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Optimization of Neem Leaf Extract (*Azadirachta indica* A. Juss) to Control Whitefly (*Bemisia tabaci* (Gennadius) on Eggplant (*Solanum melongena* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. Author MY wrote and prepared the original draft of the manuscript, performed the methodology and did investigation. Author NK reviewed and edited the manuscript, did data curation. Author BHN did formal analysis and performed the methodology. Author NKAV did investigation and data curation. Authors AW, FP, SAL and II edited the article. All authors read and approved the final manuscript.

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ABSTRACT

Bemisia tabaci (Gennadius) is one of the main pests in eggplant (*Solanum melongena* L.) cultivation, which can cause a 20-100% decrease in yield. Controlling *B. tabaci* using chemical insecticides has many negative impacts, as an alternative, the use of neem leaf extract (*Azadirachta indica* A. Juss) is used which has the potential as a botanical insecticide. This study aims to determine the concentration of neem leaf extract that is effective and efficient in controlling *B. tabaci* in eggplant plants. The study was conducted in Lolu Village, Biromaru District, Sigi Regency, Central Sulawesi Province and neem leaf extraction was carried out at the Plant Pest and Disease Laboratory, Faculty of Agriculture, Tadulako University from November 2024 to February 2025. The experiment used a randomized block design (RBD) with 6 treatments and 4 replications so that 24 experimental units were obtained. The treatment consisted of several concentrations of neem leaf extract, namely P0 = control (0 g.L^{-1}), P1-P5 (0.5 g.L$^{-1,}$ 1 g.L^{-1}, 2 g.L^{-1}, 4 g.L^{-1}, 8 g.L^{-1}). The results showed that the use of neem leaf extract was effective in controlling *B. tabaci* on eggplant plants. Concentrations of 2-4 g.L^{-1} were effective and efficient in controlling *B. tabaci* with a population density of 0.35-0.74 individuals plant^{-1}, the attack intensity decreased to 3.43-4.97% and eggplant production reached 7.54-8.26 t ha^{-1}.

Keywords: Bemicia tabaci; botanical insecticide; neem leaf extract; Solanum tuberosum.

1. INTRODUCTION

Eggplant (*Solanum melongena* L.) is one of the important vegetable commodities in tropical areas, including Indonesia. In addition to having high nutritional value, such as vitamins A, B, C, potassium, phosphorus, and iron, eggplant is also a source of income for many farmers (Akin-Osanaiye et al., 2024; Mansurat et al., 2023; Mwinuka et al., 2021; Taufik et al., 2020). However, the productivity of this plant is often hampered by pest attacks, one of which is the whitefly (*Bemisia tabaci* Genn.). This pest sucks plant fluids and acts as a vector for viral diseases and triggers the growth of sooty mold which interferes with the photosynthesis process (Bornancini et al., 2020). As a result, whitefly attacks can cause a 20-100% decrease in crop yields (De Barro et al., 2011).

The use of chemical pesticides often has negative impacts on the environment and human health. Farmers generally rely on synthetic insecticides to control whiteflies. However, excessive use has caused various problems, such as pest resistance, environmental pollution, and negative impacts on non-target organisms, including humans (Abubakar et al., 2022). Therefore, environmentally friendly control alternatives are needed, such as neem leaf extract (*Azadirachta indica* A. Juss). This extract contains active compounds such as azadirachtin, nimbin, and salannin, which are known to be effective in disrupting insect development. Botanical pesticides are effective in controlling pests and have minimal negative impacts on the environment and human health (Mordue (Luntz) & Nisbet, 2000).

Neem leaves contain active compounds such as azadirachtin, which have antifeedant, growth inhibitor, and insecticide properties (Boursier et al., 2011; Oyege et al., 2025). The effectiveness of neem leaf extract in controlling whiteflies has been proven in several studies (Yuniati et al., 2024). However, information regarding the optimal dose of neem leaf extract to control *B. tabaci* in eggplant plants is still very limited, especially in real cultivation conditions.

This study hypothesizes that neem leaf extract can significantly suppress the whitefly population on eggplant plants, with a certain dose that provides maximum effectiveness without damaging the plants or the environment. This study has a novel value because it tests the optimal dose of neem leaf extract in realistic field conditions, not only on a laboratory scale. This will bridge the gap between academic research and practical applications in the field, while providing concrete solutions for farmers.

