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# Field evaluation of plant-based oils against major sucking pests of chili

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## Abstract

Chilli (*Capsicum annuum* L.) is one of the most important spice crops globally, renowned for its pungency, flavor, and nutritional value. This comprehensive study investigated the potential of botanical oils as sustainable alternatives for pest management in chili cultivation. A field experiment was conducted during the 2024 Rabi season at Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh, employing a Randomized Complete Block Design with three replications. The study evaluated four botanical oils (neem, karanja, mahogany, and castor at 3% concentration) against the standard synthetic insecticide imidacloprid (0.2%). Results demonstrated that while imidacloprid provided the highest pest reduction (72.34% for aphids and 68.43% for thrips) and maximum yield (4.20 tons/ha, representing a 40% increase over control), botanical oils showed promising efficacy. Neem oil emerged as the most effective botanical treatment, achieving 62.55% aphid reduction and 52.23% thrips reduction, with a yield of 3.90 tons/ha (30% increase over control). Karanja oil followed with 45.32% aphid and 44.42% thrips reduction. Economic analysis revealed competitive benefit-cost ratios for neem (3.70) and karanja oils (3.63), demonstrating their economic viability. These findings highlight that neem and karanja oils can serve as effective, eco-friendly components of integrated pest management in chili cultivation. They offer substantial pest control, yield improvement, and economic returns while addressing critical concerns about environmental sustainability, pesticide resistance, and food safety. The study provides valuable insights for developing sustainable pest management strategies in chili production systems, particularly for smallholder farmers in tropical and subtropical regions.

**Keywords:** Chilli, plant based pesticides, sucking pests, *Scirtothrips dorsalis*, *Aphis gossypii*, .

## Introduction

Vegetables play a crucial role in our diet as they supply the essential vitamins, carbohydrates, and minerals required for a healthy and balanced nutrition. Among these, chili (*Capsicum annuum* L.) stands out as one of the most economically important and popular vegetable crops due to its red fruits, which serve as a spice, and its green fruits, which are eaten in salads or as vegetables. It is highly valued for their pungency, color, and flavor, making them a popular ingredient in numerous dishes (Hossain *et al*. 2021). *Capsicum annuum* is rich in capsaicin, an active compound known for its antioxidant properties and health benefits, such as improving metabolism and reducing the risk of chronic diseases like cardiovascular problems and diabetes (Chowdhury *et al*. 2020). Besides the traditional use of chilies as vegetables, spices, sauces and pickles, the green chili fruits are a good source of vitamin A and C (Singh *et al*. 2007) which is crucial for immune function, skin health, and wound healing (Saha *et al*. 2020). As such, the cultivation of chili peppers has both economic and health implications for the country (Islam *et al*. 2021). The total area under chili cultivation has expanded as farmers seek to meet growing consumer demand both locally and abroad (Saha *et al*. 2020). Chilli production in the country, with over 50,000 hectares of land in recent years (BBS 2021). Moreover, the rise of modern farming techniques, such as the use of greenhouses and improved irrigation practices, has contributed to increased productivity and a more consistent supply of high-quality chili peppers throughout the year (Islam *et al*. 2021).

Despite the potential of *Capsicum annuum,* challenges like pest infestations, disease management, and fluctuating market prices remain key factors that affect its productivity and profitability in Bangladesh (Rahman *et al*. 2020). Among these, damage due to insect infestation is an important one. Insect pests pose a challenge to chili cultivation due to their unpredictable behavior. Chilli plants are attacked by around 35 species of arthropods, with mites, thrips, aphids, and whiteflies being the most common pests (Pradeep and Korat 2018). Aphids, particularly *Aphis gossypii* and *Myzus persicae*, are known for their rapid reproduction and ability to infest large areas, making them a major threat to chili crops (Chaudhary and Bhowmik 2020). Thrips, whitefly and mites suck sap from the plants with their piercing-sucking mouthparts, causing leaf curling, leaf and fruit dropping and withering to the infested plants. Thrips and whitefly help in transmitting virus diseases (Jones 2003). An infestation of yellow mite, *Polyphagotarsonemus latus* Banks and thrips, *Scirtothrips dorsalis* Hood, results in severe leaf curl of chili plants and causes yield loss of 30%-55% (Rai *et al*. 2007). The management of these sucking and foliar pests utilizing various non-chemical means, including as cultural, mechanical, biological, and host plant resistance, was limited worldwide. Management tactics in Bangladesh and other countries are currently limited to the frequent use of dangerous chemical pesticides (Alam 2005, Anon 2005, Misra and Senapati 2003, Singh and Choudhary 2001; Bhargava *et al*. 2001; Ali and Karim 1994, Yadgirwar *et al*. 1994, Singh *et al*. 1999). Farmers use synthetic insecticides four to six times to manage sucking pests, reducing natural adversaries and beneficial species. Although neonicotinoids are commonly used to treat homopteran insect pests, little study has been done on their effects on natural adversaries (Cloyd and Bethke 2011). However, this form of insect pest control technique, which relied only on chemical protection, had several limits and undesired side effects (Husain 1993, 1984), causing harm to non-target organisms such as fish, beneficial insects, and other wildlife. They pollute water bodies, threatening aquatic life, and harm pollinators such as bees, upsetting ecosystems. Pesticides create ecological imbalances, disrupting food webs and biodiversity.

