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Research Article

EFFECTS OF BOTANICAL EXTRACTS ON THE DEVELOPMENTAL AND REPRODUCTIVE TRAITS OF FALL ARMYWORM (*SPODOPTERA FRUGIPERDA*)

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ABSTRACT

Fall armyworm (*Spodoptera frugiperda*) is a polyphagous pest of many crops, especially cereals, necessitating eco-friendly control strategies. The present study assessed the impact of natural plant extracts on its life-history traits. The results showed that larval mortality was highest (73.18%) when treated with *Azadirachta indica* oil extract, followed by *Datura stramonium* (63%), *Eucalyptus tereticornis* (45%), and the lowest mortality (12%) was observed in the control. Pupal mortality was also highest (26.66%) in treatments with *A. indica* oil extract, while no pupal mortality was recorded in the control group. The pre-oviposition period was longest after treatment with *A. indica* (6.01 days), followed by *E. tereticornis* (5.01 days) and *D. stramonium* (4.52 days). The oviposition period lasted 6.02 days with *A. indica* treatment, 5.19 days with *E. tereticornis*, and 5.02 days with *D. stramonium*, whereas the longest oviposition period (8.02 days) was recorded in the untreated group. The post-oviposition period was shortest with *A. indica* (1.58 days), followed by *E. tereticornis* (1.38 days) and *D. stramonium* (1.09 days). The adult lifespan of *S. frugiperda* was significantly reduced in all treatments: *A. indica* (10.85 days), *D. stramonium* (11.98 days), and *E. tereticornis* (13.12 days), compared to the control (14.52 days). The average number of eggs laid per female was 205.52 ± 10.52 with *E. tereticornis*, 180.52 ± 9.52 with *D. stramonium*, and 114.52 ± 10.52 with *A. indica*. The mean egg hatching rates were 40% with *E. tereticornis*, 28% with *D. stramonium*, and 20% with *A. indica*, respectively.

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INTRODUCTION

Maize (*Zea mays* L.) is a highly important and productive cereal and fodder crop worldwide (Shiferaw et al., 2011), valued for its role as a staple food and its stover, which meets the growing demand for animal feed (Bahar et al., 2007). Globally, the demand for maize has surpassed that of other cereals, driven by a significant dietary shift towards higher-protein foods, fueled by rising personal incomes and urbanization (Chang et al., 2019). However, maize crops face serious threats from foliage-damaging herbivores such as the black cutworm (*Agrotis ipsilon*), European corn borer (*Ostrinia nubilalis*), Asian corn borer (*Ostrinia furnacalis*), corn earworm (*Helicoverpa zea*), and fall armyworm (*Spodoptera frugiperda*), due to high susceptibility of the crops throughout the growing seasons (Shelton et al., 2002; Guo et al., 2022). Among these, the fall armyworm (FAW), *S. frugiperda*, is a polyphagous and economically significant insect pest native to tropical and subtropical regions. It causes substantial economic losses of up to 65% in various cash crops, vegetables, and cereals (Ahmad and Arif, 2009), primarily by damaging growing shoot tips and fruits, which severely reduces both the quantity and quality of maize yields (Babu et al., 2000).

Conventional pesticides are synthetic chemicals that are toxic, potentially harmful to living organisms, and may even be carcinogenic. As an alternative, pest control can involve the use of less harmful and more environmentally friendly methods, such as biopesticides. Plant-based pesticides, derived from various plants, can control pests through non-toxic mechanisms. Many plants contain bioactive compounds that provide a safer alternative to synthetic pesticides for pest management (Akbar et al., 2022).

Farmers primarily rely on synthetic pesticides to combat herbivorous pests. However, their indiscriminate use has led to serious issues, including environmental pollution, the development of insect resistance, and toxicity to non-target organisms, such as natural enemies and humans (Saranraj and Jayaprakash, 2017). Therefore, the use of plant bio-extracts as biological control agents presents a more sustainable and eco-friendly pest management strategy (Bano and Muqarab, 2017).

Research on the use of plant secondary metabolites to combat arthropod crop pests has primarily focused on identifying bioactive compounds. Although hundreds of plant species and their pesticidal compounds have been discovered, only a few have been commercialized. The application of botanically-based pesticides in agriculture remains limited (Tembo et al., 2018).

