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Evaluation of the Insecticidal Activity of Lerak-Based Surfactant and Mahogany (*Swietenia macrophylla*) and Sugar Apple (*Annona squamosa*) Seed Extracts with Different Solvents on *Spodoptera frugiperda* Mortality

Tiara Maharani[1,*], Marheni[1], Darma Bakti[1]

Abstract

Spodoptera frugiperda is an invasive maize pest that inflicts significant damage. The excessive use of chemical insecticides poses risks to the environment and human health, highlighting the need for eco-friendly alternatives. This study evaluated the effectiveness of soapberry (*Sapindus rarak*) surfactant combined with mahogany (*Swietenia mahagoni*) and sugar apple (*Annona squamosa*) seed extracts, utilizing methanol and hexane solvents, against *S. frugiperda* mortality. The research was conducted in a screen house at the Faculty of Agriculture, University of North Sumatra, from June 2024 to January 2025, employing a Randomized Complete Block Design with three replications and nine treatments. The observed parameters included larval mortality, pupal and adult emergence, and Lethal Time 50 (LT50). The treatment using sugar apple seed extract with 80 ml of methanol and 10 ml of soapberry surfactant demonstrated the highest mortality rate and significantly inhibited larval development. The addition of soapberry surfactant enhances the effectiveness of the extracts by improving their spread on leaf surfaces. This botanical insecticide shows promise as an eco-friendly alternative for controlling *S. frugiperda*; however, further research is necessary for field testing and formulation optimization.

Keywords: Mahogany Seed, Methanol, *S. frugiperda*, Soapberry Surfactant, Sugar Apple Seed

1. Introduction

Food is a fundamental necessity for the global population. The demand for available food must adequately meet the needs of each demographic. However, the current situation indicates that food availability, particularly rice, cannot keep pace with the population growth rate, which continues to rise annually (Sumunar & Budiman, 2021). Corn can serve as a viable alternative to address the shortfall in rice (Sumunar & Budiman, 2021). Corn production is projected to increase yearly with the growing population, which will likely enhance people's purchasing power and income (Ladonu et al., 2023). Nevertheless, farmers face several challenges in cultivating corn, including pests and diseases, one of the most significant being the armyworm pest.

According to Trisyono et al. (2019), Spodoptera frugiperda was first detected in Indonesia in May 2019, specifically in East and Central Lampung. Identification was based on larval morphology, characterized by an inverted "Y" marking on the head and black spots on the abdominal segments. The pest causes severe damage to young maize plants, with infestation levels reaching up to 100% in plants around two weeks old. Larvae attack the plant's growing point, disrupting the formation of new leaves or shoots. Known for their high feeding capacity, *S. frugiperda* larvae often burrow into plant tissues to feed, making early detection difficult when populations are low. The adult moth is a strong flier with a wide dispersal range

*Correspondence: tiaramaharani7003@gmail.com
1) Universitas Sumatera Utara - Jl. Prof A. Sofyan No.3. Kampus USU, Medan, Indonesia

(CABI, 2019).

Previous research by Yanuwiadi (2013) showed that mahogany seed extract caused 10% mortality in Spodoptera litura, with pupal formation reaching 70% and adult emergence at 76.67%. Meanwhile, a study by Muthu et al. (2023) examined the toxic and histological effects of methanolic extract from Annona squamosa seeds on third instar larvae of S. litura, revealing that at a 2.5% concentration, the extract resulted in 96.67% larval mortality. On the other hand, Suryaningsih et al. (2016) evaluated the repellent activity of soapberry (Sapindus rarak) fruit extract against the storage pest Callosobruchus maculatus, which demonstrated a repellency of 77.9% after 72 hours at a 4.5% concentration. Based on these findings, the present study aims to combine the three plant extracts to explore their potential synergistic effects in pest control.

This research aims to analyze the effectiveness of botanical insecticides from mahogany and sugar apple seeds with different solvents combined with soapberry surfactants on *S. frugiperda* mortality and pest development in corn plants.