To overcome the hazards of chemical pesticides, the use of botanicals is now emerging as one of the prime means to protect crops (Kovarikova and Pavela 2019). Botanicals like neem seed kernel extract, neem oil, karanj oil, garlic extract etc. aid in the reduction of pest population (Meena and Tayde 2017). Moreover, castor oil can increase the effectiveness of insecticides and acaricides under laboratory and field conditions (Veena *et al*. 2017). Plant-based compounds called biopesticides are used to manage insect pests (Patil and Maha 2008). These naturally existing molecules work by using non-toxic methods to control pests (Eswara and Srinivasa 2004). Botanical oils have emerged as a significant tool in the management of insect pests, due to their natural origin, minimal environmental impact, and low toxicity to humans and animals. The use of botanical insecticides has grown especially in integrated pest management (IPM) systems, which aim to reduce reliance on synthetic pesticides while maintaining effective pest control (Isman, 2006, Khater 2012). Keeping these perspectives in mind, the experiment was carried out to assess the comparative effectiveness of certain botanical oils and tested insecticides against the sucking insects of chili crop, and to compute the benefit cost ratio (BCR) to the tested botanical oils for sucking pests in chili crop.

## Materials and methods

The experiment on the population dynamics and management of sucking insect pests in chili was conducted at the experimental field of Hajee Mohammad Danesh Science and Technology University (HSTU) in Dinajpur, Bangladesh from January to May 2024.

**Study location and climatic conditions:** The experimental site was established in the research field of the Department of Entomology at Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur,-5200, from January to May 2024. The field was located at 25°41′N latitude and 88°39′E longitude, with a height of 38.49 meters above sea level. The experimental location corresponds to the Agro-ecological zone of "Old Himalayan Piedmont Plain" (AEZ-1). The experimental site was located in the subtropical climatic zone, which is characterized by low temperatures, low relative humidity, and minimal rainfall from January to May. The soil type of the research field was sandy loam. The area corresponds to the agroecological zone of "Old Himalayan Piedmont Plain" (AEZ-1).The organic matter content was quite low.

**Cultivation of chili:** The experiment was set up in

Randomized Complete Block Design (RCBD) with three replications ($R_1$, $R_2$, and $R_3$). The territory was divided into three equal blocks. Each block was divided into 6 plots, with 6 treatment combinations chosen at random. The experiment included a total of 18 unit plots. Each unit plot measured 1.2 m × 1m, with a plot spacing of 0.5 m and a block distance of 1.0 m. The experiment field measured 11 m long and 6 m wide. Each block was viewed as a single replication.

**Treatments of the experiment:** The experiment was designed to investigate the efficacy of various botanical oils with chemical pesticides in comparison to alternative less toxic yet effective control strategies against sucking insects. The following treatments were used in this experiment:

$T_1$ = Imitaf 20 SL (Imidacloprid) @ 0.2%

$T_2$ = Castor oil (*Ricinus communis*) @ 3%

$T_3$ = Mahogany oil (*Swietenia macrophylla*), @ 3%

$T_4$ = Neem oil (*Azadirachta indica*) @ 3%

$T_5$ = Karanja oil (*Pongamia pinnata*) @ 3%

$T_6$ = Untreated (control)

**Collection and formulation of botanical oils:** Plant oils of neem (*Azadirachta indica*), mahogany (*Swietenia macrophylla*), karanja (*Pongamia pinnata*), and castor (*Ricinus communis*) were collected from Dinajpur's local market. Three percentage (3%) concentrations were made individually for each oil by combining 15 ml of oil with 485 ml of water. Each concentration received a single drop of tween-20 as an emulsifier, which was thoroughly mixed. A knapsack hand sprayer of 2 liters capacity was used to apply the prepared oils uniformly.

**Collection of chemical insecticide:** One chemical insecticide named Imitaf 20 SL (Imidacloprid) was collected from the dealer shop at the local market of Dinajpur, Bangladesh. It was used to check the comparison of effectiveness of botanical oils.

**Application of insecticides:** Botanical oils were applied with a knapsack sprayer. The first application was initiated after the 6$^{th}$ week of transplantation, and subsequent applications in each treatment were made at 10 day intervals. Precautions were taken to prevent drift to neighboring plots.

**Identification of thrips species:** Thrips species were collected from chili fields and kept in 70% ethanol for future species identification. The preserved dead adult thrips were placed in a test tube filled with 10% KOH solution and then boiled for 5-10 minutes. After washing with running water, it was immersed in 30%, 50%, 70%, 90%, and absolute alcohol respectively for 5-10 minutes. Following that, it was soaked in xylene to remove the alcohol before being mounted on the slide with glycerin. The prepared slide was then examined by using a 40x compound microscope.

**Data collection:** Aphids and thrips were counted from treated and untreated chili plots beginning 45 days after transplantation. Sucking insects were counted as adults and nymphs. Each plot contained six plants whereas three plants were randomly selected. Six leaves were randomly selected from each three plants, two from the bottom (older leaves), two from the middle, and two from the top. The leaf's lower surface was meticulously checked for insects. Observation of the symptoms formed on the leaves and flowers, the number of insects per plant was recorded before treatment and at intervals of 1, 3, 7, and 10 days beginning in the sixth week after transplanting and continuing until the eleventh week. Three plants were randomly chosen from each plot and tagged. The selected plants were monitored at weekly intervals in the morning. The number of insects per plant was counted to estimate the infestation intensity. The results were converted into the mean number of insects per leaf and per flower. Fruits were picked, and the total weight of fruits which is collected from per plot in both control and treatment plots was computed and recorded.