Plant extracts have the potential to play a vital role in protecting crops, fruits, vegetables, and even stored grains, while also reducing the need for and risks associated with synthetic insecticides. As naturally occurring compounds derived from plants, plant oils are referred to as botanical insecticides (Isman, 2000).

Several studies (Kim et al., 2003; Lee et al., 2003; Asian et al., 2005; Cetin and Yanikoglu, 2006; Negahban et al., 2007; Ahmed et al., 2009; Ayvaz et al., 2009) have identified a variety of essential plant oils and extracts, such as those from neem, eucalyptus, akk, Datura, Khabar, and several other plants, that effectively repel a wide range of insect pests. These natural alternatives have proven to be effective substitutes for synthetic insecticides.

Plant extracts can interfere with herbivorous insects by disrupting their reproduction, halting their development, or reducing the duration of their larval stages (Jiang et al., 2011; Nadeem et al., 2012).

Therefore, we investigated the effects of plant-extracted oils on the life traits of *S. frugiperda* on maize under laboratory conditions. This research aims to provide farmers with valuable insights for developing more effective pest management strategies that enhance crop resilience while reducing *S. frugiperda* populations.

MATERIALS AND METHODS

Study site

An *in vitro* trial was conducted to evaluate the efficacy of different plant extracts on the developmental stages of *S. frugiperda* at the Laboratory of Biological Control, Department of Plant Protection, Faculty of Crop Protection, Sindh Agriculture University, Tandojam. The experiment was carried out under controlled conditions: 25 ± 2°C temperature, 75 ± 5% relative humidity, and a photoperiod of 16:8 h (light:dark).

Treatments

The treatments were as followed:

T1 = Neem (*Azadirachta indica*)

T2 = Jimsonweed (*Datura stramonium*)

T3 = Forest red gum (*Eucalyptus tereticornis*)

T4 = Control (no treatment)

Steam distillation for plant oil extraction

Fresh leaves of *A. indica*, *D. stramonium*, and *E. tereticornis* were collected from Tandojam, district Hyderabad, Sindh. These plant species were selected due to their abundance, familiarity among farmers, and well-documented efficacy, bioactive constituents, and safety.

To ensure consistency, the leaves were thoroughly washed to remove dirt and impurities, and then crushed to increase the surface area for extraction. The crushed leaves were placed in a distillation flask with enough water to cover the bottom of the flask without submerging the leaves completely.

The flask was connected to a condenser and a collecting flask. Water was heated to produce steam, which passed through the plant material, breaking down the oil glands and releasing the essential oils. The steam carrying the essential oils then entered the condenser, where it cooled and condensed into liquid form.

The condensed mixture of water and essential oil was collected in the receiving flask. Due to the difference in density, the oil naturally separated from the water. A separating funnel was used to isolate the essential oil, which was then stored in clean, airtight, dark glass bottles to prevent oxidation and preserve its quality until use.

Experimental setup and data observation

The experiment was conducted using a completely randomized design with three replications under laboratory conditions. First instar *S. frugiperda* larvae (n = 100) were collected from local maize fields and released onto the tender leaves of maize plants grown in pots in the laboratory. Each pot was enclosed in a fine nylon mesh bag to prevent larval escape. The larvae were allowed to settle on the plants for one day before the application of plant oil treatments.

The treated plants were observed daily for live larvae until pupation. The number of dead larvae in each treatment (per pot) was recorded daily, and larval mortality percentages were corrected using Abbott's formula (Abbott, 1925). Pupae that survived were collected from each treatment and monitored for adult emergence. After emergence, adult males and females were separated and placed in individual netted cages containing a 2-ml vial with 10% honey solution. A virgin male was introduced into each cage, and mating pairs were left undisturbed.

Data were collected on various life history traits of *S. frugiperda*, including larval mortality, pupal mortality, pre-oviposition period, oviposition period, post-oviposition period, fecundity, adult longevity, and fertility. Observations were recorded for maize plants treated with plant oils and compared with the untreated control.

Statistical analysis

Differences among treatments were analyzed using Analysis of Variance (ANOVA), followed by Tukey's Honestly Significant Difference (HSD) test for mean separation at the 95% confidence level. All statistical analyses were conducted using Statistix 8.1 software.

RESULTS

Larval mortality

The efficacy of different plant-extracted oils resulted in significant mortality of *S. frugiperda* larvae. The highest mortality was observed with neem oil (73%), followed by jimsonweed oil (63%), and forest red gum oil (45%) (Figure 1). The untreated control exhibited the lowest mortality (14%). The LSD test revealed a highly significant difference among all treatments ($P < 0.001$).