This study aims to determine the optimal concentration of neem leaf extract that is most effective and efficient in suppressing the *B. tabaci* population on eggplant plants and evaluate the effect of various concentrations of neem leaf extract on population density, intensity of whitefly attacks and productivity of eggplant plants. The results of this study are expected to contribute to the development of science in the field of sustainable agriculture. In addition, this study will also provide practical recommendations for farmers in controlling whiteflies naturally, reducing dependence on synthetic insecticides, and supporting environmental conservation efforts.

2. MATERIALS AND METHODS

2.1 Location of the Experimental Site

The research was conducted in Lolu Village, Sigi Biromaru District, Sigi Regency, Central Sulawesi Province. The process of making neem leaf extract (*A. indica*) was carried out at the Pest and Disease Laboratory, Faculty of Agriculture, Tadulako University, Palu from November 2024 to February 2025. The selection of the location was based on agro-climate suitability, the availability of eggplant plants (*S. melongena*) as research objects, and accessibility to neem leaf raw materials.

2.2 Research Design

This study used a Randomized Block Design (RBD) with six treatments and four replications, so that there were a total of 24 experimental units. The treatments consisted of: P0: Control (without extract, only water). P1–P5: Neem leaf extract with graded concentrations (0.5 $g.L^{-1}$, 1 $g.L^{-1}$, 2 $g.L^{-1}$, 4 $g.L^{-1}$, and 8 $g.L^{-1}$). The extract concentration refers to previous research (Shofa, 2021).

2.3 Research Implementation

2.3.1 Eggplant nursery

Eggplant seeds of the Yufita F1 variety are sown in plastic trays filled with nutrient-enriched cocopeat media. Each hole is filled with one seed, and the seedlings are transferred to the beds after 3 weeks or reaching a height of ±15 cm.

2.3.2 Land preparation

The land is cleared of weeds, plowed, and hoed to a depth of 30 cm to improve soil aeration. The beds are made with a size of 3 m × 2 m, a planting distance of 60 cm × 50 cm, and a distance between beds of 50 cm to facilitate drainage and maintenance.

2.3.3 Fertilization

Fertilization is carried out in two stages, namely basic fertilizer in the form of manure applied a week before planting with a dose of 10 tons per hectare, and follow-up fertilizer in the form of application of inorganic NPK fertilizer with a dose of 200 kg N ha^{-1} + 100 kg P_2O_5 ha^{-1} + 75 kg K_2O ha^{-1}.

2.3.4 Planting and maintenance

Seeds are planted by making holes 2–3 cm deep and after they grow the plants are maintained by watering, weeding and controlling pests and diseases.

2.4 Preparation and Application of Neem Leaf Extract

The preparation of the extract refers to (Ervinatun et al., 2018). Preparation of simplicia is made by taking 5 kg of fresh neem leaves, washing them, drying them for 4-5 days, and then grinding them into powder. Extraction by taking 1.2 kg of powder, soaked in 96% ethanol for 48 hours, then filtered. Evaporation by filtrate is concentrated with a rotary evaporator at a temperature of 60°C until a thick extract of 205.6 grams is obtained with a yield of 17.13%. Application is done by diluting the extract according to the treatment and spraying weekly starting from 2 WAP (Weeks After Planting) to 6 WAP, using a handsprayer.

2.5 Observation Variables

2.5.1 Pest population density

Pest Population Density is calculated according to the formula (Pratiwi et al., 2022)

$$KP = \sum \frac{JH}{JT}$$

Note: KP: Population density; JH: Number of pests; JT: Number of sample plants.

2.5.2 Attack intensity

Attack intensity calculated using the Formula (Amelia et al., 2020).

$$I = \frac{\sum (n \times v)}{Z \times N} \times 100\%$$

Note: I = Intensity of pest attack (%) n = Number of damaged leaves in each attack category v = Scale value of each attack category Z = Highest set scale value N = Number of leaves observed

2.5.3 Eggplant production

Fruits were weighed per sample plot and converted to hectares using the formula.

Production t ha^{-1} = $\frac{\text{Area 1 Ha}}{\text{sample plot area}}$ × production of 1 observed sample plot

2.6 Data Analysis

Data were analyzed using ANOVA to determine whether there was a significant effect or not and further HSD test (5% level) to see the significant effect between treatments.