2. Material and Methods

The research was conducted at the Greenhouse, Faculty of Agriculture, University of North Sumatra (coordinate point 3°33'24.6"N 98°39'16.8"E, elevation 30 masl), from June 2024 to January 2025. Equipment included plastic jars, knives, measuring glasses, blenders, analytical scales, magnifiers, sieves, brushes, trays, scissors, gauze, rubber bands, insect cages (inchases), sprayers, polybags, rotary evaporators, cameras, and stationery. Materials included second-instar larvae of *S. frugiperda*, 10-day-old corn plants, extract of mahogany seeds, extract of sugar apple seeds, extract of soapberry fruits, methanol, hexane, and cypermethrin insecticide.

The study was conducted using a Randomized Complete Block Design (RCBD) with a non-factorial arrangement consisting of nine treatments: cypermethrin-based insecticide; mahogany seed extract with methanol 80 ml/L + soapberry fruit extract 10 ml/L; mahogany seed extract with hexane 80 ml/L + soapberry fruit extract 10 ml/L; mahogany seed extract with methanol 80 ml/L + soapberry fruit extract 20 ml/L; mahogany seed extract with hexane 80 ml/L + soapberry fruit extract 20 ml/L; sugar apple seed extract with methanol 80 ml/L + soapberry fruit extract 10 ml/L; sugar apple seed extract with hexane 80 ml/L + soapberry fruit extract 10 ml/L; sugar apple seed extract with methanol 80 ml/L + soapberry fruit extract 20 ml/L; sugar apple seed extract with hexane 80 ml/L + soapberry fruit extract 20 ml/L.

Blocking was based on application time. Each treatment was replicated three times, with 10 larvae per replicate. In total, 27 experimental units were established, each consisting of three corn plants, resulting in 81 corn plants grown in polybags. Each plant was infested with 10 second-instar larvae of *S. frugiperda*.

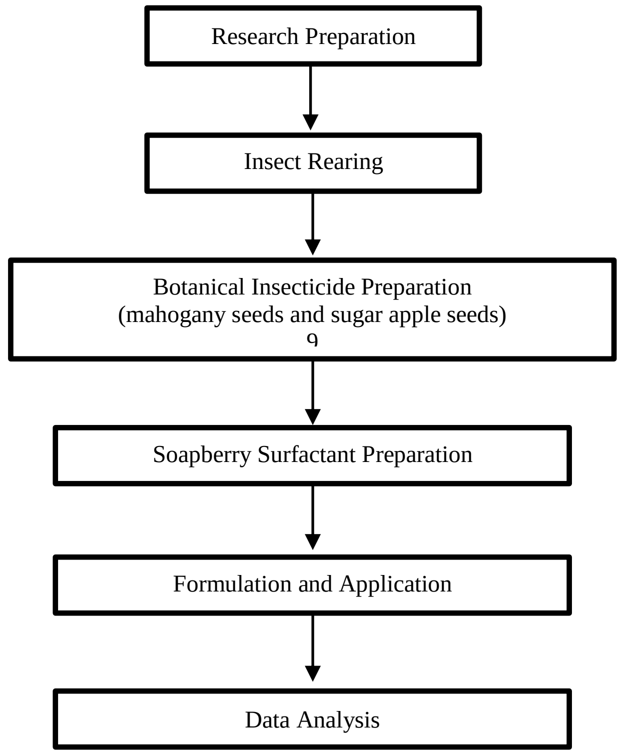

Figure 1. Research flow diagram

2.1. Insect Rearing

Larvae were raised in plastic jars, fed young corn leaves, and reared until the second instar.

2.2. Botanical Insecticide Preparation

Mahogany and sugar apple seeds were dried, ground, extracted with methanol or hexane by maceration for 24 hours using a shaker, filtered, and evaporated with a rotary evaporator at 50°C (methanol) or 40°C (hexane).

2.3. Soapberry Surfactant Preparation

Soapberry fruits were sliced, soaked overnight, blended, diluted, filtered, and refrigerated.

2.4. Formulation and Application

Extracts were combined with surfactants and sprayed on corn plants twice a week. Cypermethrin was applied as a chemical control.