Pupal mortality

The data presented in Figure 2 showed that pupal mortality of *S. frugiperda* was highest (21.25%) when treated with neem oil extract, followed by jimsonweed, which caused 18.50% mortality. In comparison, treatment with forest red gum resulted in 15.25% pupal mortality. The lowest mortality (11.25%) was recorded in the control treatment.

Pre-oviposition period (days)

The pre-oviposition period (POP) of *S. frugiperda* was significantly influenced by plant-extracted oils. The longest POP was observed with Neem oil treatment, lasting 6.01 days, followed by forest red gum at 5.01 days, and jimsonweed at 4.52 days. The LSD test indicated a significant difference among all treatments ($P < 0.0001$) (Figure 3).

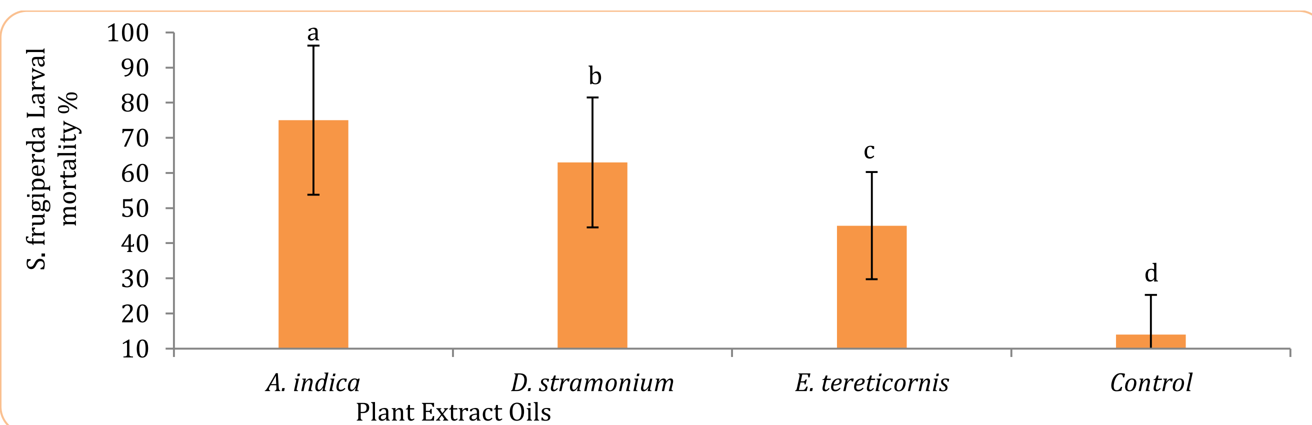

Figure 1. Effect of plant extract on larval mortality (%) of *S. frugiperda*.

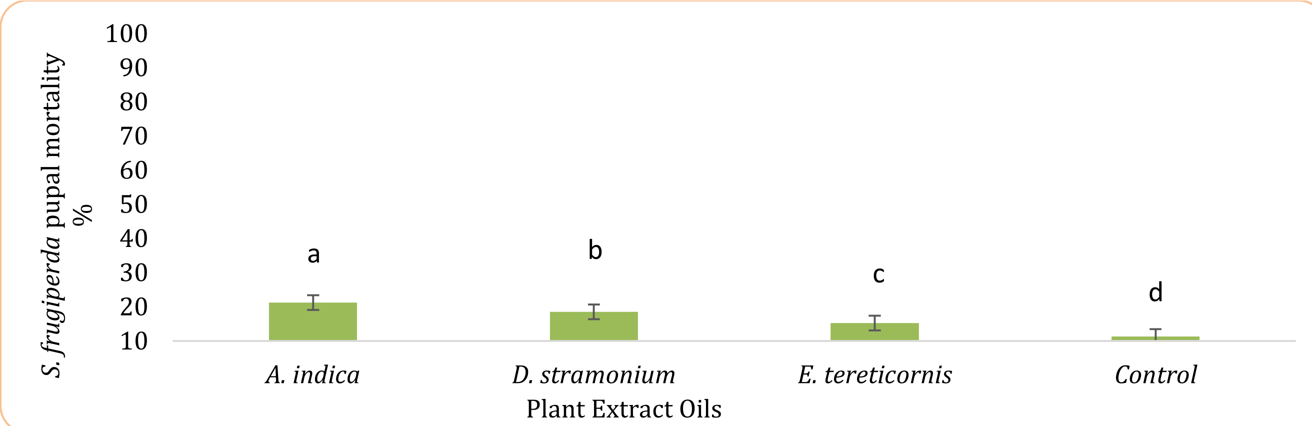

Figure 2. Effect of plant extract on the pupal mortality (%) of *S. frugiperda*.