3. RESULTS

3.1 Whitefly Population Density

The results showed that neem leaf extract significantly suppressed the population density of whiteflies (*B. tabaci*). The extract concentration of 8 g.L^{-1} (P5) produced the lowest population density (0.22–1.19 individuals/plant), significantly different from the control/0 g.L^{-1} (2.51–4.29 individuals plant^{-1}) (Table 1). However, the concentration of 2 g.L^{-1} (P3) showed adequate population reduction with results that were not significantly different from higher concentrations.

3.2 Attack Intensity

The results showed that neem leaf extract significantly reduced the intensity of whitefly (*B. tabaci*) attacks. A concentration of 8 g.L^{-1} (P5) produced the lowest attack intensity (1.53–17.53%), significantly different from the control (9.13–42.30%). However, a concentration of 2 g.L^{-1} had shown adequate effectiveness with results that were not significantly different from higher concentrations, except for observations 6 WAP which were different from a concentration of 8 g.L^{-1} (Table 2). Low concentration (2 g.L^{-1}) was quite effective, indicating potential efficiency in saving field application costs.

3.3 Plant Production

This study proved that neem leaf extract was effective in controlling whiteflies and significantly increased eggplant production. Concentration of 8 g.L^{-1} (P5) produced the highest production (8.38–8.98 t ha^{-1}), significantly different from the control (5.71–6.03 t ha^{-1}) (Table 3). Concentration of 1 g.L^{-1} has shown a significant effect and concentration of 8 g.L^{-1} provides maximum eggplant production. However, considerations of cost and efficiency make concentration of 4 g.L^{-1} more feasible for field application because plant production does not differ with higher concentration. For further research, more stable extract formulations or combinations with other biological agents can be explored to increase durability and effectiveness in the field.

Table 1. Average whitefly population density (tail/plant) at various concentrations of neem leaf extract

Treatment	2 WAP	3 WAP	4 WAP	5 WAP	6 WAP
P_0 (Control)	2.51^{d}	2.92 ^{d}	4.29 ^{d}	3.07 ^{d}	2.56 ^{b}
P_1 (0.5 g.L^{-1})	1.91^{c}	1.53 ^{c}	2.88 ^{c}	2.32 ^{c}	1.98 ^{b}
P_2 (1 g.L^{-1})	1.67^{c}	1.06 ^{bc}	2.15 ^{bc}	1.55 ^{b}	0.97 ^{a}
P_3 (2 g.L^{-1})	1.49 ^{bc}	0.74 ^{ab}	1.73 ^{ab}	1.41 ^{ab}	0.81 ^{a}
P_4 (4 g.L^{-1})	1.24 ^{b}	0.38 ^{a}	1.45 ^{ab}	1.14 ^{ab}	0.35 ^{a}
P_5 (8 g.L^{-1})	0.81^{a}	0.25 ^{a}	1.19 ^{a}	0.73 ^{a}	0.22 ^{a}
HSD 5%	**0.42**	**0.57**	**0.88**	**0.69**	**0.76**

Note: Numbers with the same letter in the same column are not significantly different based on the HSD Test at 5% level. WAP= week after planting

Table 2. Average intensity of whitefly attacks (%) at various concentrations of neem leaf extract

Treatment	2 WAP	3 WAP	4 WAP	5 WAP	6 WAP
P_0 (Control)	9.13 ^{d}	21.22 ^{b}	42.30 ^{d}	36.06 ^{d}	35.57 ^{d}
P_1 (0.5 g.L^{-1})	7.08 ^{c}	11.59 ^{a}	34.36 ^{c}	26.44 ^{c}	24.86 ^{c}
P_2 (1 g.L^{-1})	5.56 ^{c}	10.04 ^{a}	25.83 ^{b}	22.89 ^{bc}	20.43 ^{bc}
P_3 (2 g.L^{-1})	4.97 ^{b}	9.69 ^{a}	23.32 ^{ab}	21.31 ^{abc}	17.70 ^{b}
P_4 (4 g.L^{-1})	3.43 ^{b}	7.74 ^{a}	20.08 ^{ab}	18.03 ^{ab}	16.12 ^{b}
P_5 (8 g.L^{-1})	1.53 ^{a}	5.13 ^{a}	17.53 ^{a}	15.57 ^{a}	9.92 ^{a}
HSD 5%	**1.71**	**7.27**	**7.24**	**6.64**	**5.35**

Note: Numbers with the same letter in the same column are not significantly different based on the HSD Test at 5% level. WAP= week after planting

Table 3. Average eggplant production (tons/ha) at various concentrations of neem leaf extract