2.5. Data Analysis

Data on mortality of larvae, pupae, imago, and LT 50 (linear interpolation) were analyzed using SPSS ANOVA test and Duncan's Multiple Range Test (DMRT) if significant.

3. Results and Discussion

3.1. Mortality of *S. frugiperda*

The mortality rates of *S. frugiperda* larvae subjected to mahogany and sugar apple seed extracts combined with various solvents and surfactants are summarized in Table 1.

Table 1. Effect of mahogany and sugar apple seed extracts combined with soapberry on larval mortality of Spodoptera frugiperda.

Treatment	Larval mortality (%) at Days After Application (DAA)				
	1	2	3	4	5
P0	25.66±0.57a	29.00±1.00ab	29.66±0.57a	29.66±0.57a	29.66±0.57a
P1	21.00±1.00bc	26.66±0.57bcd	29.66±0.57a	29.66±0.57a	29.66±0.57a
P2	18.66±4.16c	25.00±2.00de	29.33±1.15ab	29.33±1.15ab	29.33±1.15ab
P3	19.00±1.00c	25.66±2.08cde	27.00±1.73c	27.00±1.73c	27.00±1.73c
P4	18.66±1.15c	23.33±1.15e	26.66±0.57c	26.66±0.57c	26.66±0.57c
P5	24.33±1.52ab	29.66±0.57a	29.66±0.57a	29.66±0.57a	29.66±0.57a
P6	23.66±2.08ab	29.66±0.57a	29.66±0.57a	29.66±0.57a	29.66±0.57a
P7	22.66±3.05abc	27.66±2.08abc	28.00±1.73ab	28.00±1.73ab	28.00±1.73ab
P8	22.33±2.08abc	27.66±0.57abc	27.66±0.57bc	27.66±0.57bc	27.66±0.57bc

Note: Values followed by the same letter in the row are not significantly different based on Duncan's Multiple Range Test (DMRT). P0 (insecticide active ingredient cypermethrin); P1 (mahogany seed extract with methanol 80 ml/L + soapberry fruit extract 10 ml/L); P2 (mahogany seed extract with hexane 80 ml/L + soapberry fruit extract 10 ml/L); P3 (mahogany seed extract with methanol 80 ml/L + soapberry fruit extract 20 ml/L); P4 (mahogany seed extract with hexane 80 ml/L + soapberry fruit extract 20 ml/L); P5 (sugar apple seed extract with methanol 80 ml/L + soapberry fruit extract 10 ml/L); P6 (sugar apple seed extract with hexane 80 ml/L + soapberry fruit extract 10 ml/L); P7 (sugar apple seed extract with methanol 80 ml/L + soapberry fruit extract 20 ml/L); P8 (sugar apple seed extract with hexane 80 ml/L + soapberry fruit extract 20 ml/L).

The mortality of Spodoptera frugiperda showed significant differences among treatments, and no further increase in larval death was observed after 3 days after application (DAA). The highest mortality was recorded in treatment P1 (mahogany seed extract with 80 ml/L methanol and 10 ml/L soapberry extract), which was not significantly different from treatments P5 (sugar-apple seed extract with 80 ml/L methanol and 10 ml/L soapberry extract) and P6 (sugar-apple seed extract with 80 ml/L methanol and 20 ml/L soapberry extract), with a total of 89 out of 90 larvae dead. Meanwhile, the lowest mortality was observed in treatment P4 (mahogany seed extract with 80 ml/L hexane and 20 ml/L soapberry extract). The results indicate no significant difference in mortality levels between chemical and botanical insecticides. However, the main distinction lies in the timing of larval death, as botanical insecticides act more slowly in controlling *S. frugiperda*. This is due to the gradual mechanism of botanical insecticides, which interfere with the pest's reproductive system, are more environmentally friendly, and can be prepared independently by farmers.