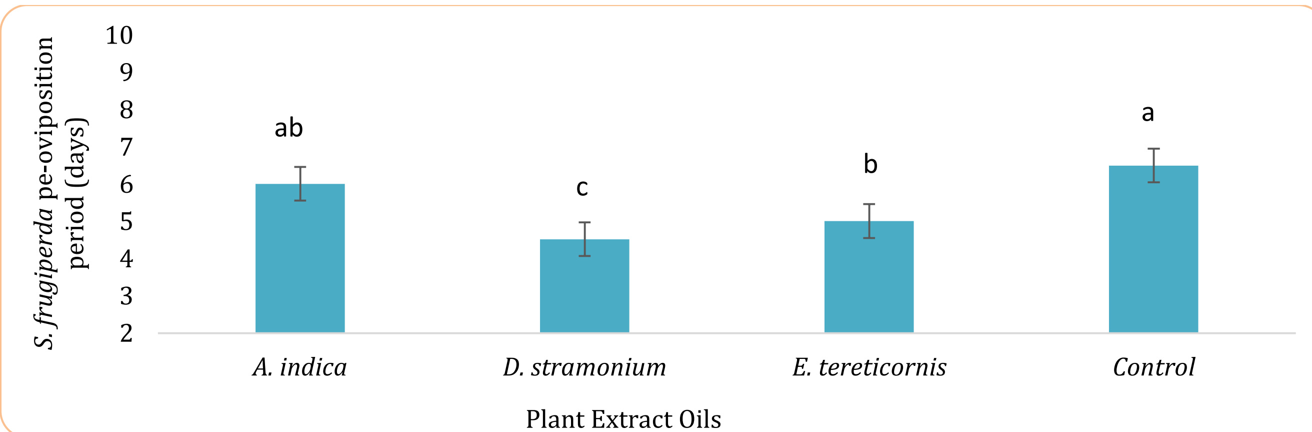

Figure 3. Effect of plant extract on the pre-oviposition period of *S. frugiperda*.

Oviposition period (days)

The oviposition period lasted 6.02 days in the treatment with neem oil extract, followed by 5.19 days with forest red gum and 5.02 days with jimsonweed. The longest oviposition period, 8.02 days, was observed in the untreated control (Figure 4). A significant difference was observed among all treatments ($P < 0.001$).

Longevity (days)

The LSD test revealed a statistically significant difference among all treatments ($P < 0.003$) (Figure 6). The adult lifespan of *S. frugiperda* showed a significant difference among all treatments. Adults treated with neem had the shortest lifespan (10.85 days), followed by jimsonweed at 11.98 days, and forest red gum at 13.12 days. In contrast, the untreated group exhibited the longest lifespan at 14.52 days.

Post-oviposition period (days)

The shortest post-oviposition period was recorded with neem oil treatment at 1.58 days, followed by forest red gum at 1.38 days, and jimsonweed at 1.09 days. A significant difference was observed among all treatments ($P < 0.001$). The longest post-oviposition period, 1.85 days, was recorded in the control group (Figure 5).

Fecundity

The egg-laying capacity of female *S. frugiperda* is shown in Figure 7. The mean number of eggs laid by individual female *S. frugiperda* was 205.52 ± 10.52 when treated with forest red gum, followed by jimsonweed with 180.52 ± 9.52, and neem extracted oil with 114.52 ± 10.52, respectively. The results of ANOVA showed a significant difference between all treatments ($P < 0.0001$).

Fertility

Statistical analysis showed a significant difference between all treatments ($P < 0.001$) (Figure 8) regarding fertility. The average egg hatching percentage of *S. frugiperda* females treated with forest red gum was 40%, followed by jimsonweed at 28%, and neem extracted oil at 20%, respectively.

