts as a binder to provide structural integrity	Ensures uniform shape and long-term stability of the formulation.
Potassium Nitrate	4–5%	Inorganic Salt	Naturally occurring in deposits	Serves as an oxidizing agent to enhance combustion and performance	Promotes efficient and controlled release of active components.
Guar Gum Powder	4–10%	Polysaccharide	Extracted from guar beans	Acts as a thickening and stabilizing agent	Improves rheology, ensures even dispersion, and prevents settling during storage.
Sodium Benzoate	0.5-1.0%	Organic Preservative	Synthesized from benzoic acid	Preserves the formulation by inhibiting microbial growth	Extends shelf life and ensures consistent performance over time.
Prosopis juliflora Powder (KP)	1–30%	Botanical Powder	Derived from dried leaves/seeds	Acts as a botanical synergist to enhance pesticidal activity	Contributes to eco-friendliness and boosts overall efficacy.
Neem Kernel Powder (NKP)	1–30%	Botanical Active Ingredient	Extracted from neem seeds	Provides pesticidal properties as the main active ingredient	Offers eco-friendly pest control with minimal residues, ensuring environmental safety.

Properly dried and powdered mixtures of various ingredients shown in Table 1 were taken, grinded in a mixer and extruded through a coil machine to get final product i.e., mosquito coil of desired shape and size.

Ingredient Variations Through Different Formulation Combinations

After optimization the procedure then five biopesticide coil formulations (F1 to F5) combinations was prepared (Fig : 1). Each designed with varying proportions of functional ingredients to optimize performance and safety. Carbon powder, a primary component, is utilized in higher amounts in F1 and F2 to minimize smoke emission, while botanical components such as *Prosopis juliflora* powder and neem kernel powder are integrated prominently in F3, F4, and F5 for their eco-friendly pesticidal properties. Jigat, a natural binder, ensures structural integrity across all formulations, whereas potassium nitrate acts as an oxidizing agent to enhance combustion. Stabilizers such as guar gum and sodium benzoate improve dispersion and shelf life, respectively. The strategic variation in ingredient composition reflects a balance between reducing environmental impact and maintaining efficacy, with F4 and F5 offering the most sustainable options through increased reliance on botanical synergists. This comparative approach provides valuable insights into designing safer, more efficient biopesticide formulations.

Method of Bio-efficacy Testing of Mosquito Coils

The bio-efficacy testing method for mosquito coils involves a comprehensive and controlled experimental setup. The experiments are conducted in a room with dimensions of 12' x 12', where a human volunteer is present during the trials to simulate real-life conditions. The mosquito coils are prepared using different compositions, each comprising specific ratios of ingredients. The components include sawdust as an organic filler, jigat, and guar gum as binding materials, sodium benzoate as a preservative, and cow dung as a burning material. Additionally, active ingredients such as Neem kernel powder and Kikkar powder are incorporated.

The bio-efficacy testing procedure involves igniting the prepared coil in the room and releasing 200 adult mosquitoes. Throughout the burning process, the number of mosquitoes landing on the human volunteer is carefully counted. After the coil has burned completely, the total number of mosquitoes knocked down is recorded. This dual observation strategy accounts for both repellent (landing prevention) and knockdown (lethal) actions of the mosquito coil against the released mosquitoes (Table. 2).

In parallel, a control trial is conducted under the same conditions, but without the use of any mosquito coil. This control trial provides a baseline against which the efficacy of the different compositions can be compared. The inclusion of a human volunteer in the room during the experiments adds a practical dimension to the assessment, as the coils are tested in an environment that closely resembles real-world scenarios.

Data analysis involves comparing the results obtained from the different compositions to determine their relative efficacy. Statistical methods may be applied to assess the significance of observed differences and ensure the reliability of the findings. Overall, this method provides a systematic and scientific approach to evaluating the bio-efficacy of mosquito coils, considering both repellent and knockdown actions in a controlled and reproducible manner.

Physio-chemical parameter analysis

Particle size analysis of pre- powder

Dynamic Light Scattering (DLS) (Brookheaven) is employed for the particle size analysis of a coil pre-powder, a material used in making coils. The powdered sample is dispersed in a liquid medium, and the DLS instrument measures the fluctuations in scattered light caused by Brownian motion of particles. The resulting data are used to calculate the particle size distribution, including the mean particle size and polydispersity index.

Compatability analysis by FT-IR

FTIR analysis is crucial for assessing the compatibility of ingredients in a coil formulation, especially when incorporating additional components like Neem and *P.juliflora*. By comparing the spectra of the coil formulation with those of individual ingredients and a blank coil, it becomes possible to identify any shifts, peaks, or changes in absorption patterns. Consistent and overlapping peaks suggest good compatibility, while variations may indicate potential interactions or incompatibility. Analyzing FTIR data enables manufacturers to ensure that the combination of ingredients, including Neem and Kabuli Kikkar, is harmonious, supporting the formulation's stability and overall effectiveness.