Treatment	8 WAP	9 WAP
P_0 (Control)	6.03 ^{a}	5.71 ^{a}
P_1 (0.5 g.L^{-1})	6.95 ^{ab}	7.22 ^{b}
P_2 (1 g.L^{-1})	7.67 ^{bc}	7.31 ^{b}
P_3 (2 g.L^{-1})	7.75 ^{bc}	7.54 ^{bc}
P_4 (4 g.L^{-1})	8.11 ^{c}	8.26 ^{cd}
P_5 (8 g.L^{-1})	8.38 ^{c}	8.98 ^{d}
HSD 5%	**1.15**	**0.82**

Note: Numbers with the same letter in the same column are not significantly different based on the HSD Test at 5% level. WAP= week after planting

4. DISCUSSION

Based on the data in Table 1, the highest whitefly population density occurred in the control (P0), especially at 4 WAP (4.29 tails plant^{-1}) and was significantly different from other treatments. These results prove that neem leaf extract can be an environmentally friendly solution to control *B. tabaci*, with a concentration treatment of 2 g.L^{-1} (P3) having a significant effect and not significantly different from higher concentrations of 4-8 g.L^{-1} (P4 and P5) in most observations (3-6 DAP). This shows that neem leaf extract can be an environmentally friendly solution to control *B. tabaci* with a relatively low concentration of 2 g.L^{-1}. The results showed that neem leaf extract significantly reduced the intensity of whitefly attacks (*B. tabaci*). A concentration of 8 g.L^{-1} (P5) produced the lowest attack intensity (1.53–17.53%), significantly different from the control (9.13–42.30%). However, the concentration of 2 g.L^{-1} has shown adequate effectiveness with results that are not significantly different from higher concentrations, except for observations 6 DAP which are different from the concentration of 8 g.L^{-1} (Table 2). Low concentration (2 g.L$^{-1)}$ is quite effective, showing potential efficiency in saving field application costs.

Based on the data in Table 2, it shows that the pattern of decreasing intensity of whitefly attacks is in line with the increasing concentration of neem leaf extract. The decrease in attack intensity is caused by the reduced feeding activity of whiteflies due to the active compounds in neem leaf extract. At a concentration of 2 g.L^{-1} neem leaf extract has shown adequate effectiveness in killing whitefly pests with results that are not significantly different from higher concentrations, except for observations 6 DAP which are different from the concentration of 8 g.L^{-1} (Table 2). The concentration of 2 g.L^{-1} shows effective treatment and potential efficiency in saving field application costs.

The effectiveness of the extract is supported by active compounds such as azadirachtin which interfere with pest development. This finding strengthens the position of neem leaf extract as an alternative environmentally friendly control that is effective in suppressing *B. tabaci*, especially in sustainable agricultural systems. Neem leaf extract (*A. indica*) has long been known as an effective natural pest control agent thanks to the combination of its active compounds that work synergistically. One of its main advantages is its ability to provide multitarget effects, thereby minimizing the risk of pest resistance. This finding is in line with research (Mordue (Luntz) & Nisbet, 2000) which confirms the role of neem extract as a sustainable pest control solution. The concentration of the extract plays an important role in determining its killing power. The higher the concentration used, the greater the number of pests that can be controlled. This is due to the increased levels of azadirachtin, the main compound in neem leaves which is bioactive. Conversely, low concentrations can slow down pest death because the active ingredient content is lower (Isman, 2006).

Azadirachtin works through several unique mechanisms: 1) Antifeedant Effect. This compound stimulates refusal to eat through chemoreceptors in the insect's mouth, interferes with the perception of food stimuli (Hasanuzzaman et al., 2016; Salbiah & Andria, 2021), can reduce plant damage through antifeedant mechanisms and inhibition of insect development (Isman, 2020), and works as an antifeedant and growth regulator in insects (Kurniati et al., 2018). 2) Developmental Disorders. The Azadirachtin compound inhibits the hormone ecdysone, disrupts the molting process (skin changes) and metamorphosis (Noor et al., 2023), the salanin compound acts as a reducer of pest appetite, which reduces the insect's destructive power even though the insect is not dead (Maharani et al., 2020). This neem leaf extract can be quickly absorbed through the skin surface, paralyzing pests and causing immediate death. So that the poison contained in neem leaves will affect the food digestion process, so that the food digestion process cannot take place (Pavela et al., 2025). 3) Decreased reproduction. This compound interferes with the insect reproductive tissue, reducing fertility and the number of eggs produced (Maharani et al., 2020). Neem extract can affect pests through various mechanisms. Among them, it can inhibit the development of eggs, larvae, or pupae, and interfere with the skin change process in the larval stage. Neem extract also acts as a repellent, preventing females from laying eggs, reducing appetite, and inhibiting reproduction. All of this is related to the presence of active compounds such as antifeedants and repellents contained in neem leaves (Kurniati et al., 2018; Pavela et al., 2025).