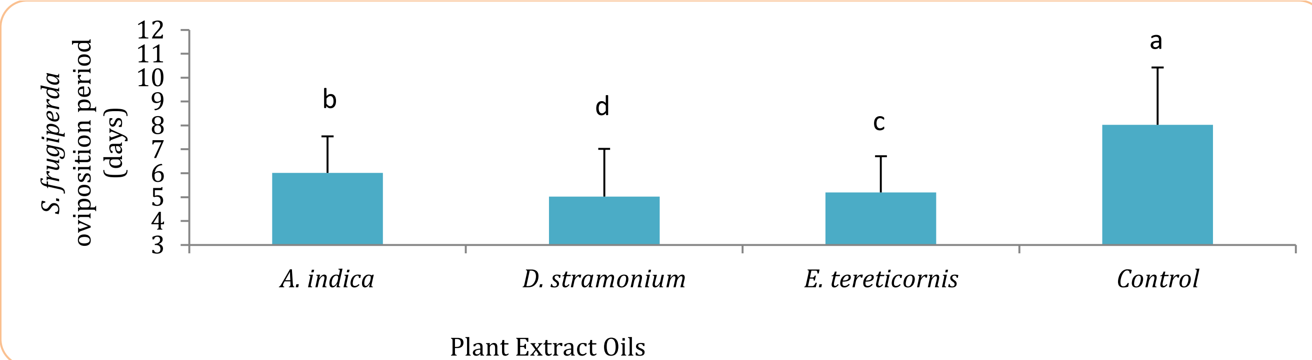

Figure 4. Effect of plant extract on the oviposition period of *S. frugiperda*.

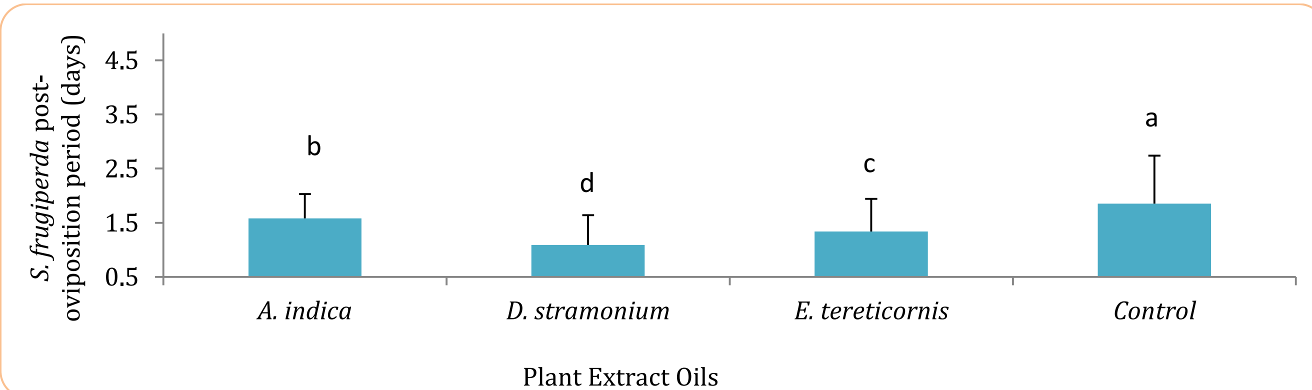

Figure 5. Effect of plant extracts on the post-oviposition period of *S. frugiperda*.

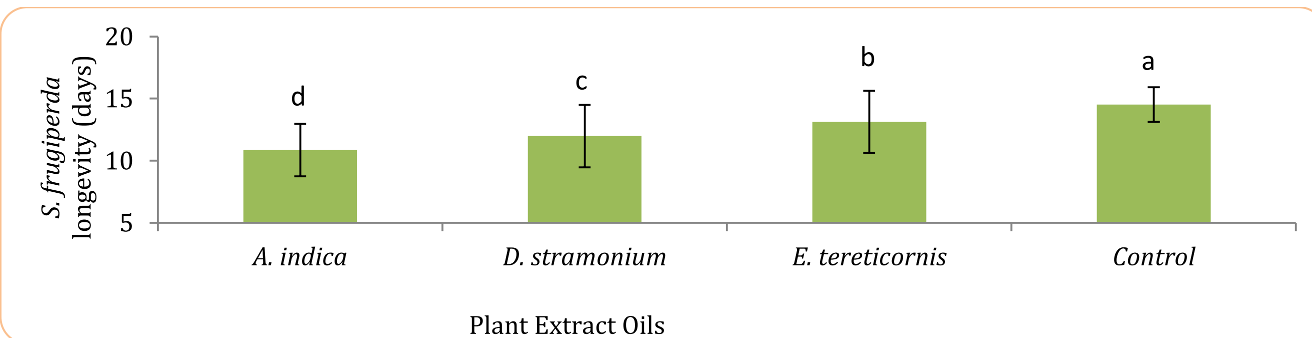

Figure 6: Effect of plant extract on the longevity of *S. frugiperda*.