**Estimation of percent reduction of aphid and thrips:** The following calculation was used to compute the percentage of population reduction of aphids and thrips under different treatments.

$$\text{Percentage reduction (\% R)} = \frac{\text{No. of insects in the control - No. of insects in the treatment}}{\text{No. of insects in the control}} \times 100$$

**Estimation of yield:** The weight of chili fruits was recorded separately for each plot, and yield was calculated for each plot. The yield was then converted to per hectare basis using the formula below (Usman *et al*. 2015).

$$\text{Yield (kg ha}^{-1}) = \frac{\text{Yield plot-1}}{\text{Plot size}} \times 10{,}000$$

**Percent increase of yield of treatment over control:** The percent increase in yield over control in different treatments was calculated using the following formula (Vanisree *et al*. 2017).

$$\text{Increase (\%) of yield in treatment over control} = \frac{\text{Yield in treatment - Yield in control}}{\text{Yield in control}} \times 100$$

**Economic analysis:** Economic assessments were performed to establish the most profitable combinations of treatments.

**Benefit cost ratio (BCR):** The economic indicator BCR for each treatment combination was calculated using the formula below (Sravanthi *et al*. 2016).

$$\text{Benefit cost ratio (BCR)} = \frac{\text{Gross return}}{\text{Total cost of production (cost of treatments+common cost}} \times 100$$

The gross return was determined using the sale price of chili green fruits. The market value of the fruit was estimated at Tk. 85.00 kg$^{1}$.

**Statistical analyses:** For statistical analysis, all obtained data from various parameters was integrated and structured. The data was statistically analyzed using Statistix 10 software to determine the significance of variance (ANOVA) among treatments. Means were separated using the LSD test ($P<0.05$).

## Results and Discussion

**Efficacy of botanical oils against aphids on chili after 1st application:** The efficacy of various treatments was evaluated based on their mean values, percentage reduction over BS, and reduction over control (Table 1). T1 (Imitaf 0.2%) demonstrated the most significant reduction over BS (60.61%), with a 40.47% reduction over control, making it the most effective treatment. The mean value (5.22) was notably lower than all other treatments, indicating its superior performance. Among botanical treatments, T4 (Neem oil 3%) showed the second-highest reduction over BS (48.29%) and a 33.06% reduction over control, with a mean value of 5.87, significantly lower than most treatments except T1. This was followed by T5 (Karanja oil 3%), which recorded a reduction over BS 39.22% and a 20.75% reduction over control, with a mean value of 6.95, proving its moderate effectiveness. On the other hand, T3 (Mahogany oil 3%) exhibited a reduction of 34.61% over BS and an 18.35% reduction over control, with a mean value of 7.16, indicating slightly lower effectiveness compared to T4 and T5. T2 (Castor oil 3%) had the lowest reduction over BS among the treated groups (21.73%) and a 12.31% reduction over control, with a mean value of 7.69, making it the least effective among the applied treatments. The untreated group (T6) had the highest mean value (8.77), confirming the necessity of treatment applications. Statistical analysis using lettering suggests that T1 (Imitaf) significantly differed from other treatments, showcasing the lowest mean value (5.22) and the highest efficacy. Similarly, T4 (Neem oil) showed significant differences compared to T2 and T3, which did not differ significantly from each other. The data also indicate that the 7th and 10th days after spray recorded the lowest values for most treatments, suggesting that treatment efficacy improved over time, particularly with prolonged exposure (Table 1). The order of treatment efficacy can thus be ranked as follows: T1 (Imitaf 0.2%) >

**Table 1. Number of aphids at per leaf treated by different botanical oils at different time intervals after 1st application**

| Treatments | BS | Days After Spray ( DAS) | | | | | % Reduction Over BS | % Reduction over control |
|---|---|---|---|---|---|---|---|---|
| | | 1 DAS | 3 DAS | 7 DAS | 10 DAS | Mean | | |
| Imitaf 20SL($T_1$) | 10.36 a | 6.62 b | 5.36 c | 4.82 bc | 4.08 d | 5.22 d | 60.61 | 40.47 |
| Castor oil ($T_2$) | 9.34 a | 8.54 ab | 7.83 ab | 7.08 ab | 7.31 ab | 7.69 ab | 21.73 | 12.31 |
| Mahogany oil ($T_3$) | 10.11 a | 8.21 ab | 7.31 abc | 6.53 abc | 6.61 bc | 7.16 bc | 34.61 | 18.35 |
| Neem oil ($T_4$) | 9.36 a | 7.87 ab | 6.14 bc | 4.65 c | 4.84 cd | 5.87 cd | 48.29 | 33.06 |
| Karanja oil ($T_5$) | 10.12 a | 7.92 ab | 7.75 ab | 5.99 bc | 6.15 bc | 6.95 bc | 39.22 | 20.75 |
| Untreated ($T_6$) | 9.89 a | 9.27 a | 8.98 a | 8.41 a | 8.44 a | 8.77 a | | |
| LSD (0.05) | 2.4299 | 1.7039 | 1.3782 | 1.4953 | 1.1602 | 1.4341 | | |
| P value | 0.9015 | 0.0899 | 0.002 | 0.0018 | 0.0001 | | | |

Different letter(s) in a column are significantly different at 5% level of probability by least significant difference (LSD). T1 = Imitaf 20 SL (Imidacloprid) @ 0.2%; T2 = Castor oil @ 3%; T3 = Mahogany oil @ 3%; T4 = Neem oil @ 3%; T5 = Karanja oil @ 3%; T6 =Untreated (control). All treatments were applied at 10 days intervals. BS-Before Spray, DAS-Days After Spray.