In addition to azadirachtin, neem extract contains supporting compounds such as salannin, meliantriol, and nimbin which strengthen the antifeedant and growth regulator effects. This combination affects the physiology of pests holistically, ranging from decreased appetite, developmental disorders, to reproductive disorders. Increasing the concentration of neem leaf extract will affect the high content of active ingredients in the substance, which functions effectively in killing pests. Neem leaves themselves contain components that can produce an aroma that repels the presence of pests. In addition, neem leaf extract contains parasinin, an alkaloid that can reduce the pest population in plants (Gupta et al., 2013; Quelemes et al., 2015).

Neem extract has advantages over synthetic insecticides, including: 1) Environmentally friendly, which is easily decomposed with minimal residue, so it is safe for non-target insects and can be applied close to harvest time, 2) Safe for vertebrates, which is low toxicity to humans and livestock (Seriana et al., 2019), 3) Minimal resistance, the multitarget work of its active compounds makes it difficult for pests to adapt (Isman, 2020; Sari et al., 2022), 4) Works systemically and can penetrate insect cuticles, paralyzing pests quickly and disrupting their digestive system (Tiwari et al., 2014).

The results of the regression analysis showed a strong relationship between population density and attack intensity with the equation Y = 7.4463x + 5.7715 with a coefficient of determination value of R^2 = 0.9937 (Fig. 1). The high and low intensity of attacks is influenced by population density, the lower the population density of whiteflies, the intensity of attacks will decrease and vice versa if the population density is high, the intensity of attacks will increase. It was revealed that population density <1 (tail plant^{-1}) increased attack intensity only <15% and if population density>3 tails plant^{-1} the intensity of attacks increased to>30%.

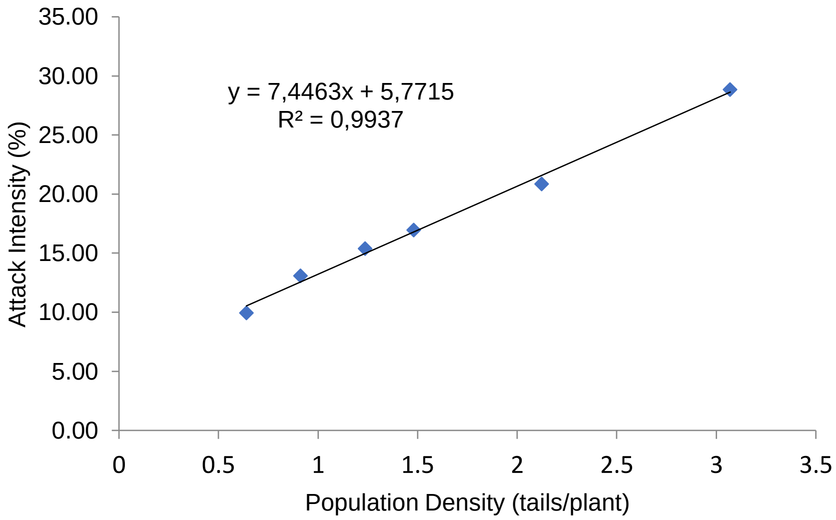

Fig. 1. Relationship between population density and intensity of whitefly attacks on eggplant plants

Regression analysis of the relationship between population density and eggplant production has the equation Y = -1.0745x + 9.187 with a coefficient of determination R^2 = 0.9739 (Fig. 2). A population density of 1 (head plant^{-1}) can increase production to reach ±8 t ha^{-1}, while a population density> 3.00 (head plant^{-1}) shows an increase in production of only <6 tons/ha, which means that the higher the population density, the lower the eggplant production, conversely if the population density is low, the higher the production.

Regression analysis of the relationship between attack intensity and production results has the equation y = -0.145x + 10.032 with a coefficient of determination value of R^2 = 0.9898 (Fig. 3) which means that the higher the attack intensity, the lower the production results, conversely if the attack intensity is low, the higher the production results. If the R^2 value is higher, it can indicate a close relationship. This is because damage occurs to the leaves so that the surface area of the leaves for photosynthesis is reduced.

