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# The Effectiveness of *Andaliman* Leaf Extract as an Environmentally Friendly Botanical Pesticide

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## ABSTRACT

The botanical pesticide from Andaliman leaf extract (*Zanthoxylum acanthopodium* DC.) has been developed and tested to determine the mortality rate of beet armyworm larvae (*Spodoptera exigua*) and the biological safety of natural enemies (parasitoids and predators) over a four-day (96 hours) experiment. A non-factorial, completely randomized design was applied, with treatment types including control (P0), Soursop leaf extract (P1), Mahogany leaf extract (P2), Papaya leaf extract (P3), and Andaliman leaf extract (P4), each with a dosage of 50% and three replications for each treatment. The results showed that treatment P4 had the highest mortality rate (57.5%), followed by P2 (45%), P3 (27.5%), and P1 (25%). The highest average daily mortality of *Spodoptera exigua* larvae was also found in treatment P4 (4 larvae), followed by P2 (2 larvae), P3 (2 larvae), and P1 (1 larva). The average percentage of biological safety for natural enemies after the application of the botanical pesticide from Andaliman leaf extract showed a survival rate of 70% for parasitoid wasps (*Trichogramma sp.*) and 75% for predators ladybug (*Cheilomenes sexmaculatus*) which is still within normal limits. These results indicate that Andaliman leaf extract is effective as an environmentally friendly botanical pesticide.

***Keywords:*** *Andaliman, Botanical Pesticide, Environmentally Friendly, Leaf Extract*

## INTRODUCTION

Andaliman, scientifically known as *Zanthoxylum acanthopodium* DC., is a flowering plant belonging to the Rutaceae family (Syahputra et al., 2023; Wijaya et al., 2019). Native to the tropical rainforests of Southeast Asia, it is particularly prevalent in the highland regions of North Sumatra, Indonesia (Nurlaeni et al., 2021). This plant holds significant cultural value, especially in Batak cuisine, due to its unique aromatic properties (Prastowo et al., 2023). Andaliman typically grows as a shrub or small tree, reaching heights of 3 to 5 meters (R. Dewi et al., 2021). The plant's glossy, dark green compound leaves emit a distinctive aromatic scent when crushed, while its small, greenish-white flowers are arranged in terminal panicles (Rahmi et al., 2023). The fruits are small, reddish-brown to black berries that contain the aromatic compounds used as a spice when dried (Megawati et al., 2023). Taxonomically, Andaliman belongs to the kingdom Plantae, clade Angiosperms, clade Eudicots, order Sapindales, family Rutaceae, genus Zanthoxylum, and species Z. acanthopodium (Situmorang et al., 2020). The botanist de Candolle first described the plant, hence the abbreviation "DC." in its scientific name (Silalahi et al., 2021). Its taxonomy reflects its close relation to other aromatic plants within the Rutaceae family, which includes citrus and rue. The distinctive characteristics and aromatic properties of Andaliman highlight its importance within this botanical group.

Andaliman thrives in specific environmental conditions, primarily found in the highland regions of North Sumatra (Surya & Tedjakusuma, 2022). The plant prefers a tropical highland climate with moderate to high humidity and grows best at altitudes ranging from 800 to 1,500 meters above sea level (Nurlaeni et al., 2021). It requires well-drained, fertile soils rich in organic matter, with slightly acidic to neutral pH levels (pH 5.5 to 7.0) (Siregar et al., 2019). Optimal growth occurs between 18°C and 25°C, and the plant does not tolerate extreme heat or frost (Kintamani et al., 2019). Regular rainfall is crucial, as Andaliman needs consistent moisture but should not be waterlogged (Gultom et al., 2023). It requires partial to full sunlight, though it can tolerate some shade in its juvenile stages. The Andaliman plant is widely recognized for its culinary and medicinal uses (Syahputra et al., 2023). In Batak cuisine, dried fruits are a staple spice, imparting a unique numbing and citrusy flavour to dishes (Djati & Christina, 2019). Additionally, Andaliman has been traditionally used in herbal medicine for its potential antimicrobial and anti-inflammatory properties (Syaputri et al., 2022). The plant's significance extends beyond its aromatic qualities, contributing to the cultural and medicinal heritage of North Sumatra.

