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Evaluation on selected Malaysian native eggplant varieties (*terung telunjuk* and *terung rapuh*) fungal disease and their control

Nurul Ammar Illani, Jaafar[1*], Aminah, Mahmud [1], Razean Haireen, Mohd. Razali[2], Nurul Afiqah, Shamsolanwar [1], Umikalsom, Mohamed Bahari [2] & Faziah, Umar [1]

[1]Agrobiodiversiti and Environment Research Centre, Malaysian Agricultural Research and Development Institute (MARDI), MARDI Headquaters, Persiaran MARDI-UPM, 43400 Serdang, Selangor, MALAYSIA.

[2]Industrial Crop Research Centre, MARDI Headquaters, Malaysian Agricultural Research and Development Institute (MARDI), Persiaran MARDI-UPM, 43400 Serdang, Selangor, MALAYSIA.

*Corresponding author: ammarj@mardi.gov.my

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Abstract: Native eggplant varieties such as *terung telunjuk* and *terung rapuh* are gaining renewed interest among Malaysian farmers due to their unique traits and potential for low-input farming. However, these varieties are susceptible to fungal diseases, particularly leaf blight and fruit rot caused by *Phomopsis vexans*. This study investigated the incidence and severity of fungal diseases in the field and evaluated various disease control strategies using chemical fungicides, biocontrol agents, and botanical treatments. Field surveys identified *P. vexans* as the primary pathogen, confirmed through morphological and molecular analyses. *In vitro* assays revealed that biofungicides containing *Trichoderma* spp. and *Bacillus* spp. demonstrated superior antifungal activity (97.64% and 93.89% inhibition, respectively), outperforming most chemical and botanical treatments. *Moringa* extract, neem oil, and garlic oil also exhibited notable inhibition of fungal growth, while azoxystrobin-based fungicides showed moderate efficacy. Field trials further confirmed the efficacy of integrated treatments, especially combinations of biofungicides with azoxystrobin or copper hydroxide, which significantly reduced disease severity and improved yield. The results suggest that integrated disease management strategies incorporating microbial biocontrol agents and selective chemical fungicides offer effective and sustainable control of *P. vexans* in traditional eggplant varieties.

Keywords: *Solanum melongena*, terung telunjuk, terung rapuh, *Phomopsis vexans*, leaf blight, fruit rot

1.0 Introduction

Eggplant (*Solanum melongena* L.), or *terung* as it is locally known in Malaysia, is one of the most important vegetable crops grown worldwide due to its culinary versatility, nutritional composition, economic, cultural significance and adaptability to tropical environments (Rodríguez-Burruezo et al., 2008). It is widely featured in Malaysian cuisine and remains a dietary staple across various ethnic communities. Globally, the crop's popularity has contributed to the development of various cultivars with differences in fruit shape, size, color, and maturation period (Bhuvaneswari et al., 2023).

In Malaysia, eggplant is one of the top five vegetables cultivated nationally, with a planted area of 2,705 hectares and a total production of 45,776 metric tons recorded in 2023 (Umikalsum et al., 2025). Malaysia is home to a wide array of *S. melongena* landraces and wild relatives, which are valuable for their unique traits and potential for sustainable cultivation. However, commercial production is increasingly dominated by hybrid and improved varieties, resulting in the gradual displacement of traditional cultivars. To address this, researchers and agricultural development programs have begun to explore indigenous and traditional eggplant varieties in Malaysia.

Malaysia's native eggplant varieties, including *terung telunjuk* (long, green at young and orange at mature), *terung rapuh* (round, light to purple skinned, soft textured), *terung asam* (round, sour, yellow), and *terung susu* (white skinned), are still cultivated by smallholder farmers and prized for their unique flavour and adaptability (Figure 1). Comparative studies have shown that traditional varieties often contain higher levels of protein, carbohydrates, and bioactive compounds compared to commercial types (Sharma et al., 2021; Gürbüz et al., 2018). In particular, *terung* *rapuh* has demonstrated high antioxidant activity and nutritional content, while *terung telunjuk* shows lower susceptibility to pest and disease pressure (Umikalsum et al., 2025). Besides, *terung telunjuk* and *terung rapuh* have attracted attention due to their adaptability, continuous fruiting potential, and suitability for low-input farming systems (Alam et al., 2021).