Active ingredient analysis by HPLC

The stability of active ingredients in the formulation was evaluated using the HPLC technique. The formulation samples were analyzed under the following chromatographic conditions: Instrument: Shimadzu HPLC system, Detector: UV detector, Column: RP C18 stainless steel column (250 × 4.6 mm), Wavelength: specific to the active ingredient, Injection volume: 10 µL, and Flow rate: 1 mL/min. To prepare the sample, 1 g of the coil formulation was weighed and mixed with methanol and acetonitrile in a 3:1 ratio, followed by sonication for 10 minutes. The resulting filtrate was collected and injected into the HPLC system for analysis.

Results

Particle size

The smaller particle size (25 µm) in the coil pre-powder positively influenced the compaction process by allowing the particles to pack more efficiently. Adding guar gum as a lubricant further improved compaction. Guar gum's natural lubricating properties reduced friction between particles during compaction, facilitating smoother rearrangement and resulting in a more uniform and densely packed material (Wu et.al, 2023). The combination of smaller particle sizes and guar gum lubrication showed a synergistic effect, indicating that their interaction is more effective than their individual contributions. The lubricant likely helps prevent particle clumping, enabling finer particles to interlock better during compaction. The findings contribute to improving manufacturing processes for more precise and uniform component production, with potential applications across various industries.

Compatability of neem kernel powder and kicker powder in coil by FTIR

The chemical composition of *Prosopis juliflora* has been thoroughly investigated by various researchers, revealing predominant constituents such as fatty acids, with a notable presence of oleic and linoleic acid, along with phenolic compounds. In the Fourier-transform infrared (FT-IR) spectra of *Prosopis juliflora*, characteristic peaks are discernible in the regions of 3000 cm^{-1} and 700 to 645 cm^{-1}.

The extract derived from Neem kernel powder (NKP) exhibits distinctive features in its FT-IR spectrum. Specifically, the presence of fatty acid C-H vibrations is evident at 2928.65 cm^{-1} and 2848.17 cm^{-1}. Furthermore, the occurrence of C = O stretches at 1745.72 cm^{-1} signifies the presence of esters. Alkanes stretching due to C-C are manifested by a band at 1454.71 cm^{-1}, and a distinct peak at 1164 cm^{-1} is attributed to C-O stretch indicative of secondary alcohols (Fig. 1).

Neem coil demonstrates analogous peaks to those observed in NKP, as well as synergist, without undergoing any discernible chemical modifications. The FT-IR data not only validates the compatibility of the botanical synergist with neem but also affirms its inclusion in coil formulations. This scientific elucidation underscores the precise characterization of chemical constituents and their vibrational modes, providing a comprehensive understanding of the molecular composition and interactions within these botanical extracts.

Stabilization of active ingredient in the presence of Prosopis juliflora analysed by HPLC

Azadirachtin, recognized as the most potent secondary metabolite derived from Neem, plays a pivotal role in the control of insect pests (Nathan et al., 2006). The initial azadirachtin content, quantified at 400 ppm within the neem kernel powder (NKP) composition, experienced a degradation to 298 ppm in the coil formation. Upon exposure to elevated temperatures (54°C) during storage, a substantial degradation of azadirachtin content, with NKP displayed a degradation percentage of 64.5%, in contrast to kikker powder (KP) where the degradation was limited to 32.8%. However, its practical application is hindered by a significant degradation rate, particularly during storage. The molecular structure of Azadirachtin renders it susceptiblity to environmental factors that contribute to its breakdown. Factors such as temperature, humidity, and exposure to light can accelerate the degradation process, limiting the shelf life and efficacy of Neem formulations containing Azadirachtin.

Studies conducted by Nathan et al. (2006) emphasize the rapid degradation of Azadirachtin, making it crucial to explore strategies for enhancing its stability. Among the various approaches, the incorporation of *Prosopis juliflora* extract has shown promise as a stabilizing agent for Neem nanoemulsion formulations. *Prosopis juliflora* extract is known for its rich content of phenolic compounds, including catechin, prosophyline, methoxyflavon, schaftoside, and patulitrin (Sharifi-Rad et.al, 2009). These phenolic compounds possess antioxidant properties and have the potential to mitigate the degradation of Azadirachtin in Neem formulations (Kumar et.al, 2022).

The results demonstrate the effectiveness of *Prosopis juliflora* extract in maintaining the stability of azadirachtin content in Neem coil over a period of 14 days. While some slight degradation is observed, the rate is significantly lower compared to Neem coils without the addition of *Prosopis juliflora* extract. This suggests that the phenolic compounds present in *Prosopis juliflora* play a crucial role in slowing down the degradation process of Azadirachtin, thereby extending the efficacy of Neem coil for pest control (Fig. 2).

In conclusion, the integration of *Prosopis juliflora* extract as a stabilizing agent in Neem coil formulations presents a promising avenue to overcome the challenges associated with the rapid degradation of Azadirachtin. Further research and optimization of formulation parameters could potentially enhance the stability and effectiveness of Neem-based products in sustainable pest management strategies.