The Andaliman plant (Zanthoxylum acanthopodium DC.), well-known for its culinary use in Batak cuisine, harbours untapped potential in its leaves that could revolutionize the field of sustainable agriculture. Traditionally, the focus has been on the aromatic fruits of the plant, leaving the leaves underutilized. However, recent studies have indicated that Andaliman leaves contain various bioactive compounds that could serve as effective botanical pesticides (Amelia et al., 2020). These compounds offer a natural alternative to synthetic pesticides, often associated with environmental and health risks. Andaliman leaves are rich in essential oils, alkaloids, flavonoids, and other phytochemicals that exhibit pesticidal properties (Yang et al., 2022). Essential oils from the leaves have been found to possess insecticidal and repellent activities, making them ideal candidates for developing natural pesticides (Rahmi et al., 2023). Alkaloids and flavonoids contribute to the plant's defence mechanisms, acting as natural deterrents against pests (Divekar et al., 2022). These compounds disrupt the nervous system of insects, inhibit feeding, and interfere with reproduction, thereby reducing pest populations without harming beneficial organisms (Hikal et al., 2017).

The potential of Andaliman leaves as botanical pesticides aligns with the growing demand for environmentally friendly pest control solutions (Silaban et al., 2020). Synthetic pesticides, while effective, often lead to the development of resistant pest strains and contaminate soil and water resources (Ayilara et al., 2023). On the other hand, botanical pesticides are biodegradable and pose minimal risk to non-target organisms, including humans and wildlife (Riyaz et al., 2022). By utilizing Andaliman leaves, farmers can reduce their reliance on chemical pesticides, promoting sustainable agricultural practices and enhancing crop safety (Nurlaeni et al., 2021). Moreover, the development of Andaliman leaf-based pesticides can offer economic benefits to local communities. North Sumatra, where the plant is predominantly found, can become a hub for producing and commercializing these botanical pesticides. This would create new income opportunities for local farmers and encourage the conservation and sustainable use of Andaliman plants. Integrating Andaliman leaves into pest management strategies could pave the way for innovative and eco-friendly agricultural solutions, fostering environmental and economic sustainability. Based on the potential of Andaliman leaves, this research aims to test the effectiveness of Andaliman leaf extract as an environmentally friendly botanical pesticide.

## MATERIALS & METHODS

This research on the effectiveness of Andaliman leaf extract as an environmentally friendly botanical pesticide was conducted from January to February 2024 at the laboratory of Universitas Pembangunan Panca Budi Medan. The tools used in this research included plastic cups, tweezers, scissors, an oven, beakers, Erlenmeyer flasks, test tubes, filters, stirrers, a blender, dark or brown glass bottles, plastic bottles, rubber bands, markers, a camera, and writing tools. The materials used included Soursop leaves, Mahogany leaves, Papaya leaves, Andaliman leaves, distilled water, shallot plant leaves, Spodoptera exigua larvae, Trichogramma sp., Cheilomenes sexmaculatus beetles, label paper, honey, tape, cardboard paper, filter paper, gauze, and cotton.

The experimental design utilized a completely randomized non-factorial approach, incorporating five treatments: P0 (control), P1 (50% Soursop leaf extract), P2 (50% Mahogany leaf extract), P3 (50% Papaya leaf extract), and P4 (50% Andaliman leaf extract). Each treatment was replicated four times, resulting in a total of 20 experimental units for the parameters tested. This design ensured a robust analysis of the effectiveness and safety of each botanical extract. Four key parameters were assessed during this study. First, a phytochemical screening was conducted to identify the active compounds in each botanical extract that contribute to pesticidal properties. This qualitative analysis involved detecting the presence of critical pesticidal compounds such as alkaloids, flavonoids, and essential oils. Second, the mortality rate of *Spodoptera exigua* larvae was measured by calculating the percentage of larvae that died over four days (96 hours). Third, the total mortality of *Spodoptera exigua* larvae was recorded at the end of the testing period to assess the effectiveness of each treatment in killing the beet armyworm larvae. Fourth, the biotic safety of the botanical pesticides on natural enemies, specifically parasitoid wasps (*Trichogramma* sp.) and ladybug beetle predators (*Cheilomenes sexmaculatus*), was evaluated by observing their survival rates after exposure to the botanical extracts for four days (96 hours).