A study by Analisa et al. (2022) also revealed that chemical insecticides are faster in controlling pests such as Ostrinia furnacalis, Helicoverpa armigera, and Spodoptera frugiperda. On the other hand, botanical insecticides such as areca seed extract, sugar-apple seed extract, and bintaro leaf extract remain effective in suppressing pest populations. However, they require more time to show results and help reduce plant damage.

This study demonstrated that mahogany and sugar apple seed extracts differed in their effectiveness against *S. frugiperda* mortality, influenced by the type of solvent used and the addition of soapberry surfactant. Phytochemical tests revealed that mahogany and sugar apple seed extracts contained various active compounds contributing to larval mortality. The primary bioactive compounds with insecticidal potential include flavonoids, alkaloids, saponins, and tannins, each possessing different toxic mechanisms against insects. Mahogany and sugar apple seeds contain flavonoids and alkaloids that function as antifeedants and neurotoxins for insects. These compounds disrupt the insect's nervous system and hormonal regulation, which ultimately causes paralysis and death of the larvae (Rahmawati et al., 2021).

Treatment with mahogany seed extract using methanol 80 ml/L combined with soapberry fruit extract 10 ml/L (P1) resulted in relatively high mortality, likely due to the higher content of flavonoids, alkaloids, and saponins in the methanol extract of mahogany seeds. In contrast, treatment with mahogany seed extract using hexane 80 ml/L combined with soapberry fruit extract 10 ml/L (P2) resulted in lower mortality compared to P1, possibly because hexane primarily extracts non-polar compounds such as triterpenoids and steroids, which have weaker insecticidal effects. Although saponins were still present in the hexane extract, their concentration was lower than in the methanol extract, reducing insecticidal efficacy.

Similarly, the treatment with mahogany seed extract using hexane 80 ml/L combined with soapberry fruit extract 20 ml/L (P4) resulted in the lowest observed mortality. This suggests that while adding surfactants may enhance extract dispersion, the effectiveness remains dependent on the phytochemical composition extracted by hexane. The lower alkaloids and flavonoids in the hexane extract likely contributed to its reduced insecticidal activity.

Larval death of Spodoptera frugiperda was caused by the toxicity of botanical insecticides acting within the insect's body. Symptoms observed following exposure to botanical and chemical insecticides included body discoloration (darkening to black), a softer texture, and a less fragile structure when touched with a brush (Figure 2). Dead larvae typically dried out within one day. In addition, larvae exposed to insecticides exhibited reduced activity and decreased feeding behavior, leading to less severe damage to the host plant.

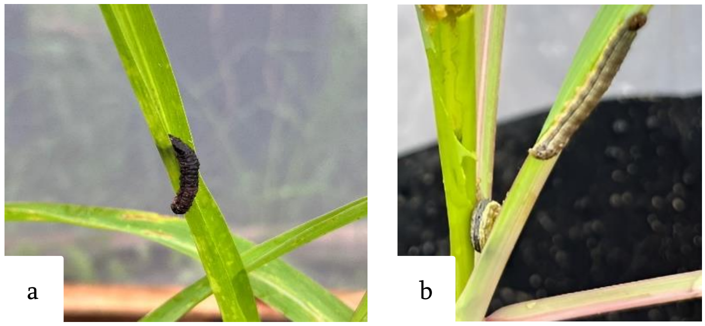

Figure 2. Mortality of *S. frugiperda* larvae. a). dead larvae, b). healthy larvae

3.2. Pupal Formation

The study results showed that treatments with mahogany seed and sugar apple seed extracts, using different types of solvents and additional surfactants, significantly affected the pupal formation of *S. frugiperda*, as presented in Table 2.

Table 2. Effect of mahogany seed and sugar apple seed extract treatments with various solvents and surfactants on the pupal formation of *S. frugiperda*.