T4 (Neem oil 3%) > T5 (Karanja oil 3%) > T3 (Mahogany oil 3%) > T2 (Castor oil 3%) > T6 (Untreated Control). Considering these findings, among botanical oils, T4 (Neem oil 3%) remains the most effective treatment and demonstrating the highest reduction percentage and sustained impact over time. These findings align with previous studies by Ahmed *et al.* (2021) and Sharma *et al.* (2020), who reported that imidacloprid-based treatments (such as Imitaf) provided the highest aphid suppression, while botanical oils like Neem and Karanja showed moderate but significant reductions. Neem oil showed promising results, achieving a 48.29% reduction over BS with a mean of 5.87 aphids, which aligns with recent studies by Widodo *et al*. (2023) and Rahman & Hasan (2021) demonstrating the effectiveness of neem extracts in suppressing aphid attacks on chili and other crops due to their insecticidal secondary metabolites. Similarly, Kumar *et al.* (2019) found that Neem oil significantly reduced aphid populations within 7 days, supporting the present study's findings on its effectiveness as an alternative to chemical insecticides. Karanja oil provided a 39.22% reduction over BS, while Mahogany oil resulted in a 34.61% reduction over BS. These findings are supported by studies by Gadge *et al*. (2023) indicating that karanja oil can be effective against sucking pests, though often at higher doses or in combination with other oils. Castor oil, however, demonstrated the lowest efficacy among the tested botanical oils with a 21.73% reduction over BS, although some research by Piffer *et al.* (2023) suggests its potential in controlling certain aphid species. A study by Yasmin *et al.* (2017) assessed the potency of three botanical oils neem, karanja, and mahogany against *Aphis craccivora* nymphs under laboratory conditions. The findings indicated that mahogany oil exhibited significant repellent effects, with a repellency rate of 77.33%. This overall pattern suggests that while synthetic insecticides like Imitaf provide immediate and high control, botanical alternatives, particularly neem and karanja, offer viable eco-friendly options for aphid management, albeit with varying degrees of efficacy.

Table 2 reflects a clear distinction in treatment effectiveness against aphid infestation after the second application, with substantial variations in mean population, percent reduction over BS, and reduction over control. Imidacloprid (T1) exhibited the strongest suppression, reducing aphid counts to a mean of 1.88 per leaf, accompanied by a 67.07% reduction over BS and a 71.12% decrease over the untreated control (T6). Neem oil (T4) followed, reducing aphids to a mean of 2.66, corresponding to a 57.25% reduction over BS and 59.13% over control. Karanja oil (T5) resulted in a moderate mean of 3.75, 40.19% population reduction over BS and 42.39%

over control. Mahogany oil (T3) showed similar moderate effects, with a mean aphid count of 4.23, and reductions of 37.14% over BS and 32.41% over control. Castor oil (T2), however, had the least impact among the treatments, with a relatively high mean of 5.8, and lower reduction rates of 22.57% over BS and 10.9% over control. The untreated control remained the least effective. Statistical analysis confirmed significant differences, particularly from the 3rd day onward (p-values < 0.05), and LSD lettering distinguished T1 and T4 from less effective treatments. The aphid population consistently declined toward the 7th and 10th days after spraying, suggesting increasing residual action over time for both chemical and botanical agents. Each treatment's effectiveness was shaped by both immediate suppression and residual longevity, with the chemical option clearly leading, yet Neem oil showing strong potential among natural alternatives. The observed trend establishes a ranking of treatment effectiveness as follows: T1 (Imitaf 0.2%) > T4 (Neem oil 3%) > T5 (Karanja oil 3%) > T3 (Mahogany oil 3%) > T2 (Castor oil 3%) > T6 (Untreated Control). Based on these findings, among botanical oils, T4 (Neem oil 3%) remains the most effective treatment and demonstrating the highest reduction percentage and sustained impact over time. Patel and Singh (2021) found that botanical insecticides like Neem and Karanja oil provided significant aphid suppression, though their effectiveness was slightly lower compared to synthetic alternatives. Desai *et al.* (2020) observed that repeated applications of Neem oil led to a cumulative reduction in aphid numbers over a 10-day period, reinforcing its role as a sustainable pest management option. Verma and Choudhary (2017) highlighted that Neem-based treatments delayed aphid resurgence longer than untreated controls, suggesting their potential integration in integrated pest management (IPM) programs. Mahogany oil and Karanja oil also showed considerable reductions of 37.14% and 40.19% over BS, respectively, further supporting research on the broad-spectrum insecticidal and repellent effects of various botanical oils against sucking pests by Yasmin *et al.* (2023) and Gadge *et al.* (2023).

Conversely, Castor oil showed a moderate 22.57% reduction over BS, indicating its comparative lower efficacy in direct aphid control in this context, although Piffer et al. (2023) have shown it can enhance the action of other pesticides or control different pest types. The continued effectiveness of these treatments underscores the potential for integrated pest management strategies combining both synthetic and botanical agents to achieve sustainable aphid control.

The comparative performance of treatments against aphid infestation on chili clearly showed statistically significant differences (p < 0.001) across treatments (Table 3). The synthetic insecticide Imidacloprid (T1 @ 0.2%) was the most effective, recording the lowest mean aphid count (0.62 aphids/leaf), which translated to a 72.34% reduction over BS in aphid population and an 88.16% reduction over the untreated control (T6), which had the highest infestation with a mean of 5.24. This confirmed the strong systemic action of Imidacloprid in suppressing sucking pests. Among botanical oils, Neem oil (T4 @ 3%) was the most promising alternative. It resulted in a mean aphid population of 1.11, indicating a 62.55% reduction over BS and 78.81% reduction over control. Neem's strong antifeedant and growth regulatory properties, mainly due to azadirachtin, likely contributed to this performance. Statistically, Neem oil significantly differed from less effective treatments and maintained consistent efficacy throughout all observations. Karanja oil (T5 @ 3%) was the second-best botanical treatment, showing moderate suppression with a mean of 2.84, 45.32% population reduction over BS, and 45.80% reduction over control. While less effective than Neem, it still performed significantly better than the control. Mahogany oil (T3 @ 3%) followed with a mean of 3.28, 40.49% reduction over BS, and 37.40% reduction over control, indicating only moderate impact. Castor oil (T2 @ 3%) was the least effective botanical, with a mean aphid count of 3.58, 38.03% reduction over BS, and only 31.67% reduction over control, showing minimal statistical difference from the untreated plots. In conclusion, the treatment ranking based on overall efficacy was: T1 (Imidacloprid) > T4 (Neem oil) > T5 (Karanja oil) > T3 (Mahogany oil) > T2 (Castor oil) > T6 (Control). While Imidacloprid remained the most potent, Neem oil stood out as the best botanical treatment, offering effective pest suppression and aligning well with eco-friendly and sustainable pest management goals. Essani *et al.* (2020) found that neem seed extract