**Preparation of Botanical Pesticide Extract**

Preparing botanical pesticides begins with washing the leaf materials under running water to remove any attached dirt. The leaves are chopped into small pieces and air-dried for about 14 days. Once thoroughly dried, they are ground into a fine powder and sifted. This powdered material is then macerated with a solvent (distilled water) at a ratio of 1:10 for three days, with intermittent stirring. Following maceration, the mixture undergoes filtration to obtain the extract, which is stored in a tightly sealed erlenmeyer flask. Any remaining leaf powder undergoes further maceration until the solution becomes clear. The combined maceration extracts are thoroughly blended and evaporated using an oven set at 50°C.

**Figure 1. The process of making botanical pesticides**

**Phytochemical Screening Test**

Phytochemical screening was performed in the Biochemistry Laboratory to analyze the secondary metabolites present in the botanical pesticide extract. This screening aimed to identify and gather information about the secondary metabolite compounds within the extract.

**Rearing *Spodoptera exigua* Larvae**

The larvae are gathered directly from shallot plants at the Balai Induk Hortikultura (BIH) Kutagadung Berastagi. They are placed into plastic cups filled with fresh shallot leaf feed. Once the larvae reach the prepupal stage, they are moved into gauze containers. This prepupal phase lasts 1-2 days and is characterized by a shortened, wrinkled, slightly curved body. The pupal stage lasts about 8-10 days before transforming into an adult. Pupae are transferred to more extensive, modified containers. Adults are fed with a honey solution absorbed in cotton rolls and hung. The cotton rolls are changed daily. After laying eggs, *Spodoptera exigua* eggs are moved to another container and covered with gauze. The egg stage takes about 3-5 days, with the eggs turning dark just before hatching. After 12-14 days, larvae in the third instar stage are ready for testing.

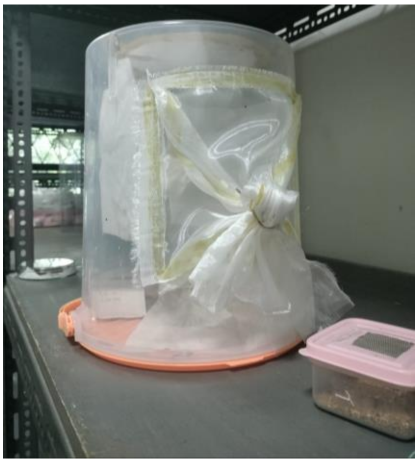


**Figure 2. The rearing process of *Spodoptera exigua* larvae**

**Propagating Natural Enemies (Parasitoids and Predators)**

The *Trichogramma sp.* parasitoid eggs, sourced from IPB University, are bred using *Crocidolomia pavonana* eggs collected on filter paper. These parasitized eggs on the filter paper are placed inside test tubes. After one week, 10 *Trichogramma sp.* parasitoids emerge and are transferred to test tubes for each experimental treatment.

Imago *Cheilomenes sexmaculatus* are harvested from shallot fields, then cultivated and propagated in the laboratory. Ten pairs of adult beetles are placed in a breeding container. The adults are fed whiteflies, with their diet replenished daily. After laying eggs, *Cheilomenes sexmaculatus* eggs are transferred to another container and covered with gauze. The egg stage lasts 2-4 days, while the larval phase spans 6-10 days, during which they are fed whiteflies and nurtured. The pupal stage lasts 2-4 days, and upon pupation, the newly emerged adults, distinguished by their orange and pale red body colouration, are ready for experimentation.