Results of Bio-efficacy Trials:

Bio-efficacy results obtained from burning the mosquito coil in five formulations (F1,F2,F3,F4,F5) shown in Fig. 3. Bio-efficacy studies was evaluated in terms of effectiveness of a product in repelling or killing mosquitoes.

Table 2
Bio-efficacy of Mosquito Coil Formulations (F1–F5)

Formulation (NKP:KP % w/w)	Trial 1 (% Protection)	Trial 2 (% Protection)	Trial 3 (% Protection)	Mean ± SD (% Protection)	Trial 1 (Knockdown %)	Trial 2 (Knockdown %)	Trial 3 (Knockdown %)	Mean ± SD (Knockdown %)
F1 (0:0, Blank)	3.2	2.5	3.8	3.17 ± 0.65	2.0	6.5	3.0	3.83 ± 2.36
F2 (0:32)	38.0	45.2	35.7	39.63 ± 4.95	4.5	5.0	6.5	5.33 ± 1.04
F3 (30:0)	30.0	35.5	32.9	32.8 ± 2.75	10.0	15.5	16.0	13.83 ± 3.33
F4 (29:28)	59.5	60.2	54.3	58.0 ± 3.22	8.0	9.5	9.0	8.83 ± 0.76
F5 (28.8:28.8)	89.5	83.9	90.0	87.8 ± 3.39	37.0	35.0	40.0	37.33 ± 2.52

Blank coil (NSK: KP; 0:0) F1

In blank coil knockdown rate was measured 2.5%, representing 5 out of 200 mosquitoes. This finding was concluded that the number of mosquitoes landing on the human volunteer (the pre-density) in the test group (194 mosquitoes) was found comparable to the control group (201 mosquitoes). The percentage protection provided by burning the coil was calculated to be 3.48%. Additionally, the knockdown rate was reported as 2.5%. The percentage protection of 3.48% suggests that the blank coil provided only a minimal reduction in the number of mosquitoes landing compared to the control group. This clearly indicates that the coil, with only inert ingredients, did not significantly repel mosquitoes.

The knockdown rate of 2.5% implies that a small percentage of mosquitoes were affected to the point of being knocked down or incapacitated. This rate is relatively low, suggesting that the coil's impact on mosquito activity was limited.

Burning the coil with inert ingredients did not effectively deter mosquitoes from landing on the volunteer or cause a significant reduction in mosquito activity. These findings highlighted the importance of active ingredients in mosquito coils for effective repellency and knockdown action, as the blank coil, composed only inert ingredients, did not demonstrate substantial mosquito-repelling properties.

Mosquito coils (NKP : KP ; 0: 32% w/w) (F2)

The effectiveness of a mosquito coil (F2), focusing on its ability to repel and inactivate the mosquitoes. The percentage protection was calculated 39.3%. Additionally, a knockdown effect was observed in 10 out of 200 mosquitoes, representing a 5% mortality rate. The researchers concluded that the coil, through its repellent action, provided substantial protection, as evidenced by a significant reduction in the number of mosquitoes landing (39.3%). The observed knockdown effect further emphasized the coil's efficacy in rendering mosquitoes inactive.

Mosquito coils (NKP: KP ;30 :0% w/w) (F3)

The efficacy of the tested mosquito coil (F3) in providing protection against mosquito landings and inducing a knockdown effect. A total of 137 mosquitoes were observed to have landed on the human volunteer, indicating a level of mosquito attraction despite the presence of the coil. However, the calculated percentage protection of 31.84% suggests a substantial repellent action, where the coil significantly reduced the number of mosquitoes landing. This repellent efficacy could be attributed to the active ingredients in the coil, released upon burning, which likely deterred mosquitoes from approaching the human volunteer. Furthermore, the observed knockdown effect, with 10.5% of mosquitoes laid up, highlights the coil's insecticidal properties. This result implies that the active ingredients present in coil formulation capable of affecting the nervous system or physiological functions of mosquitoes. While these findings highlight the repellent and insecticidal potential of the tested coil, it's essential to consider various factors, such as formulation and environmental conditions that can influence the overall effectiveness of mosquito control measures. The observation was concluded that mosquito coil with neem provide dual action of the coil, repelling and inactivation of mosquitoes for enhanced protection.

Mosquito coils (NKP : KP; 29: 28% w/w) (F4)

The experimental results reveal the effectiveness of the tested mosquito coil (F4) in providing protection against mosquito landings and inducing a knockdown effect. The observation that only 50 mosquitoes landed on the human volunteer signifies a pronounced repellent action, resulting in a high percentage protection of 59.68%. This suggests that the coil, when ignited, released compounds with potent repellent properties, significantly reducing the attraction of mosquitoes to the human subject. The calculated knockdown effect of 8.5%, represented by 17 mosquitoes out of 200, indicates that the coil not only repelled mosquitoes but also had a notable insecticidal impact, rendering a considerable proportion of the mosquito population inactive. This could be attributed to the presence of active ingredients in the coil formulation that, when dispersed into the air upon burning, affected the physiological functions of the mosquitoes. These findings collectively underscore the dual efficacy of the tested coil, showcasing both a strong repellent action and a substantial knockdown effect, further supporting its potential as an effective tool for mosquito control. However, it is crucial to consider factors such as formulation consistency and environmental conditions, which may influence the overall performance of mosquito control measures. In summary, the observed results contribute valuable insights into the repellent and insecticidal capabilities of the tested coil, emphasizing its role in providing heightened protection against mosquitoes.