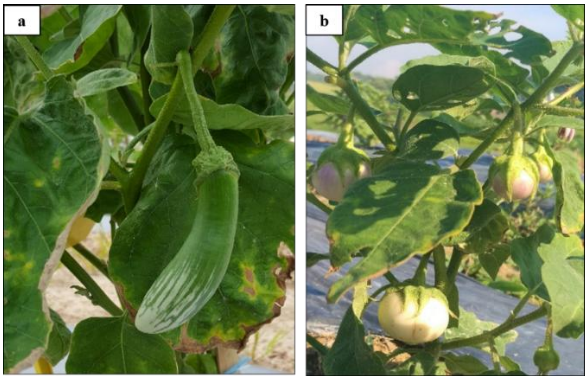

Fig. 1: (a) *Terung telunjuk* crop with the early emerged green colour fruit. (b) *Terung rapuh* crop displaying the light to purple colour fruit.

Despite their potential, traditional eggplant varieties like other solanaceous crops are vulnerable to various fungal diseases that significantly affect yield and fruit quality. Common pathogens to eggplant include *Fusarium oxysporum* f. sp. *melongenae* (Fusarium wilt), *Phomopsis vexans* (fruit rot, leaf, and stem blight), and *Alternaria solani* (leaf spot), which thrive under the warm and humid conditions typical of Southeast Asia (Mahadevakumar et al., 2017; Pandey, 2010; Umikalsum et al., 2025). These diseases remain major constraints to production, particularly where chemical management is either inaccessible or unsustainable. *Terung telunjuk* and *terung rapuh* are susceptible to insect pests and fungal diseases, which significantly reduce their yield potential. Among these, leaf blight and fruit rot, caused by the fungal pathogen *P. vexans*, are among the most serious diseases affecting eggplant crops globally. These diseases result in economic losses through direct damage to marketable fruits and reduced plant productivity (Rohini et al., 2023).

Currently, many eggplant farmers rely heavily on chemical fungicides for disease control. However, concerns about environmental contamination, health risks, and pathogen resistance have led to growing interest in integrated disease management (IDM) approaches. These include the use of resistant cultivars, cultural practices, and biocontrol agents (Ha, 2015). Meanwhile, advancements in digital agriculture and artificial intelligence offer new tools for early disease detection and precision interventions (Jafar et al., 2024). Nonetheless, data on how traditional Malaysian varieties respond to these interventions remain limited.

Therefore, this study aims to evaluate the fungal disease scenery affecting Malaysian traditional eggplant varieties (*terung telunjuk* and *terung rapuh*) and explore their potential for sustainable disease management. Specifically, the research seeks to identify the major fungal pathogens infecting *terung telunjuk* and *terung rapuh*, assess the susceptibility or resistance levels of these varieties under field conditions, and investigate appropriate disease control strategies, particularly those aligned with environmentally sustainable agricultural practices. By focusing on under-utilized traditional eggplants, the study would contribute to the broader goals of conserving agrobiodiversity, improving crop resilience, and promoting integrated approaches to plant health management in Malaysia's vegetable production systems.

2.0 Methodology

2.1 Screening of fungal disease incidence and symptoms on traditional eggplant in the field

Field surveys were conducted in symptomatic eggplant (*Solanum melongena* L.) cultivation areas in study plots at Jalan Kebun and Serdang, Selangor, with particular focus on major fungal diseases on *terung telunjuk* and *terung rapuh*. Disease observations were carried out during the peak vegetative and fruiting stages of the crop. Visual assessments were conducted on all plants within each plot to identify and record symptoms of common eggplant diseases. The disease incidence of each symptom was estimated based on the percentage of visibly affected plant tissue or fruits. For each variety, mean disease incidence percentages were calculated from all observed replicates to allow for comparative analysis across cultivars. Infected tissues, including leaves and fruits showing necrotic lesions were collected in sterile paper bags and transported to the laboratory for pathogen isolation.

2.2 Isolation of fungal pathogen

Fungal isolation was carried out on Potato Dextrose Agar (PDA) media. Small sections of infected tissue were surface sterilized using 1% sodium hypochlorite, rinsed with sterile distilled water, and plated on PDA under aseptic conditions. Plates were incubated at 25 ± 2°C for 7-15 days. Emerging fungal colonies were sub-cultured on new plates.

Morphological identification was conducted based on colony characteristics and microscopic features of conidia and pycnidia, following descriptions by Islam et al. (2020a) and Mahadevakumar et al. (2017).