DISCUSSION

The current research aims to provide baseline data that can be used to develop integrated pest management (IPM) guidelines for farming communities to control fall armyworm under field conditions. Maize is an economically important cereal crop (Nabeel et al., 2018; Seerat et al., 2022); however, the invasive fall armyworm causes substantial yield losses (Jing et al., 2020). In many developing countries, synthetic pesticides are often misused, leading to negative impacts on ecosystems and human health (Ecobichon, 2001).

Biological control options, such as extracts from medicinal plants, have long been considered more sustainable and suitable for smallholder farmers in these regions (Isman, 2006, 2008; Sola et al., 2014). Previous studies suggest that plant-based oils can serve as effective alternatives to synthetic insecticides. Their efficacy, however, may vary depending on factors such as the developmental stage of the insect, species, and the plant source used (Tunc et al., 2000; Chiasson et al., 2001; Choi et al., 2003; Sedy and Koschier, 2003; Negahban et al., 2007).

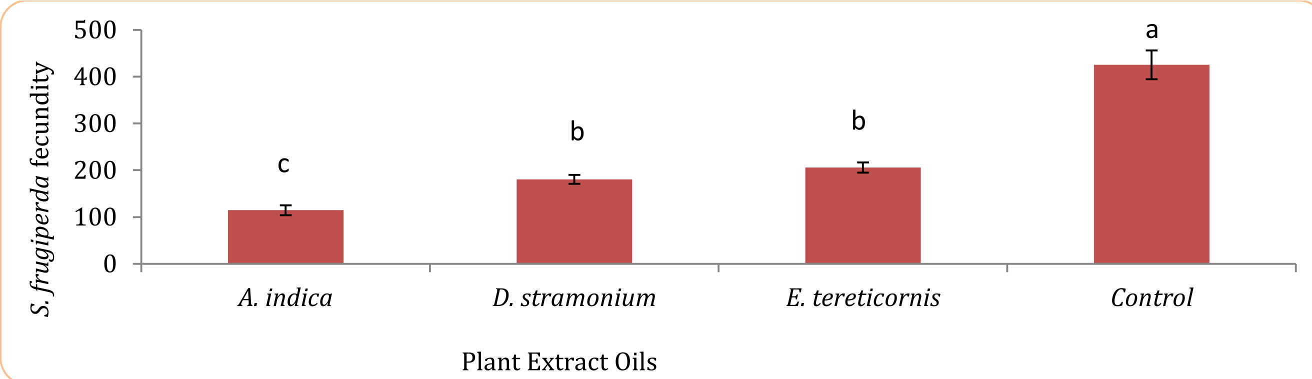

Figure 7. Effect of plant extract on the fecundity of *S. frugiperda*.

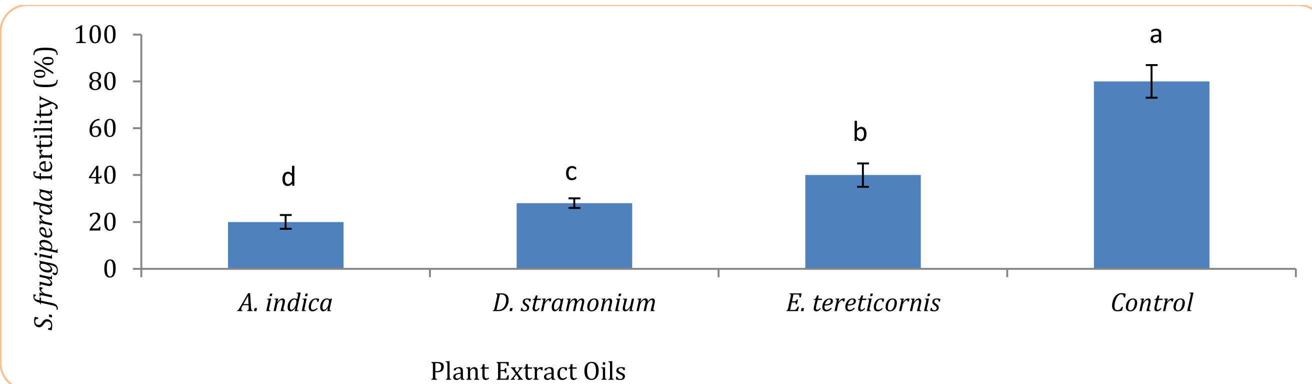

Figure 8: Effect of plant extract on the fertility period of *S. frugiperda*.