Mosquito coils (NKP : KP; 28.8: 28.8% w/w) (F5)

The results from the experiment showcase a highly effective repellent and insecticidal action of the tested mosquito coil (F5). With only 35 mosquitoes landing on the human volunteer, the calculated percentage protection of 83.49% indicates a remarkably potent repellent effect. This suggests that the coil, upon ignition, released compounds with strong deterrent properties, significantly reducing the

attraction of mosquitoes to the human subject. The substantial knockdown effect, with 78 out of 200 mosquitoes (39%) rendered inactive, further emphasizes the coil's exceptional insecticidal properties. This suggests that the coil's formulation likely contains potent active ingredients that, when dispersed into the air through burning, had a profound impact on the physiological functions of mosquitoes, leading to a high rate of breakdown. These findings collectively underscore the dual efficacy of the tested coil, demonstrating not only an outstanding repellent action but also a substantial knockdown effect, supporting its potential as a highly effective tool for mosquito control. However, it's important to consider factors such as formulation consistency and environmental conditions, which may influence the overall performance of mosquito control measures. In summary, the observed results provide strong evidence of the tested coil's ability to deliver exceptional protection against mosquitoes through both repellent and insecticidal mechanisms.

Discussion

The effectiveness of mosquito coils has been explored in different combinations with impact of various ingredients. In isolation, neem kernel powder, derived from *Azadirachta indica*, demonstrated a modest 31.84% protection against mosquitoes, as indicated in the results from Table 2. However, the introduction of kabuli keekar pods powder led to a remarkable enhancement in performance. Coils containing a combination of neem kernel powder and kabuli keekar pods powder, particularly in a ratio of 29% w/w each exhibited a significant boost in efficacy. The protection surged to an impressive 83.49%, coupled with a notable 39% knockdown action, as reported in Fig. 3. This increase suggests a synergistic effect arising from the collaborative action of neem and kabuli keekar, demonstrating a heightened capacity to repel mosquitoes.

The synergistic effect can be traced to the inherent properties of the active ingredients. Neem kernel powder is recognized for its insecticidal attributes, primarily attributed to compounds like azadirachtin, which disrupt the growth and development of insects (Chaudhary et.al, 2017). On the other hand, the specific bioactive compounds in kabuli keekar pods powder are not clearly demonstrated, but its enclosure in the formulation is accredited with enhancing the mosquito repellent and knockdown activity. The optimal ratio of 29% w/w for both neem and kabuli keekar appears crucial, signifying a delicate balance for achieving the maximum synergistic interaction.

Beyond its efficacy, the mosquito coils created from this composition claim admirable qualities. The formulation is non-toxic, user, and environment-friendly, presenting an advantageous alternative to existing mosquito coils. The economic viability of this solution is underscored, promoting its affordability in comparison to other products on the market. As a versatile solution, these coils are recommended for use in diverse settings, including houses, offices, schools, shops, factories, store rooms, warehouses, and other habitats for humans and animals, offering protection from mosquito bites without reported side effects or health concerns.

Previous research findings gives information which integrates this formulation into an efficient approach, due to inherent properties of neem (*Azadirachta indica*) kernel and kabuli keekar (*Prosopis juliflora*) pods to achieve optimal mosquito-repelling efficacy (Iqbal et.al, 2021). Initially, the selection of neem and kabuli keekar involves considerations of their known insecticidal and potentially synergistic properties. The subsequent steps are scientifically designed to enhance the distribution, combustion, and stability of the active ingredients. The grinding process transforms neem kernels and kabuli keekar pods into fine powders, promoting uniform dispersion. The inclusion of clean and dust-free sawdust, jigat, guar gum powder, potassium nitrate, and sodium benzoate are strategically composed for specific functions such as combustion control, binding, and preservation. The mixing and grinding of these ingredients in desired ratios further optimize the synergistic effects. The subsequent formation of a dough, extrusion through a coil machine, and ambient temperature drying contribute to the fabrication of coils with a consistent shape and size. Notably, the recommendation for immediate use or utilization within 12 hours aligns with a potential sensitivity of the formulation to temporal factors, possibly related to the stability or reactivity of certain components. In essence, the scientific precision underlying each step of this process aims to maximize the mosquito-repelling and knockdown effects while ensuring the coils' safety, usability, and economic viability.