2.3 Pathogen identification using internal transcribed spacer (ITS) region gene sequencing

Molecular identification was performed using polymerase chain reaction (PCR) with species-specific primers targeting the internal transcribed spacer (ITS) region, following protocols as described by Mahadevakumar et al. (2017). The fungal isolates were grown on PDA medium for 7 to 15 days. Fungal mycelia from full grown PDA were harvested and genomic DNA was extracted following the protocol provided by company for DNA extraction kit (PrimeWay Genomic II DNA Extraction Kit, 1st BASE) and subsequently used for PCR amplification. The internal transcribed spacer (ITS) region of ribosomal DNA was amplified using the primer pair ITS1 (5'-CGGATCTCTTGGTTCTGGCA-3') and ITS4 (5'-GACGCTCGAACAGGCATGCC-3'). PCR reactions were carried out in a total volume of 25 µl, consisting of 1 µl genomic DNA, 2.5 µl of 10× PCR buffer, 2.5 µl of 2.5 mM $MgCl_2$, 2.0 µl of 2 mM dNTPs, 1.0 µl each of forward and reverse primers (20 pM), 0.2 µl of Taq DNA Polymerase (Vivantis, USA), and 14.8 µl of nuclease-free water. The thermal cycling conditions included an initial denaturation at 95°C for 3 minutes, followed by 35 cycles of denaturation at 94°C for 30 seconds, annealing at 55°C for 30 seconds, and extension at 72°C for 1 minute, with a final extension step at 72°C for 10 minutes. Amplification was performed using a thermal cycler (MJ Research PTC-200 Peltier Thermal Cycler, Bio-Rad). PCR products were resolved on a 1.5% agarose gel alongside a 1 kb DNA marker, and successfully amplified fragments were sequenced directly. The DNA sequencing results obtained from isolates in this study were compared with available sequences in GenBank using BLASTN tools through the National Centre for Biotechnology Information (NCBI).

2.4 *In vitro* evaluation of potential control agent against fungal pathogen

An *in vitro* study was conducted to evaluate the efficacy of various potential fungicide in inhibiting the growth of fungal pathogen, using the poisoned food technique. The fungicides tested included plant based, commercial chemical fungicide and biofungicide (Table 1). Each fungicide was incorporated separately into sterilized Potato Dextrose Agar (PDA) medium. A volume of 20 mL of the amended PDA was poured into sterile Petri dishes.

Table 1: Treatments used for *in vitro* assay

Type	Treatments	Main / active ingredient
Commercial biofungicide (plant base)	Garlic oil Neem oil Bio-Guard	Garlic Neem Herbal extracts of flavonoids and terpenoids
Plant base extract	*Moringa* extract *Lemon myrtle* extract	*Moringa* *Lemon myrtle*
Commercial biofungicide (microbe base)	Tricho Care Bacillus Care	*Trichoderma* spp. beneficial *Bacillus* spp.
Commercial chemical fungicide	Armada® 50 WDG Amistar® Kocide™ 2000	trifloxystrobin + triadimefon azoxystrobin copper hydroxide

A 7 mm diameter fungal plug of fungal subculture, taken from the actively growing edge of a culture, was placed at the centre of each plate. Control plates were prepared without any fungicide to serve as a growth baseline. All treatments were performed in triplicate, and plates were incubated at 25 ± 2°C for 7 to 15 days.

Radial mycelial growth was measured in two perpendicular directions once the fungus in the control plates had reached full growth. The degree of inhibition was calculated as the percentage reduction in radial growth in treated plates compared to the control. The percentage inhibition of mycelial growth by each treatment was calculated following the formula of Vincent (1947):

$$\text{Inhibition (\%)} = [(C - T) / C] \times 100$$

Where:
C = radial growth of fungal colony in the control plate (mm)
T = radial growth of fungal colony in the treated plate (mm)

This formula expresses the reduction in mycelial growth of the treated plates relative to the untreated control.

All treatments were replicated three times, and the mean values of inhibition were used for analysis. The experimental data were subjected to Analysis of Variance (ANOVA) using standard statistical software to determine the significance of treatment effects. Mean comparisons were carried out using Tukey's Honest Significant Difference (HSD) test at a 5% level of significance ($p < 0.05$). Results were expressed as mean ± standard error (SE), and treatments were grouped according to statistical similarity.

2.5 Field trial assessment of potential fungicides for fungal disease control

The study was conducted in an open field at Malaysian Agricultural Research and Development Institute (MARDI) (Figure 2). Two traditional varieties of Malaysian eggplant (*terung telunjuk* and *terung rapuh*) were used for this study. Field trials were conducted under natural infection conditions to evaluate the effectiveness of selected fungicides and biocontrol agents.

Fig. 2: Field study plot in MARDI.

The experiment was laid out in a Randomized Complete Block Design (RCBD) with ten treatments (T1–T10), each replicated three times for both (*terung telunjuk* and *terung rapuh*). Each replicate consisted of 10 plants, totalling 30 plants per treatment. Each plot consisted of ten plants with a spacing of 75 cm × 75 cm. The treatments included various combinations of commercial plant based (garlic oil, neem oil and Bio-Guard), commercial biofungicide (microbe based) (Tricho Care and Bacillus Care) and commercial chemical fungicide (Armada® 50 WDG, Amistar® and Kocide^{TM} 2000) and untreated controls Table 2 details out the treatments involved for *terung telunjuk* while Table 3 belongs to *terung rapuh* treatments.