**Table 2. Number of aphids per leaf treated by different botanical oils at different time intervals after 2nd application**

| Treatments | BS | Days After Spray (DAS) | | | | | % Reduction Over BS | % Reduction over control |
|---|---|---|---|---|---|---|---|---|
| | | 1 DAS | 3 DAS | 7 DAS | 10 DAS | Mean | | |
| Imitaf 20 SL($T_1$) | 4.10 d | 2.7 b | 2.05 b | 1.42 d | 1.35 c | 1.88 c | 67.07 | 71.12 |
| Castor oil ($T_2$) | 7.31 ab | 6.07 a | 5.78 a | 5.71 ab | 5.66 ab | 5.8 ab | 22.57 | 10.9 |
| Mahogany oil ($T_3$) | 6.73 abc | 4.88 ab | 4.34 ab | 4.17 bc | 4.23 abc | 4.40 abc | 37.14 | 32.41 |
| Neem oil ($T_4$) | 5.1 cd | 3.16 b | 3.06 ab | 2.26 cd | 2.18 bc | 2.66 bc | 57.25 | 59.13 |
| Karanja oil ($T_5$) | 6.17 bc | 4.45 ab | 3.76 ab | 3.11 cd | 3.69 abc | 3.75 abc | 40.19 | 42.39 |
| Untreated ($T_6$) | 8.16 a | 6.59 a | 6.23 a | 6.58 a | 6.67 a | 6.51 a | | |
| LSD (0.05) | 1.0717 | 1.6347 | 2.1365 | 1.5184 | 2.5321 | 1.9554 | | |
| P value | 0.0001 | 0.0019 | 0.0106 | 0.0001 | 0.0068 | | | |

Different letter(s) in a column are significantly different at 5% level of probability by least significant difference (LSD). T1 = Imitaf 20 SL (Imidacloprid) @ 0.2%; T2 = Castor oil @ 3%, T3 = Mahogany oil @ 3%, T4 = Neem oil @ 3%, T5 = Karanja oil @ 3%, T6 =Untreated (control). All treatments were applied at 10 days intervals. BS-Before Spray, DAS-Days After Spray.

achieved an 87.75% reduction in aphid populations on mustard crops, while neem oil resulted in a 76.02% reduction.

Vinodhini and Malaikozhundan (2011) reported that neem seed kernel extract (5%) was highly effective against sucking pests, including aphids, on cotton. The study also noted that neem oil (3%) provided significant control, though slightly less effective than the seed extract. Harika and Gogoi (2021) conducted a field experiment to assess the impact of various biopesticides on sucking pests of okra, including aphids. They found that plots treated with karanja oil at a 5% concentration had an average of 6.82 aphids per three leaves, whereas untreated control plots had 12.47 aphids per three leaves. This indicates a reduction of approximately 45.3% in aphid population due to karanja oil application. Akashe et al. (2013) evaluated various plant oils, including castor oil. The results showed that castor oil, along with neem oil, was effective in reducing aphid populations, leading to increased seed yield.

According to the findings presented in Table 4, significant differences were observed in the effectiveness of various treatments against thrips infestation on chili flowers after the second application. The chemical treatment Imidacloprid (T1) recorded the highest performance, with the lowest mean thrips count of 2.21 per flower. This corresponded to a 68.43% reduction over BS in thrips population and a 56.75% reduction over the untreated control (T6), which had the highest mean thrips count of 5.11. Among the botanical treatments, Neem oil (T4 at 3%) demonstrated the best performance with a mean thrips count of 2.61, achieving a 52.23% reduction over BS and 48.92% reduction over control. This result closely followed that of the chemical insecticide, highlighting Neem oil as a strong eco-friendly alternative. Karanja oil (T5) showed moderate efficacy, reducing the thrips population by 44.42% over BS and achieving 38.74% reduction over control with a mean of 3.13. Mahogany oil (T3) had a mean thrips count of 3.29, 37.77% reduction over BS and 35.61% reduction over control, indicating moderate effectiveness. Castor oil (T2) was the least effective among the botanicals, with a mean of 3.79, corresponding to 29.2% reduction over BS and 25.83% reduction over control. The untreated control (T6) had the highest thrips count, emphasizing the need for intervention. Statistical analysis showed that differences among treatments became significant starting from the third day after spray ($p < 0.05$), confirming the treatment impact. The efficacy of different treatments on thrips infestation in chili flowers was evaluated based on the percentage reduction in thrips population post-application. The results indicated significant differences among the treatments ($P < 0.05$) with chemical and botanical oils demonstrating varying degrees of effectiveness. Among the treatments, Imitaf (T1, 0.2%) exhibited the highest thrips reduction (68.43%) with an over-control reduction of 56.75%. This result aligns with previous findings by Kumar *et al.* (2020) who reported similar effectiveness of imidacloprid-based insecticides against thrips in solanaceous crops. Among the botanical oils, Neem oil (T4, 3.0%) showed the highest efficacy with a 52.23% reduction in thrips population, followed by Karanja oil (T5, 3.0%) with 44.42% reduction. Similar trends were observed in studies by Gupta *et al.* (2019) and Sharma *et al.* (2021), which demonstrated the insecticidal properties of neem and karanja oils in reducing thrips populations in chili and other vegetable crops. Mahogany oil (T3, 3.0%) showed moderate efficacy with a 37.77% reduction, comparable to findings reported by Rahman *et al.* (2018), who highlighted the potential of mahogany extracts in integrated pest management (IPM) strategies. Castor oil (T2, 3.0%) resulted in a 29.2% reduction, indicating lower efficacy compared to neem and karanja oils but still significantly better than the untreated control (T6). This aligns with the research of Singh and Patel (2017), who found castor oil to have moderate repellency effects against sucking pests. Overall, the findings suggest that Imitaf (T1) remains the most effective treatment, followed by neem and karanja oils among botanicals. These results reaffirm the potential of botanical oils as eco-friendly alternatives to synthetic insecticides in chili cultivation, supporting previous literature on sustainable pest management strategies (Das *et al.* 2020; Ahmad *et al*. 2016).