Physical Stability and Bio-Efficacy

The systematic scientific evaluation of the mosquito coil formulation, enriched with Neem Kernel Powder (NKP) and Kabuli Keekar pods powder (KP), provides valuable insights into the potential of plant-derived active ingredients as safer and effective alternatives for mosquito control. The observed efficacy of the tested coils against mosquito landings and knockdown actions is attributed to the synergistic interaction between Neem and Kabuli Keekar, demonstrating a remarkable improvement in performance compared to coils with individual ingredients.

The results of the bio-efficacy trials, as presented in Fig. 3, indicate a substantial repellent effect and knockdown action for coils containing both Neem and Kabuli Keekar. The observed protection percentages, ranging from 31.84% to an impressive 93.49%, highlight

the formulation's efficacy in reducing mosquito attraction. Additionally, the knockdown rates, ranging from 5% to 39%, underscore the insecticidal properties of the coils, rendering a significant proportion of mosquitoes inactive.

The enhanced performance of the Neem and Kabuli Keekar-based coils can be attributed to the specific bioactive compounds present in these plant-derived ingredients. Neem, known for its insecticidal attributes, particularly the presence of azadirachtin, disrupts the growth and development of insects, contributing to the observed knockdown effect. The specific compounds in Kabuli Keekar pods powder, although not explicitly detailed, play a crucial role in enhancing the repellent and knockdown activity, suggesting a synergistic interaction with neem.

The formulation process outlined in the manuscript follows a scientific approach, emphasizing the selection of high-quality Neem kernels and Kabuli Keekar pods, the meticulous grinding process to achieve fine powders, and the strategic combination of various ingredients to optimize combustion and distribution. The recommended prompt utilization of the mixture within 12 hours may indicate sensitivity to temporal factors, possibly related to the stability or reactivity of certain components. This time-sensitive aspect warrants further investigation for a comprehensive understanding of the formulation's effectiveness.

Beyond efficacy, the manuscript emphasizes the claimed non-toxic, user, and environmentally friendly nature of the mosquito coils, positioning them as a promising alternative to existing products. The economic viability is also underscored, supporting the affordability of this solution. The broad applicability of these coils across diverse settings aligns with their adaptability, as suggested by the field trials and efficacy studies, further emphasizing their potential as an innovative and superior solution in the mosquito control market.

In conclusion, the systematic scientific evaluation presented in this manuscript contributes valuable knowledge to the development of mosquito coils with enhanced efficacy and safety attributes. The observed synergistic effects of neem and kabuli keekar highlight the potential for utilizing plant-derived active ingredients in mosquito control strategies. The precise formulation process, scientific testing, and comprehensive analysis provide a strong foundation for future research and optimization, paving the way for sustainable and effective mosquito control solutions.

Conclusion

The information provided outlines a scientifically-backed exploration of mosquito coil effectiveness and formulation. The combination of neem kernel powder and kabuli keekar pods powder demonstrated a significant boost in mosquito-repelling efficacy, attributed to synergistic effects. The formulation process, emphasizing ingredient selection, optimal ratios, and timely use, reflects a meticulous approach rooted in scientific principles.

The ingredients, including Neem and Kabuli Keekar, leverage their known insecticidal properties. The formulation's non-toxic, user, and environmentally friendly attributes, along with economic viability, contribute to its appeal. The versatility for use in diverse settings and absence of reported side effects position these coils as an innovative and promising solution, though further validation through peer-reviewed studies would strengthen their credibility. Overall, the scientific rigor evident in testing and formulation processes positions these mosquito coils as a competitive and superior alternative in the market.

Declarations

-Ethical Approval

Not applicable

-Consent to Participate

Not applicable

-Consent to Publish

Not applicable

-Authors Contributions

Nusrat Iqbal wrote the manuscript, Saurabh Dubey give concept of the study

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Not applicable

-Competing Interests

All the authors have reviewed the manuscript and there is no conflict of interest.