**Mortality and Total Death of *Spodoptera exigua* Larvae**

Mortality testing is conducted by subjecting *Spodoptera exigua* larvae to a starvation period of 6 hours. The application of botanical pesticide is done using the dipping method, where the feed is dipped into each botanical pesticide treatment for 15 minutes and then air-dried. The dried feed is then given to 10 *Spodoptera exigua* larvae for testing. This mortality testing also provides information on the average daily death of *Spodoptera exigua* larvae and the total death over four days (96 hours). Mortality observations are conducted over four days (96 hours) using the following formula (M. Dewi et al., 2017).

$$M = \frac{a}{b} \cdot 100\%$$

where $M$ is the mortality rate of *Spodoptera exigua* (%), $a$ is the number of *Spodoptera exigua* that died, and $b$ is the number of *Spodoptera exigua* tested.

The effectiveness of botanical pesticide treatments in mortality testing of Spodoptera exigua larvae is determined based on the following categories: not practical (0-30%), less effective (31-50%), effective (51-70%), and highly effective (71-100%) (Aisyah, 2016).

**Biological Safety of Natural Enemies (Parasitoids and Predators)**

The safety testing of natural enemies follows the same method as applying botanical pesticides on *Spodoptera exigua* larvae. The botanical pesticide is applied using the residue method by spraying and coating the botanical pesticide extract onto experimental container with four repetitions. The test tubes are then air-dried for approximately 15 minutes. Next, the natural enemy, in this case, the parasitoid wasp (*Trichogramma sp.*), is placed into the experimental container, and observations on mortality and survival are conducted over four days (96 hours). The same testing procedure is applied to the natural enemy predator ladybug (*Cheilomenes sexmaculatus*).

The biological safety observation of natural enemies can be measured by calculating the survival rate of the natural enemies. The equation used to calculate the survival rate of natural enemies is as follows (Supono & Sarida, 2022).

$$SR = \frac{Nf}{Ni} \cdot 100\%$$

Where $SR$ is the survival rate of natural enemies (%), $Nf$ is the final number of natural enemies, and $Ni$ is the initial number of natural enemies.

**Data Analysis Technique**

The effectiveness of each botanical pesticide treatment on the mortality parameter of *Spodoptera exigua* larvae and the safety parameter on natural enemies is statistically analyzed using analysis of variance (ANOVA) with IBM SPSS Statistics 22 software. The significance level of each botanical pesticide treatment is analyzed using Duncan's Multiple Range Test (DMRT) at a 5% significance level.

## RESULT & DISCUSSION

**Phytochemical Screening of Botanical Pesticides**

The research results (Table 1) indicate that extracts from Soursop, Papaya, and Andaliman leaves extract contain secondary metabolites such as alkaloids, flavonoids, terpenoids, steroids, saponins, and tannins. Meanwhile, Mahogany leaf extract contains alkaloids, flavonoids, terpenoids, saponins, and tannins. These secondary metabolites have significant potential as effective botanical pesticides.

Secondary metabolites such as alkaloids are known for their toxic effects on insect pests. Previous studies have shown that alkaloids can disrupt the nervous system of insects, leading to death or an inability to feed (Isman, 2020). Flavonoids, on the other hand, have antioxidant properties and can act as insect repellents. According to previous researchers, flavonoids can reduce the appetite of insect pests and interfere with their development (Duke, 2020). Terpenoids are often used in natural pesticides due to their repellent and insecticidal properties. Previous research has demonstrated that terpenoids protect plants from insect attacks (Boncan et al., 2020). Steroids can function as insect growth regulators, inhibiting the development of larvae into adults. A study revealed that steroids could disrupt the metamorphosis process of insect pests (Kilani-Morakchi et al., 2021). Saponins have detergent properties that can damage insect cell membranes, causing death. Previous studies have shown that saponins have great potential as natural insecticidal agents (Qasim et al., 2020). Tannins can cause digestive disturbances in insects, reducing nutrient absorption and leading to death. Based on previous research, tannins can be a practical component in botanical pesticides (Perkovich & Ward, 2022).