The present study was conducted under laboratory conditions to evaluate the effects of plant extracts on the life history traits of *S. frugiperda* on maize, with the goal of generating foundational data to inform field-level applications. A similar study by Narwal et al. (1997) assessed the efficacy of tobacco, dhatura, and meetha neem against a variety of insect pests. Likewise, Bhosle et al. (2009) tested neem seed extracts for pest control and found them to be highly effective. Their findings further indicated that tobacco, datura, and meetha neem are safe, cost-effective, and nonhazardous options for managing a broad spectrum of pest insects.

Various laboratory and field studies conducted globally have demonstrated that crude botanical extracts and their essential oils can serve as effective eco-friendly alternatives for managing *S. frugiperda*, thereby reducing the reliance on synthetic insecticides (Rioba and Stevenson, 2020).

Botanical pesticides are effective in reducing the use of synthetic insecticides, as they have a lower impact on non-target species (Sagar et al., 2020). Our findings revealed that neem oil extract caused the highest larval and pupal mortality in *S. frugiperda*, followed by *D. stramonium* and *E. tereticornis*. These results are somewhat consistent with those of Ali (1993), who studied the effects of plant extracts on the growth and development of the brinjal fruit borer.

Furthermore, our results indicate that *A. indica* significantly affected the pre-oviposition period, oviposition period, and post-oviposition period of *S. frugiperda*, followed by *E. tereticornis* and *D. stramonium*. No significant changes were observed in the oviposition traits of *S. frugiperda* in the control treatment throughout the study. These findings are partially in agreement with Lima et al. (2024), who reported that neem and orange oil could prevent larval hatching from *Leucoptera coffeella* eggs when applied to adults.

Based on these observations, it is evident that botanical insecticides derived from neem and orange oils could serve as sustainable alternatives for managing the coffee leaf miner, a major pest in coffee cultivation. The present study also demonstrated that *A. indica* oil affected the total adult lifespan of *S. frugiperda*, followed by *D. stramonium* and *E. tereticornis*.

In addition, the mean number of eggs laid by individual *S. frugiperda* females was significantly reduced by *A. indica* oil, followed by *D. stramonium* and *E. tereticornis*. The average egg hatchability percentage of *S. frugiperda* was also adversely affected by neem oil treatment. A similar study by Freitas et al. (2014) reported reduced fecundity and egg hatchability in *S. frugiperda* treated with methanol extracts of Annonaceae family medicinal plants.

In conclusion, our findings confirm that various plant extracts can effectively disrupt the feeding and development of fall armyworm. These results are further supported by Hashmi (1994), who reported the efficacy of neem, tobacco-based products, and eucalyptus extracts in controlling various insect pests of agricultural importance. Similarly, Jiang et al. (2007) found that extracts from datura, neem, and eucalyptus acted as effective biopesticides against fruit borers and exhibited strong insect-repellent properties.

CONCLUSIONS

It is concluded that *A. indica* and *D. stramonium* caused larval mortality, exhibited repellent effects, and influenced key life history traits of moths, including pre-oviposition period, oviposition period, fecundity, fertility, and longevity. Our findings demonstrated that plant extracts from neem, jimsonweed, and forest red gum are effective and environmentally safe for managing oriental armyworms and other lepidopteran insect pests. Furthermore, additional studies are needed to explore the use of plant essential oils as components of IPM programs.

AUTHORS' CONTRIBUTIONS

JKL and AWS conceived the idea, executed experiments, collected, and arranged the data; KHD analyzed the data, wrote up the manuscript; JDH designed the experiments and guided the first author; ARJ analyzed and explained the plant extracts data; MNR and AL compiled the results and proofread the manuscript.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

SUSTAINABLE DEVELOPMENT GOALS TARGETED

SDG 2: Zero Hunger
SDG 3: Good Health and Well-being
SDG 12: Responsible Consumption and Production
SDG 13: Climate Action
SDG 15: Life on Land

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