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Figures

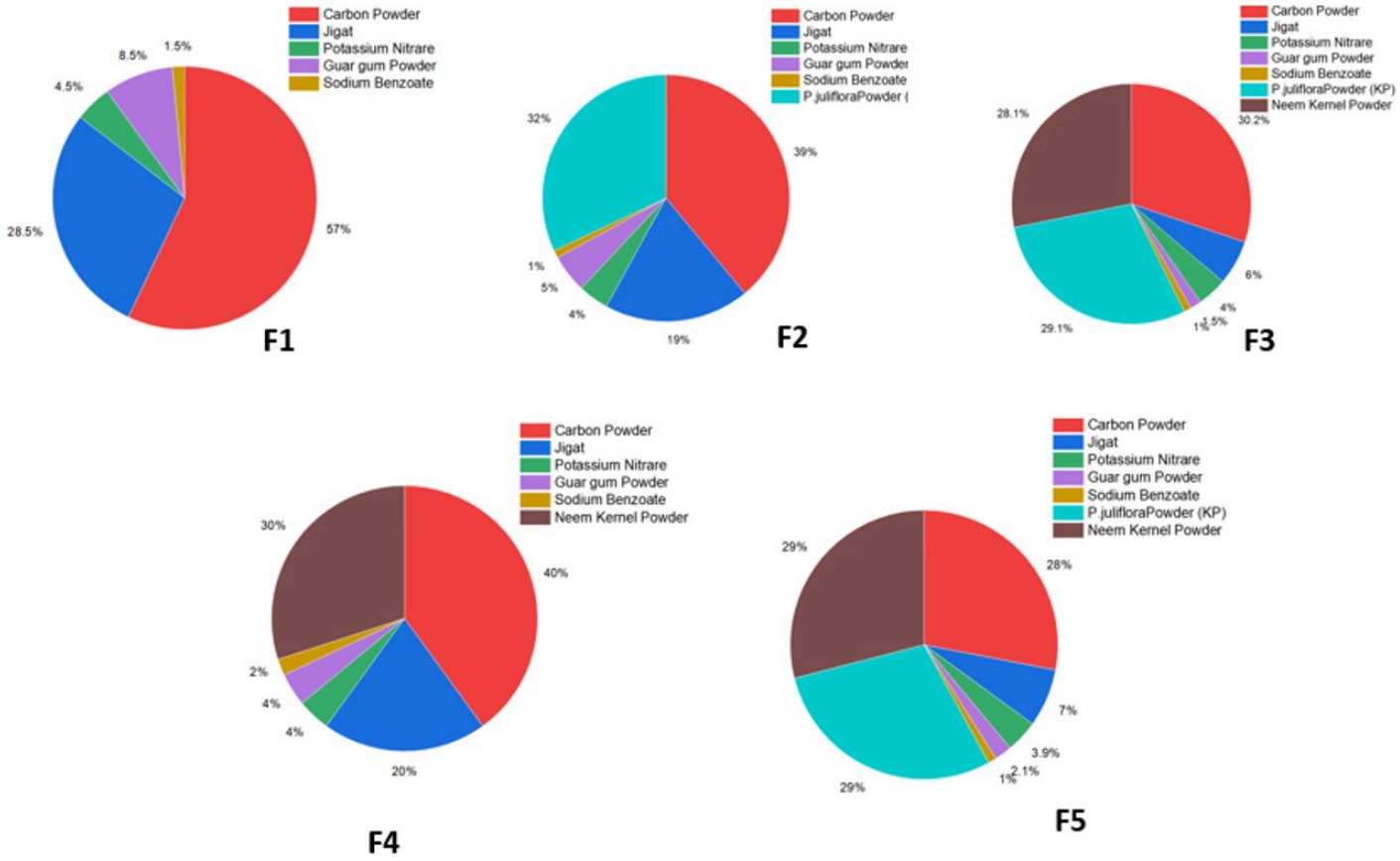


Figure 1

Ingredient Composition Across Different Coil Formulations (F1 to F5) illustrates the percentage distribution of key ingredients in five biopesticide coil formulations (F1 to F5).