Treatment	Average of pupae formed
P0	0.33±0.57c
P1	0.33±0.57c
P2	0.66±1.15bc
P3	3.00±1.73a
P4	3.33±0.57a
P5	0.33±0.57c
P6	0.33±0.57c
P7	2.00±1.73abc
P8	2.33±0.57ab

Note: Values followed by the same letter in the row are not significantly different based on Duncan's Multiple Range Test (DMRT). P0 (insecticide active ingredient cypermethrin); P1 (mahogany seed extract with methanol 80 ml/L + soapberry fruit extract 10 ml/L); P2 (mahogany seed extract with hexane 80 ml/L + soapberry fruit extract 10 ml/L); P3 (mahogany seed extract with methanol 80 ml/L + soapberry fruit extract 20 ml/L); P4 (mahogany seed extract with hexane 80 ml/L + soapberry fruit extract 20 ml/L); P5 (sugar apple seed extract with methanol 80 ml/L + soapberry fruit extract 10 ml/L); P6 (sugar apple seed extract with hexane 80 ml/L + soapberry fruit extract 10 ml/L); P7 (sugar apple seed extract with methanol 80 ml/L + soapberry fruit extract 20 ml/L); P8 (sugar apple seed extract with hexane 80 ml/L + soapberry fruit extract 20 ml/L).

Based on Table 2, the highest number of pupae was found in treatment P4, with 10 pupae, which was not significantly different from treatments P3, P7, and P8. Treatment P1 also produced a high number of pupae, which can be attributed to the mahogany seed extract in P1 containing flavonoids, saponins, and limonoids—compounds known to have antifeedant properties and the ability to inhibit insect development (Mukhtar et al., 2022). The lowest number of pupae formed was observed in treatments P0, P1, P5, and P6, each with only one pupa. No abnormal pupae were found during observations, as the larvae tend to form loose, oval-shaped cocoons underground at depths of 2 to 8 cm by binding soil particles with silk (Megasari et al., 2022). Therefore, pupae were difficult to locate in the caged area or polybags, with only a few recovered, although they were in good condition.

Research by Maslahat et al (2023) revealed that mahogany seed extract contains alkaloid compounds that have insecticidal activity. Although this study did not specifically examine its effects on *S. frugiperda* pupae and imago, the active compound content in mahogany seeds shows potential as an inhibitor of insect pest development. Research by Herminanto et al (2004) showed that a mixture of sugar apple leaf extract can prolong the larval and pupal stages, reduce the weight of the pupa, and cause the imago wings not to develop perfectly. This shows that mahogany seed and sugar apple seed extracts can inhibit the normal development of *S. frugiperda*.

The pupae of *S. frugiperda* were oval-shaped, reddish-brown, and measured approximately 14–20 mm in length. The reduction in pupal size is presumed to be due to the active compounds in the sugar apple seed extract, which may disrupt the larvae's digestive system, impairing nutrient absorption. As a result, larval development is hindered, affecting pupal size and the successful metamorphosis into adults. Additionally, the bioactive compounds in the plant extracts are suspected to have toxic effects that interfere with larval hormonal balance, leading to abnormalities in pupal formation.

3.3. Imago Formation of *S. frugiperda*

The results showed that treating mahogany seed and sugar apple seed extracts with various solvents and adding surfactants caused significant differences in the formation of *S. frugiperda* imagos as presented in Table 3.

Table 3. Effect of mahogany seed and sugar apple seed extract treatment with various types of solvents and addition of surfactants on *S. frugiperda* imago formation

Treatment	Average of imago formed
P0	0.33±0.57c
P1	0.33±0.57c
P2	0.66±1.15bc
P3	3.00±1.73a
P4	3.33±0.57a
P5	0.33±0.57c
P6	0.33±0.57c
P7	2.00±1.73abc
P8	2.33±0.57ab

Note: Values followed by the same letter in the row are not significantly different based on Duncan's Multiple Range Test (DMRT). P0 (insecticide active ingredient cypermethrin); P1 (mahogany seed extract with methanol 80 ml/L + soapberry fruit extract 10 ml/L); P2 (mahogany seed extract with hexane 80 ml/L + soapberry fruit extract 10 ml/L); P3 (mahogany seed extract with methanol 80 ml/L + soapberry fruit extract 20 ml/L); P4 (mahogany seed extract with hexane 80 ml/L + soapberry fruit extract 20 ml/L); P5 (sugar apple seed extract with methanol 80 ml/L + soapberry fruit extract 10 ml/L); P6 (sugar apple seed extract with hexane 80 ml/L + soapberry fruit extract 10 ml/L); P7 (sugar apple seed extract with methanol 80 ml/L + soapberry fruit extract 20 ml/L); P8 (sugar apple seed extract with hexane 80 ml/L + soapberry fruit extract 20 ml/L).