Regression analysis showed a negative relationship between the population/intensity of whitefly attacks and eggplant production (R^2 = 0.9739 and 0.9898), proving that pest control using neem leaf extract has a direct impact on increasing eggplant plant productivity. These results reinforce previous findings that controlling *B. tabaci* with neem leaf extract not only reduces plant damage but also significantly increases eggplant productivity. Attacks caused by whiteflies on eggplant can also affect production by causing suboptimal plant growth and development (Arsi et al., 2022). Therefore, attacks caused by whiteflies can cause quite high yield losses of up to 20-100% and can even result in crop failure (Kedar et al., 2014).

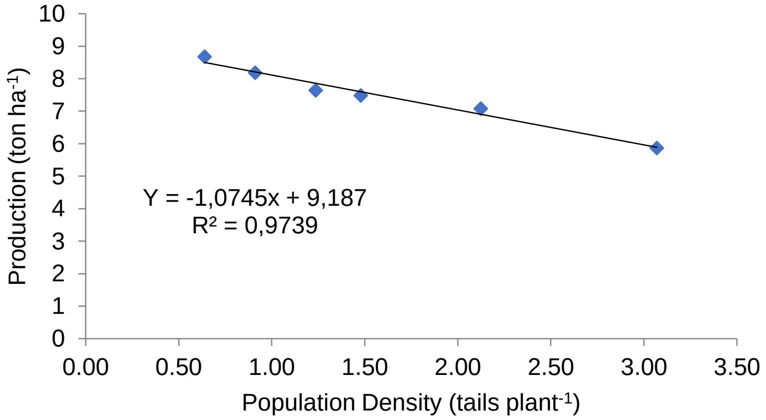

Fig. 2. Relationship between whitefly population density and eggplant production

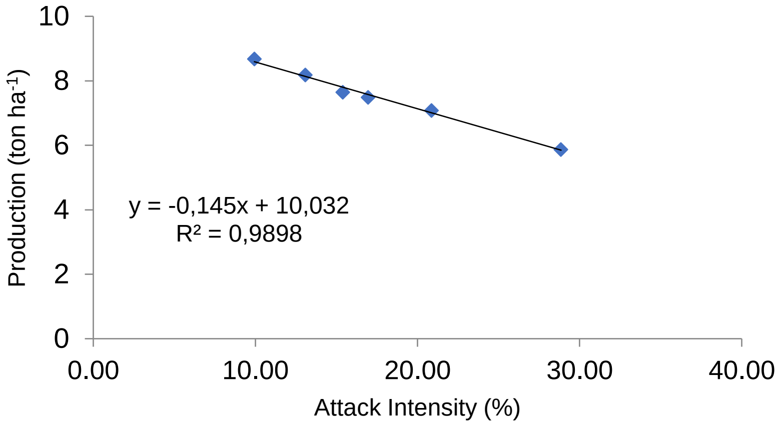

Fig. 3. Relationship between whitefly attack intensity and eggplant production

Neem leaf extract is effective in controlling whitefly attacks on eggplant because neem leaves contain natural compounds such as salanin and meliatriol which are effective as pest controllers. These compounds can inhibit pest growth and also reduce pest appetite (Hikal et al., 2017), this is in accordance with research results that the use of neem leaf extract has been shown to increase eggplant production. This is due to a decrease in the percentage of pest attacks that have a direct effect on the chlorophyll content of the leaves. Chlorophyll, as the main component of chloroplasts, has a positive correlation with the rate of photosynthesis. This photosynthesis process is important for plant growth and development (Ali & Aprilia, 2018; Wang et al., 2025).

The decrease in whitefly attacks has a direct impact on increasing eggplant production. Several factors that support this include: 1) Increased photosynthesis, leaves that are free from damage can photosynthesize optimally, supporting growth and fruiting, 2) Reduction of plant stress, plants that are not disturbed by pests are able to allocate more energy to fruit production, 3) Better fruit quality, the fruit produced is healthier and free from damage due to pest attacks.

5. CONCLUSION

Based on the research results, it can be concluded that neem leaf extract is effective and efficient in controlling whiteflies and increasing eggplant production. Considering effectiveness and cost efficiency, the optimal concentration that can be used is 2-4 $g.L^{-1}$.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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