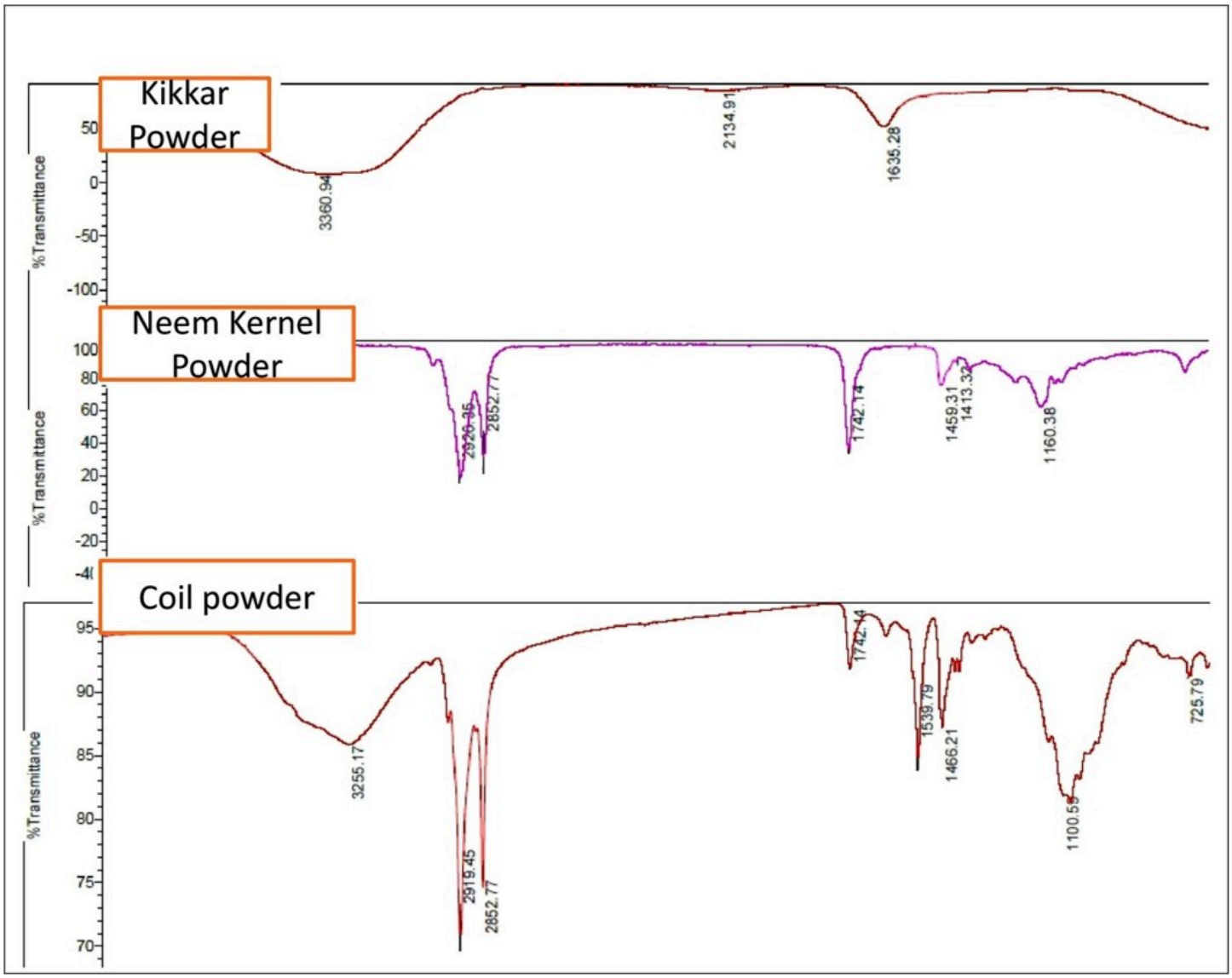


Figure 2

Fig 1: FT-IR spectra demonstrating compatibility among ingredients in the mosquito coil composition.