Based on Table 3, the highest number of images emerged was observed in treatment P4, with 10 images, which was not significantly different from treatments P3, P8, and P7. This indicates that using mahogany seed extract and sugar apple seed extract combined with soapberry fruit at the same concentration had a similar effect on the emergence of *S. frugiperda* imagos. Conversely, the fewest imagos emerged in treatments P0, P1, P5, and P6, with only one imago each. This was likely due to high larval mortality rates, which reduced the number of pupae and emerging adults in each treatment. Some imagos exhibited impaired flight ability and appeared abnormal, possibly due to malformed pupae. However, because the larvae spin silk to bind soil particles and hide within them before metamorphosis, it is difficult to determine the normality of the pupae. Abnormal *S. frugiperda* imagos generally exhibited underdeveloped wings, rendering them unable to fly long distances to forage. As a result, the life cycle of *S. frugiperda* was interrupted, preventing continuation to the next generation due to their shortened lifespan.

According to the statement of Maslahat et al (2017), it was revealed that mahogany seed extract contains alkaloid compounds that have insecticidal activity. Research by Herminanto et al (2004) showed that a mixture of sugar apple leaf extract can extend the larval and pupal stages, reduce pupal weight, and cause imago wings not to develop perfectly. This shows that mahogany and sugar apple seed extracts can inhibit the normal development of *S. frugiperda*.

3.4. Lethal Time 50 (LT 50)

Lethal time 50 (LT_{50}) refers to the time required to kill 50% of the pest population in each treatment. LT_{50} was calculated using the linear interpolation method, a simple technique to estimate values between two known data points. Based on the daily data collected, this study used the process to determine the time at which 50% of the larvae had died. The Lethal Time 50 (LT_{50}) values are presented in Table 4.

Table 4. LT_{50} values from treatments using mahogany seed extract and sugar apple seed extract with various solvents and the addition of soapberry fruit against Spodoptera frugiperda.

Treatment	Total dead larvae 1 DAA	Mortality 1 DAA (%)	LT_{50} (day)	LT_{50} (hours)
P0	77.00	85.6	0.58	14
P1	63.00	70.0	0.71	17
P2	56.00	62.2	0.80	19
P3	57.00	63.3	0.79	19
P4	56.00	62.2	0.80	19
P5	73.00	81.1	0.61	15
P6	71.00	78.9	0.63	15
P7	68.00	75.6	0.66	16
P8	67.00	74.4	0.67	16

Note: P0 (insecticide active ingredient cypermethrin); P1 (mahogany seed extract with methanol 80 ml/L + soapberry fruit extract 10 ml/L); P2 (mahogany seed extract with hexane 80 ml/L + soapberry fruit extract 10 ml/L); P3 (mahogany seed extract with methanol 80 ml/L + soapberry fruit extract 20 ml/L); P4 (mahogany seed extract with hexane 80 ml/L + soapberry fruit extract 20 ml/L); P5 (sugar apple seed extract with methanol 80 ml/L + soapberry fruit extract 10 ml/L); P6 (sugar apple seed extract with hexane 80 ml/L + soapberry fruit extract 10 ml/L); P7 (sugar apple seed extract with methanol 80 ml/L + soapberry fruit extract 20 ml/L); P8 (sugar apple seed extract with hexane 80 ml/L + soapberry fruit extract 20 ml/L).

3.5. Phytochemical Content

The phytochemical contents of mahogany seeds, sugar apple seeds, and the addition of soapberry fruit were determined through phytochemical screening. The results of the screening are presented in Table 5.