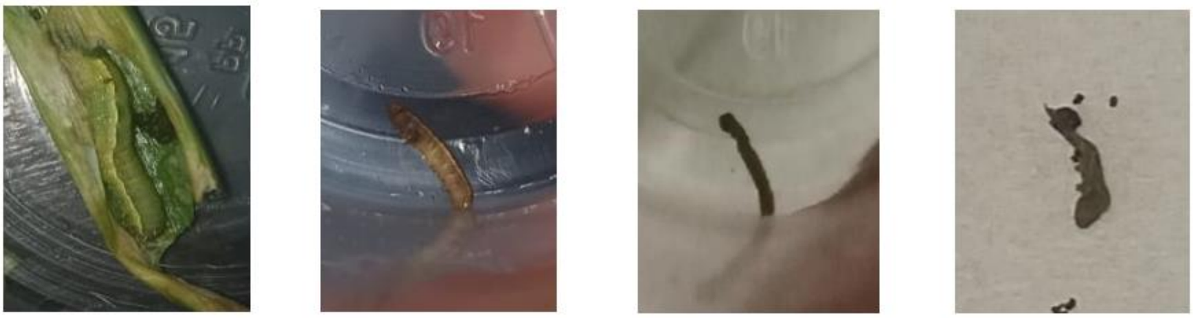
Several previous studies also support the potential of these secondary metabolites as botanical pesticides. Previous research (Lahati & Haryanto, 2020) showed that Soursop leaf extract containing alkaloids and flavonoids controlled pest attacks on bean plants effectively. Previous studies indicated that Papaya leaf extract with terpenoids and saponins could reduce the population of insect pests (Palanisamy & Basalingappa, 2020). Previous research found that Andaliman leaf extract, rich in steroids and tannins, effectively reduced armyworm attacks on plants (Harahap, 2019; Silaban et al., 2020). Previous studies demonstrated that Mahogany leaf extract containing alkaloids, flavonoids, and saponins could control pests on crops (Aslam et al., 2022). Based on these research findings and support from previous studies, the secondary metabolites in Soursop, Papaya, Andaliman, and Mahogany leaf extracts have significant potential as effective and environmentally friendly botanical pesticides.

**Table 1. Results of phytochemical screening of secondary metabolite contents in various leaf extracts**

| Metabolite compounds | Reactor | Soursop leaf | Mahogany leaf | Papaya leaf | Andaliman leaf | Color Changes |
|---|---|---|---|---|---|---|
| Alkoid | Bouchardart | + | + | + | + | Brick Red Precipitate |
| | Maeyer | + | - | - | + | Yellowish White Precipitate |
| Flavonoid | FeCl3 | + | + | + | + | Black Colloid |
| | MgHcl | + | + | - | - | Pink Solution |
| | H2SO4 | - | + | - | + | Yellowish Orange Solution |
| Terpenoid | Liebermann-Bouchard | + | - | + | - | Bluish Green Solution |
| | Salkowsky | - | + | - | + | Red Solution |
| Steroid | Liebermann-Bouchard | + | - | + | + | Bluish Green Solution |
| | Salkowsky | - | - | + | + | Red Solution |
| Saponin Tanin | Distilled Water + Shaking | + | + | + | + | Foamy |
| | FeCl3 | + | + | + | + | Black Colloid |

## Mortality of *Spodoptera exigua* Larvae

The condition of *Spodoptera exigua* larvae after applying botanical pesticides showed stages of morphological changes. Initially, *Spodoptera exigua* larvae placed in the experimental container were healthy. After consuming the treated feed with botanical pesticides, the bodies of *Spodoptera exigua* larvae began to shrink and become smaller. When shrunken and more minor, the colour of the larvae's bodies changed to dark brown. Subsequently, the larvae lost their appetite, and eventually, the bodies of *Spodoptera exigua* dried out.