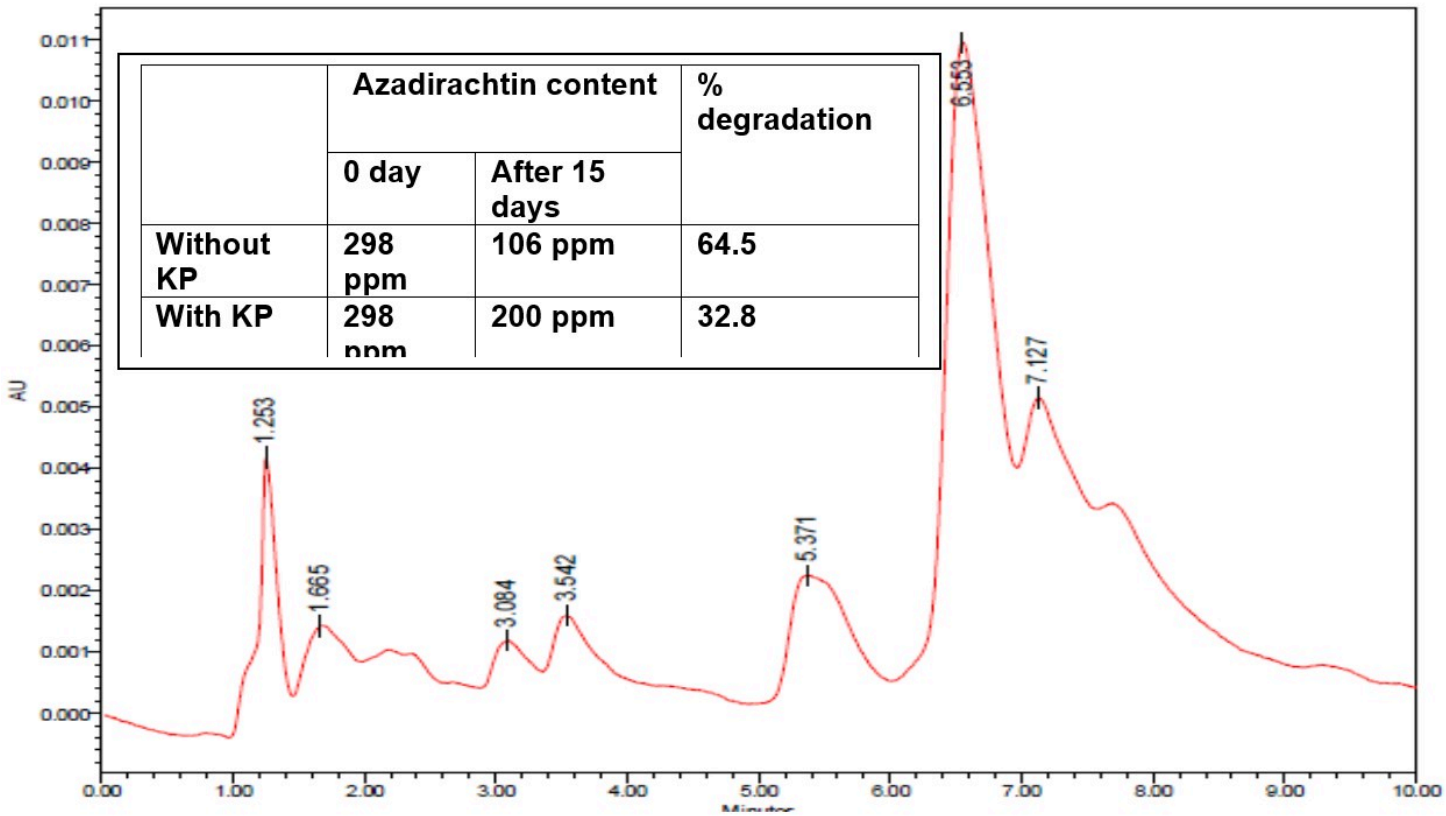


Figure 3

Fig 2: HPLC chromatogram of coil Containing Neem kernel with synergist

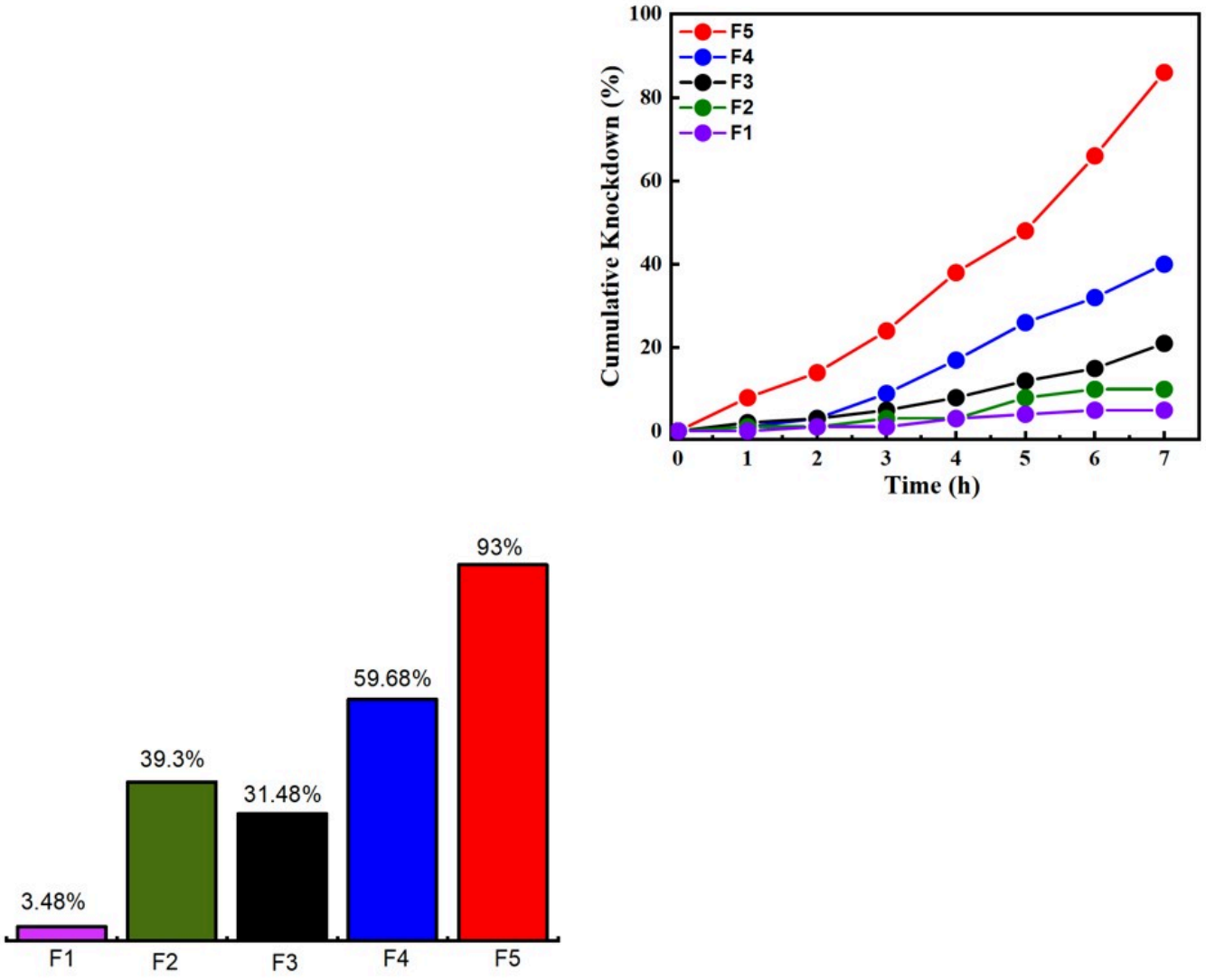


Figure 4

Fig 3: Cumulative knockdown percentage of different formulations (F1–F5) over time (0–7 hours). The formulations are represented by different colored lines: F5 (red), F4 (blue), F3 (black), F2 (green), and F1 (purple). F5 shows the highest knockdown efficacy, followed by F4, F3, F2, and F1.