Table 5 shows the results of phytochemical screening on mahogany and sugar apple seeds using various solvents. It was found that mahogany seeds contain alkaloids, flavonoids, glycosides, and saponins. Using methanol as a solvent caused changes in composition, leading to increased tannin content and decreased saponin content. When soapberry fruit surfactant was added, the phytochemical composition remained similar to that of mahogany seeds extracted using methanol. Meanwhile, using hexane as a solvent resulted in the loss of alkaloids, flavonoids, and saponins. Adding soapberry fruit surfactant to hexane extracts also led to the absence of alkaloids, while saponin content remained detectable.

Table 5. Results of Phytochemical Screening of Plants

Plant Species	Plant Past Tested	Solvent	Phytochemical Screening Test							
			Alkaloid			Flavonoid	Triterpenoids/steroids	Glycosides	Saponins	Tannin
			Bouchardat	Meyer	Dragendoff	MgHCl+ H_2SO_4	Lieberman-Bouchardat	Molish + H_2SO_4	Aquadest	$FeCl_3$
Mahogany seed	Simplex (seed)	-	+	+	+	+	-	+	+	-
Sugar apple seeds	Simplex (seed)	-	+	+	+	+	+	+	+	+
Mahogany seed	Seed	Methanol	+	+	+	+	+	+	-	+
Mahogany seed	Seed	n-Hexane	-	-	-	-	+	+	-	-
Sugar apple seeds	Seed	Methanol	+	-	+	+	+	+	+	+
Sugar apple seeds	Seed	n-Hexane	-	-	-	-	+	+	-	-
Mahogany seed + sourberry fruit	Seed & fruit	Methanol	-	+	+	+	+	+	-	+
Mahogany seed + sourberry fruit	Seed & fruit	n-Hexane	-	-	-	+	+	+	+	-
Sugar apple seed + sourberry fruit	Seed & fruit	Methanol	+	+	+	+	+	+	+	+
Sugar apple seed + sourberry fruit	Seed & fruit	n-Hexane	-	-	+	+	+	+	+	-

Notes: Bouchardat Test: KI + Aquades + Iodine, Meyer Test: $HgCl_2$ + Aquades + KI, Liebermann-Bouchardat Test: H_2SO_4 (concentrated) + CH_3COOH.

The detected Sugar apple seed extract includes alkaloids, flavonoids, triterpenoids, glycosides, saponins, and tannins. Extraction with methanol does not change the main composition, but the alkaloid content is not detected by the Meyer method. The addition of surfactants does not affect the main content. Extraction with hexane causes the loss of alkaloid, flavonoid, saponin, and tannin content. When the surfactant of the lerak fruit is added to the hexane extract, the alkaloid content (based on the Bouchardat and Meyer method) and tannins will also be lost. The type of solvent used influences compound content changes in plant seeds.

Lembang et al.'s (2020) demonstrated that the ethanol extract of Peperomia pellucida is better at extracting polar compounds like flavonoids and tannins. In contrast, n-hexane is more appropriate for non-polar compounds such as steroids and triterpenoids. The extraction efficiency relies on the appropriateness of dissolving the target compound. If it is inappropriate, the compound content can be decreased or even made undetectable. Furthermore, specific solvents have the potential to interact with compounds found in plant seeds, leading to their degradation or a change in their chemical structure. This can occur, for instance, through hydrolysis as a result of the acidic or basic properties of the solvent.

4. Conclusion

The study's results indicate that the botanical insecticide made from mahogany seed and sugar apple seed extracts, with the addition of soapberry surfactant, effectively controlled *S. frugiperda*. However, its action was slower compared to the chemical insecticide containing cypermethrin. Botanical insecticide helped to prevent the development of larvae, including the pupal and adult (imago) stages. Despite most larvae perishing after the treatment, a small number survived and grew into pupae and adults without showing any abnormalities. This suggests that the botanical insecticide inhibits development rather than immediately killing the larvae. Furthermore, incorporating soapberry fruit surfactant improves the efficiency of the natural insecticide by helping the solution spread more effectively on the surface of corn leaves. As a result, this increases the chances of insect pests being exposed to insecticide in the best possible way.

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