The efficacy of different treatments against thrips infestation on chili flowers is presented in Table 5. Among the treatments, Imitaf 20 SL (T1) at 0.2% exhibited the highest reduction in thrips population, achieving 65.19% reduction over compared to the untreated control, with a mean thrips count of 1.01 after 10 days. This significant reduction aligns with findings by Ahmed *et al.* (2021), who reported similar effectiveness of synthetic insecticides in managing thrips in solanaceous crops. Among botanical oils, neem oil (T4) at 3% demonstrated the highest efficacy, reducing thrips population by 46.88% over BS with a mean count of 1.47, which is consistent with the results reported by Sharma *et al.* (2020), who found that neem-based formulations effectively suppressed thrips populations in vegetable crops. Similarly, karanja oil (T5) exhibited a 41.75% reduction over BS, showing promising results, corroborating the findings of Patel *et al.* (2019) on the use of karanja oil for pest management in chili. Mahogany oil (T3) also performed well, reducing thrips

**Table 3. Number of aphids per leaf treated by different botanical oils at different time intervals after 3rd application**

| Treatments | BS | Days After Spray (DAS) | | | | | % Reduction over BS | % Reduction over control |
|---|---|---|---|---|---|---|---|---|
| | | 1 DAS | 3 DAS | 7 DAS | 10 DAS | Mean | | |
| Imitaf 20 SL ($T_1$) | 1.41 d | 0.94 b | 0.73 d | 0.43 d | 0.39 d | 0.62 d | 72.34 | 88.16 |
| Castor oil ($T_2$) | 5.1 ab | 4.37 a | 3.58 ab | 3.24 ab | 3.16 ab | 3.58 ab | 38.03 | 31.67 |
| Mahogany oil ($T_3$) | 4.42 abc | 4.09 a | 3.57 ab | 2.85 bc | 2.63 bc | 3.28 bc | 40.49 | 37.4 |
| Neem oil ($T_4$) | 2.35 cd | 1.23 b | 1.43 cd | 0.93 cd | 0.88 cd | 1.11 cd | 62.55 | 78.81 |
| Karanja oil ($T_5$) | 4.06 bc | 3.74 a | 3.17 bc | 2.23 bcd | 2.22 bcd | 2.84 bcd | 45.32 | 45.8 |
| Untreated ($T_6$) | 6.38 a | 5.38 a | 5.35 a | 5.05 a | 5.18 a | 5.24 a | | |
| LSD (0.05) | 1.3656 | 1.2799 | 1.2569 | 1.4108 | 1.3401 | 1.3219 | | |
| P value | 0.0001 | 0.0001 | 0.0001 | 0.0003 | 0.0002 | | | |

Different letter(s) in a column are significantly different at 5% level of probability by least significant difference (LSD). T1 = Imitaf 20 SL (Imidacloprid) @ 0.2%; T2 = Castor oil @ 3%; T3 = Mahogany oil @ 3%; T4 = Neem oil @ 3%; T5 = Karanja oil @ 3%; T6 =Untreated (control). All treatments were applied at 10 days intervals. BS-Before Spray, DAS-Days After Spray.

numbers by 38.61% over BS, comparable to observations by Rao *et al.* (2018), who reported mahogany extracts as an effective natural pest deterrent. Castor oil (T2) was the least effective among the botanical oils, with a reduction of 27.71% over BS, but it still performed better than the untreated control, aligning with reports by Kumar and Singh (2017) on castor oil's moderate insecticidal properties. The untreated control (T6) had the highest thrips infestation throughout the experiment, with a mean thrips count of 4.44, demonstrating the necessity of intervention measures for effective thrips management. The significant differences observed in the treatments, as indicated by the P-value (<0.05), suggest that both synthetic and botanical treatments play a crucial role in thrips suppression.

The effectiveness of different botanical oils and synthetic insecticides in reducing thrips infestation per flower in chili is presented in Table 6. The pre-treatment thrips population ranged from 0.84 to 3.76 thrips per flower. After the application of treatments, the thrips population varied significantly among the treatments across different observation periods (1 DAS, 3 DAS, 7 DAS, and 10 DAS). Among the treatments, T1 (Imitaf 0.2%) exhibited the highest thrips suppression, reducing the population by 63.09% over BS, with an 86.5% reduction over control. The effectiveness of synthetic insecticides such as Imitaf aligns with previous studies by Singh *et al.* (2021) and Sharma *et al.* (2019), which reported a 60–70% thrips reduction using neonicotinoid-based insecticides. T4 (Neem oil 3%) resulted in a 51.23% reduction over BS with a 74.75% reduction over control, confirming the efficacy of neem-based treatments reported by Kumar *et al.* (2020) who observed thrips mortality rates between 50–80% in horticultural crops treated with neem extracts. Similarly, T5 (Karanja oil 3%) also performed well, with a 43.35% reduction over BS and a 67.06% reduction over control, which corroborates findings by Rahman *et al.* (2021) who documented over 45% thrips suppression using karanja oil in solanaceous crops. Among the botanical oils, T3 (Mahogany oil 3%) and T2 (Castor oil 3%) showed intermediate efficacy, with reductions of 36.27% and 28.88% over BS, respectively. Their moderate effectiveness suggests that while botanical oils provide some control, they may require repeated applications or combination strategies, as indicated by Ali *et al.* (2022) in their study on botanical pesticide integration. The untreated control (T6) maintained the highest thrips population across all observation periods, indicating the need for effective pest management strategies. The statistical significance (P < 0.05) observed for all treatments highlights the reliability of the applied interventions. These results emphasize the potential of botanical oils, particularly neem and karanja oils, as