(a) (b) (c) (d)

**Figure 3. Symptoms of Spodoptera exigua Attack: a) Spodoptera exigua at the beginning when placed in the experimental container, b) Spodoptera exigua's body shrinks and becomes smaller, c) Spodoptera exigua's body changes colour to dark brown, d) Spodoptera exigua's body dries out.**

The application of botanical pesticides from various leaf extract treatments in this study resulted in significantly different average mortality rates of *Spodoptera exigua* larvae (Table 2). The treatment with Andaliman leaf extract (P4) achieved the highest average mortality rate of *Spodoptera exigua* larvae (57.5%) compared to Soursop leaf extract (P1, 25%), Mahogany leaf extract (P2, 45%), and Papaya leaf extract (P3, 27.5%). Thus, this study proves that the botanical pesticide from Andaliman leaf extract is the most effective among the various botanical pesticide treatments tested against the mortality of *Spodoptera exigua* larvae in this study.

**Table 2. Significance of differences due to the application of various botanical pesticides on the mortality of Spodoptera exigua larvae**

| **Botanical Pecticide** | **The average mortality percentage of Spodoptera exigua larvae** | | | |
|---|---|---|---|---|
| | **24 Hour** | **48 Hour** | **72 Hour** | **96 Hour** |
| P0 | 0.00a | 0.00a | 0.00a | 0.00a |
| P1 | 2.50ab | 2.50ab | 17.50cdef | 25.00def |
| P2 | 2.50ab | 15.00bcde | 30.00f | 45.00g |
| P3 | 0.00a | 12.50abcd | 22.50def | 27.50ef |
| P4 | 7.50abc | 27.50ef | 47.50gh | 57.50h |

Note: numbers followed by different letter notations indicate significant differences in the Duncan's Multiple Range Test (DMRT) at a significance level of α = 5%.

These findings are supported by previous research demonstrating the potential of Andaliman leaf extract as an effective botanical pesticide. According to previous studies, Andaliman leaf extract, rich in secondary metabolite compounds such as alkaloids, flavonoids, terpenoids, and tannins, has been proven effective in reducing grey worm attacks on plants (Harahap, 2019; Silaban et al., 2020). These compounds have significant insecticidal activity, disrupting the nervous and digestive systems of insects, causing death or developmental disturbances (Ukoroije & Otayor, 2020). Furthermore, other research has found that Andaliman leaf extract has a strong toxic effect on *Spodoptera litura* larvae, another pest similar to *Spodoptera exigua* (Toana et al., 2022). The extract showed activity that inhibited feeding and larval growth, contributing to increased mortality. Another study supporting the effectiveness of Andaliman leaf extract as a botanical pesticide also explained that the extract could reduce the population of insect pests on tomato plants with a high level of effectiveness (Nurlaeni et al., 2021). The insecticidal activity of this extract is due to a combination of active compounds that work synergistically to disrupt the biological functions of insects.

## Duration and Number of *Spodoptera exigua* Larvae Deaths During Botanical Pesticide Application

The fastest mortality time for *Spodoptera exigua* larvae in this study was 24 hours, occurring with the botanical pesticide treatment of Andaliman leaf extract, resulting in the death of 1 larva out of 10 in the experimental container. In contrast, the other botanical pesticide treatments did not show any *Spodoptera exigua* larvae deaths within this period. After 48 hours, the Andaliman leaf extract treatment still led to total larval mortality, with three larvae dead, followed by the Mahogany leaf extract treatment, with two larvae dead. By the fourth day of botanical pesticide application (96 hours), the Andaliman leaf extract treatment remained the most effective, resulting in the death of 6 larvae, followed by the Mahogany leaf extract treatment, with five larvae dead. The Soursop and Papaya leaf extract treatments each resulted in 3 larvae dead.

This study also reveals that the average daily mortality of *Spodoptera exigua* larvae with botanical pesticide application is highest for the Andaliman leaf extract, killing an average of 4 larvae per day. Then, it is followed by the Mahogany and Papaya leaf extracts, each with an average of 2 larvae per day, and finally, the Soursop leaf extract, with an average of 1 larva per day (Table 3).