**Table 4. Number of thrips per flower treated by different botanical oils at different time intervals after 2nd application**

| Treatments | BS | Days After Spray (DAS) | | | | | % Reduction over BS | % Reduction over control |
|---|---|---|---|---|---|---|---|---|
| | | 1 DAS | 3 DAS | 7 DAS | 10 DAS | Mean | | |
| Imitaf 20 SL ($T_1$) | 5.48 a | 2.88 c | 2.76 bc | 1.47 d | 1.73 c | 2.21 c | 68.43 | 56.75 |
| Castor oil ($T_2$) | 5.01 a | 4.35 abc | 3.28 b | 4 ab | 3.54 b | 3.79 b | 29.2 | 25.83 |
| Mahogany oil ($T_3$) | 5.11 a | 4.74 ab | 2.32 bc | 2.92 bc | 3.18 b | 3.29 b | 37.77 | 35.61 |
| Neem oil ($T_4$) | 5.59 a | 3.72 bc | 1.77 c | 2.31 cd | 2.67 bc | 2.61 bc | 52.23 | 48.92 |
| Karanja oil ($T_5$) | 4.57 a | 4.21 abc | 3.3 b | 2.5 cd | 2.54 bc | 3.13 bc | 44.42 | 38.74 |
| Untreated ($T_6$) | 5.83 a | 5.5 a | 5.05 a | 4.96 a | 4.95 a | 5.11 a | | |
| LSD (0.05) | 1.4685 | 1.0729 | 0.8848 | 0.9265 | 0.8658 | 0.9375 | | |
| P value | 0.4832 | 0.0051 | 0.0002 | 0.0001 | 0.0002 | | | |

Different letter(s) in a column are significantly different at 5% level of probability by least significant difference (LSD). T1 = Imitaf 20 SL (Imidacloprid) @ 0.2%; T2 = Castor oil @ 3%; T3 = Mahogany oil @ 3%; T4 = Neem oil @ 3%; T5 = Karanja oil @ 3%; T6 =Untreated (control). All treatments were applied at 10 days intervals. BS-Before Spray, DAS-Days After Spray.

**Table 5. Number of thrips per flower treated by different botanical oils at different time intervals after 3rd application**

| Treatments | BS | Days After Spray (DAS) | | | | | % Reduction over BS | % Reduction over control |
|---|---|---|---|---|---|---|---|---|
| | | 1 DAS | 3 DAS | 7 DAS | 10 DAS | Mean | | |
| Imitaf 20 SL (T1) | 1.81 c | 1.49 b | 1.1 c | 0.82 c | 0.63 c | 1.01 c | 65.19 | 77.25 |
| Castor oil (T2) | 3.68 b | 3.4 ab | 2.89 ab | 2.55 b | 2.66 b | 2.87 b | 27.71 | 35.36 |
| Mahogany oil (T3) | 3.47 b | 2.88 ab | 1.94 bc | 2.06 bc | 2.13 b | 2.25 b | 38.61 | 49.32 |
| Neem oil (T4) | 2.73 bc | 1.83 b | 1.21 c | 1.42 bc | 1.45 bc | 1.47 bc | 46.88 | 66.89 |
| Karanja oil (T5) | 2.73 bc | 2.35 ab | 1.04 c | 1.08 bc | 1.59 bc | 1.51 bc | 41.75 | 65.9 |
| Untreated (T6) | 5.17 a | 4.84 a | 4.39 a | 4.21 a | 4.32 a | 4.44 a | - | - |
| LSD (0.05) | 0.8316 | 1.6325 | 1.0714 | 0.9992 | 0.9013 | 1.1511 | | |
| P value | 0.0001 | 0.0109 | 0.0002 | 0.0002 | 0.0001 | - | | |

Different letter(s) in a column are significantly different at 5% level of probability by least significant difference (LSD). T1 = Imitaf 20 SL (Imidacloprid) @ 0.2%; T2 = Castor oil @ 3%; T3 = Mahogany oil @ 3%; T4 = Neem oil @ 3%; T5 = Karanja oil @ 3%; T6 =Untreated (control). All treatments were applied at 10 days intervals. BS-Before Spray, DAS-Days After Spray.

**Table 6. Number of thrips per flower treated by different botanical oils at different time intervals after 4th application**

| Treatments | BS | Days After spray (DAS) | | | | | % Reduction over BS | % Reduction over control |
|---|---|---|---|---|---|---|---|---|
| | | 1 DAS | 3 DAS | 7 DAS | 10 DAS | Mean | | |
| Imitaf 20 SL (T1) | 0.84 c | 0.5 c | 0.38 c | 0.47 c | 0.31 c | 0.41 c | 63.09 | 86.5 |
| Castor oil (T2) | 2.77 ab | 2.04 ab | 2.15 ab | 2.08 b | 1.97 ab | 2.06 ab | 28.88 | 32.45 |
| Mahogany oil (T3) | 2.15 bc | 1.82 b | 1.36 bc | 1.34 bc | 1.37 bc | 1.47 bc | 36.27 | 51.8 |
| Neem oil (T4) | 1.62 bc | 1.1 bc | 0.5 c | 0.71 c | 0.79 bc | 0.77 bc | 51.23 | 74.75 |
| Karanja oil (T5) | 1.73 bc | 1.39 bc | 0.74 c | 0.96 bc | 0.98 bc | 1.01 bc | 43.35 | 67.06 |
| Untreated | 3.76 a | 3.22 a | 2.6 a | 3.5 a | 2.89 a | 3.05 a | | 66.8 |
| LSD(0.05) | 0.8588 | 0.8397 | 0.6818 | 0.8258 | 0.7791 | 0.7816 | | |
| P value | 0.0003 | 0.0005 | 0.0001 | 0.0001 | 0.0003 | | | |

Different letter(s) in a column are significantly different at 5% level of probability by least significant difference (LSD). T1 = Imitaf 20 SL (Imidacloprid) @ 0.2%; T2 = Castor oil @ 3%; T3 = Mahogany oil @ 3%; T4 = Neem oil @ 3%; T5 = Karanja oil @ 3%; T6 =Untreated (control). All treatments were applied at 10 days intervals. BS-Before Spray, DAS-Days After Spray.

**Table 7. Benefit-Cost Ratio (BCR) of different treatments**

| Treatments | Yield (Kg/plot) | Yield (ton/ ha) | Yield (kg/ ha) | Price (Tk/ kg) | Yield Increase over Control (%) | Gross Return (Tk) | Total Cost (Tk) | Net Return (Tk) | BCR |
|---|---|---|---|---|---|---|---|---|---|
| T1 (Imitaf) | 0.504 a | 4.20 a | 4,200 | 85 | 40.0 | 357,000 | 91,000 | 266,000 | 3.92 |
| T2 (Castor oil) | 0.420 c | 3.50 c | 3,500 | 85 | 16.67 | 297,500 | 88,500 | 209,000 | 3.36 |
| T3 (Mahogany oil) | 0.444 bc | 3.70 bc | 3,700 | 85 | 23.33 | 314,500 | 89,000 | 225,500 | 3.53 |
| T4 (Neem oil) | 0.468 ab | 3.90 ab | 3,900 | 85 | 30.0 | 331,500 | 89,500 | 242,000 | 3.7 |
| T5 (Karanja oil) | 0.456 abc | 3.80 abc | 3,800 | 85 | 26.67 | 323,000 | 89,000 | 234,000 | 3.63 |
| T6 (Control) | 0.360 d | 3.00 d | 3,000 | 85 | - | 255,000 | 87,000 | 168,000 | 2.93 |
| Mean | 0.442 | 3.68 | | | | | | | |
| LSD (0.05) | 0.042 | 0.35 | | | | | | | |
| P value | < 0.001 | < 0.001 | | | | | | | |

Different letter(s) in a column are significantly different at 5% level of probability by least significant difference (LSD). T1 = Imitaf 20 SL (Imidacloprid) @ 0.2%; T2 = Castor oil @ 3%; T3 = Mahogany oil @ 3%; T4 = Neem oil @ 3%; T5 = Karanja oil @ 3%; T6 =Untreated (control).

viable alternatives to synthetic insecticides in thrips management, supporting sustainable and eco-friendly agricultural practices.

Effect of Botanical Oils on the Benefit-Cost Ratio (BCR) of Chilli Cultivation: The Benefit-Cost Ratio (BCR) analysis of botanical oils in chili cultivation revealed that Neem oil (3% concentration) provided the highest economic return among botanical treatments with a BCR of 3.70, resulting from a 30% yield increase and 52.23% reduction in thrips population, closely followed by Karanja oil (BCR 3.63, 26.67% yield increase, 44.42% pest reduction) and Mahogany oil (BCR 3.53, 23.33% yield increase, 38.61% pest reduction), while Castor oil showed more modest results (BCR 3.36, 16.67% yield increase, 27.71% pest reduction), though all botanical treatments outperformed the untreated control (BCR 2.93). Although the synthetic insecticide Imitaf (0.2%) achieved the highest overall BCR (3.92) with 40% yield increase and 68.43% pest reduction, the botanical alternatives - particularly Neem and Karanja oils - demonstrated competitive economic viability while offering additional benefits of being environmentally sustainable and safer for non-target organisms, making them valuable components of integrated pest management programs for chili cultivation. Numerous studies have demonstrated the economic viability of botanical pesticides in chili cultivation through Benefit-Cost Ratio (BCR) analysis. Meena and Tayde (2017) reported that neem oil achieved a BCR of 3.42 with 55.64% pest reduction, while Patel and Kumar (2017) found neem oil (2.5 ml/l) yielded a BCR of 3.58, proving competitive against synthetic alternatives (BCR 4.02). Rahman *et al.* (2021) highlighted karanja oil's stable BCR (3.35–3.60) over multiple seasons, outperforming synthetic pesticides that declined in efficacy (BCR 4.1 to 3.2). Yasmin *et al.* (2017) emphasized that including environmental costs elevated mahogany oil's true BCR to 3.82, surpassing synthetics (BCR 2.95 after accounting for contamination). Additional studies by Kumar et al. (2020) and Singh et al. (2019) reinforced these findings, showing that neem and karanja oils consistently delivered BCRs >3.5, with further economic advantages in organic markets (12–18% price premiums). While synthetic insecticides initially show higher BCRs (3.8–4.0), botanicals prove more sustainable long-term due to lower resistance risks, environmental benefits, and stable yields. Collectively, this research validates botanical pesticides particularly neem and karanja oils as economically competitive components of integrated pest management in chili cultivation.

## Conclusion

This comprehensive field work demonstrates that neem and karanja oils can serve as effective, sustainable alternatives to synthetic insecticides in chili cultivation, particularly for smallholder farmers in subtropical regions like Bangladesh, offering substantial pest control (maintaining efficacy for 7-10 days post-application), improved yields, and favorable economic returns while mitigating environmental risks. This finding will help in taking necessary effective measures to integrate these botanicals into IPM programs through farmer training on optimal application protocols (3% concentration at 10-day intervals starting from 6 weeks after transplantation) and suggests further research on synergistic oil combinations and formulation improvements for enhanced field performance.

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