**Table 3. Number of *Spodoptera exigua* larvae death due to the application of various botanical pesticides**

| Botanical Pecticide | Number of death | | | | Average |
|---|---|---|---|---|---|
| | 24 Hour | 48 Hour | 72 Hour | 96 Hour | |
| P0 | 0 | 0 | 0 | 0 | 0 |
| P1 | 0 | 0 | 2 | 3 | 1 |
| P2 | 0 | 2 | 3 | 5 | 2 |
| P3 | 0 | 1 | 2 | 3 | 2 |
| P4 | 1 | 3 | 5 | 6 | 4 |

**Biological Safety of Natural Enemies (Parasitoids and Predators)**

The biological safety experiment on natural enemies was measured by calculating the survival rate percentage. The results of the survival rate percentage in the botanical pesticide treatment experiment on the biological safety of the parasitoid wasp (*Trichogramma sp.*) over four days (96 hours) showed that the botanical pesticide from soursop leaf extract obtained the highest result at 77.50%, followed by the botanical pesticide from papaya leaf extract at 75%, the botanical pesticide from mahogany leaf extract at 72.50%, and lastly the botanical pesticide from Andaliman leaf extract at 70% (Table 4). A similar order was observed in the survival rate percentage results in the botanical pesticide treatment experiment on the biological safety of the predator ladybug (*Cheilomenes sexmaculatus*) over four days (96 hours), where the botanical pesticide from soursop leaf extract obtained the highest result at 85%, followed by the botanical pesticide from papaya leaf extract at 80%, the botanical pesticide from mahogany leaf extract at 77.50%, and lastly the botanical pesticide from Andaliman leaf extract at 75% (Table 5).

The biological safety of natural enemies also shows that the botanical pesticide from Andaliman leaf extract ranks the lowest, and the botanical pesticide from Soursop leaf extract ranks the highest in biological safety for natural enemies compared to other botanical pesticides. The high survival rates of Trichogramma sp. and Cheilomenes sexmaculatus with the treatment of Soursop leaf extract pesticide indicate lower toxicity, while the low survival rates of Trichogramma sp. and Cheilomenes sexmaculatus with the treatment of Andaliman leaf extract pesticide indicate higher toxicity compared to other botanical pesticides. Nevertheless, the biological safety level of natural enemies with the application of Andaliman leaf extract pesticide is still considered effective and safe, as it still results in a survival rate of natural enemies above 70%. The process of testing botanical pesticides on the biological safety of natural enemies is shown in Figure 4.

**Table 4. Significance of differences due to the application of various botanical pesticides on the biological safety of the parasitoid wasp (*Trichogramma sp.*)**

| Botanical Pecticide | The average survival rate percentage of wasp parasitoid (*Trichogramma sp.*) | | | |
|---|---|---|---|---|
| | 24 Hour | 48 Hour | 72 Hour | 96 Hour |
| P0 | 100.00a | 100.00a | 100.00a | 100.00a |
| P1 | 100.00a | 87.50bc | 87.50bc | 77.50de |
| P2 | 92.50b | 85.00c | 82.50cd | 72.50ef |
| P3 | 100.00a | 87.50bc | 82.50cd | 75.00ef |
| P4 | 92.50b | 82.50cd | 75.00ef | 70.00f |
| Note: numbers followed by different letter notations indicate significant differences in the Duncan's Multiple Range Test (DMRT) at a significance level of α = 5%. | | | | |

**Table 5. Significance of differences due to the application of various botanical pesticides on the biological safety of the predator ladybug (*Cheilomenes sexmaculatus*)**

| Botanical Pecticide | The average survival rate percentage of ladybug predator (*Cheilomenes sexmaculatus*) | | | |
|---|---|---|---|---|
| | 24 Hour | 48 Hour | 72 Hour | 96 Hour |
| P0 | 100.00a | 100.00a | 100.00a | 100.00a |
| P1 | 100.00a | 92.50abc | 87.50bcd | 85.00cde |
| P2 | 95.00ab | 85.00cde | 80.00def | 77.50ef |
| P3 | 97.50a | 87.50bcd | 85.00cde | 80.00def |
| P4 | 95.00ab | 87.50bcd | 82.50de | 75.00f |

Note: numbers followed by different letter notations indicate significant differences in the Duncan's Multiple Range Test (DMRT) at a significance level of α = 5%.

Previous studies have supported these findings by highlighting the relative safety of certain botanical pesticides for beneficial insects. For instance, research has shown that soursop leaf extract has minimal adverse effects on non-target organisms, including beneficial insects like parasitoids and predators (Parthiban et al., 2020). Another study found that botanical pesticides derived from papaya leaves demonstrated low toxicity to Trichogramma sp., supporting the current findings of high survival rates with papaya leaf extract treatment (Ngegba et al., 2022). On the other hand, the lower survival rates of natural enemies exposed to Andaliman leaf extract might be attributed to the higher concentration of secondary metabolites such as alkaloids and flavonoids, which, while effective against pests, could pose higher toxicity risks to non-target beneficial insects. This finding aligns with previous research indicating that certain potent botanical extracts, while effective against pest species, must be carefully managed to mitigate their impact on natural enemy populations (Damalas & Koutroubas, 2020).

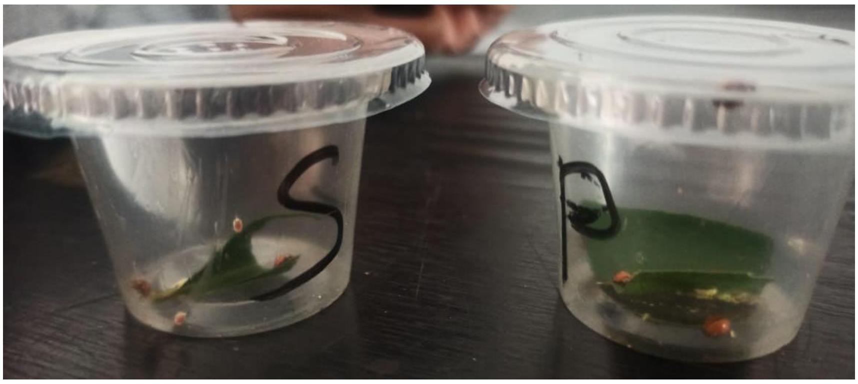


**Figure 4. The process of biological safety testing on natural enemies**

## CONCLUSION

The extract of Andaliman leaves has been proven to be an effective and environmentally friendly botanical pesticide. The application of botanical pesticides from Andaliman leaf extract on *Spodoptera exigua* larvae over four days (96 hours) resulted in the highest average mortality rate of 57.5% compared to Mahoni leaf extract (45%), Papaya leaf extract (27.5%), and Soursop leaf extract (25%). Additionally, Andaliman leaf extract caused the highest total mortality of *Spodoptera exigua* larvae, with an average daily death rate of 4 larvae. It was recorded as the botanical pesticide that caused the fastest larval death within 24 hours compared to other botanical pesticides in this study. In the biological safety testing over four days (96 hours), the highest survival rate of the parasitoid wasp (*Trichogramma sp.*) was 77.5%, achieved with Soursop leaf extract, while the lowest was 70%, achieved with Andaliman leaf extract. For the survival rate of the predator ladybug (*Cheilomenes sexmaculatus*), the highest was 85% with Soursop leaf extract, and the lowest was 75%

with Andaliman leaf extract. Based on the biological safety levels of natural enemies that survived the application of botanical pesticides, Andaliman leaf extract is still categorized as an effective and safe botanical pesticide for environmentally friendly use..

### *Declaration by Authors*

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**Conflict of Interest:** The authors declare that there are no conflicts of interest regarding the publication of this manuscript. All authors have approved the manuscript and agree with the journal's submission process..

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