Table 2: Description of fungicide treatments applied on *terung telunjuk* in the field trial

No. of treatments	Types of fungicide used	Remarks (Main / active ingredient)	Description of field application
T1	Garlic oil	Garlic	Apply every week
T2	Neem oil	Neem	Apply every week
T3	Tricho Care	*Trichoderma* spp.	Apply every week
T4	Bacillus Care	beneficial *Bacillus* spp.	Apply every week
T5	Kocide^{TM} 2000	copper hydroxide	Apply every week
T6	Amistar®	azoxystrobin	Apply every week
T7	Tricho Care / Kocide^{TM} 2000	*Trichoderma* spp. / copper hydroxide	Apply alternate week for each
T8	Bacillus Care / Amistar®	beneficial *Bacillus* spp. / azoxystrobin	Apply alternate week for each
T9	Plant Protect	cocktail of beneficial microbe, ketones, vitamin, mineral	Apply every week
T10	Negative control	plant without treatment	No control measure involved

Table 3: Description of fungicide treatments applied on *terung rapuh* in the field trial

No. of treatments	Types of fungicide used	Remarks (Main / active ingredient)	Description of field application
T1	Bio-Guard	Herbal extracts of flavonoids and terpenoids	Apply every week
T2	Neem oil	Neem	Apply every week
T3	Garlic oil	Garlic	Apply every week
T4	Garlic oil / Bio-Guard	Garlic / herbal extracts	Apply alternate week for each
T5	Garlic oil / Neem oil	Garlic / neem	Apply alternate week for each
T6	Neem oil / Bio-Guard	Neem /herbal extract	Apply alternate week for each
T7	Garlic oil / Amistar®	Garlic / azoxystrobin	Apply alternate week for each
T8	Bio-Guard / Amistar®	herbal extract / azoxystrobin	Apply alternate week for each
T9	Amistar®	azoxystrobin	Apply every week
T10	Negative control	plant without treatment	No control measure involved

Seedlings were transplanted into prepared field plots and treated at 7-day intervals**,** beginning 30 days after planting**.** Treatments were applied in accordance with manufacturer recommended dosages. Standard agronomic practices, including fertilization and weeding, were followed throughout the trial period. Disease incidence and severity were recorded weekly for 15 weeks, and yield parameters were measured at harvest. Assessment on disease incidence, and severity were calculated based of below formula.

Disease incidence (%) was calculated as:

Disease Incidence (%) = (Number of infected plants / Total number of plants) × 100

Disease severity was assessed using a 0–5 rating scale:
0 = No symptoms,
1 = 1 – 20 % leaf area infected,
2 = 21 – 40 %,
3 = 41 – 60 %,
4 = 61 – 80 %,
5 = > 81 % leaf area infected.

The Disease Severity Index (DSI) was calculated using the formula:

DSI (%) = [Σ (class rating × number of leaves in that rating) / (total number of leaves × maximum rating)] × 100

Area Under Disease Progress Curve (AUDPC) was calculated to quantify disease development over time using the formula:

$$AUDPC = \Sigma\ [(Yi + Yi{+}1)/2] \times (Ti{+}1 - Ti)$$

Where:
Yi = disease severity at time i,
Ti = time at i.

Distribution of disease severity was analyzed based on the frequency of each severity rating class. Tukey's HSD test at $p < 0.05$ was used to determine significant differences between treatments. Data on disease incidence, severity, AUDPC, and treatment efficacy were statistically analyzed using ANOVA. Mean separation was performed using Tukey's HSD test at 5% significance level.

3.0 Results and Discussion

3.1 Screening of fungal disease incidence and symptoms on traditional eggplant in the field

Based on screening of disease incidence among several eggplant varieties cultivated on study plot at Jalan Kebun and Serdang, Selangor, it was recorded that the disease symptoms varied significantly among cultivars (Figure 3). The study identified four major types of disease symptoms affecting the eggplants: blight, mosaic/mottling, fruit rot, and anthracnose. Variety *terung rapuh* exhibited the highest level of blight infection, reaching approximately 32%, whereas other varieties including *terung telunjuk, terung bulat (MTE*), and *terung panjang* showed considerably lower blight incidences, all around or below 10%. Mosaic or mottling virus disease was most severe in *terung panjang* (45%), followed by *terung telunjuk* (30%) and *terung rapuh* (24%), while *terung bulat (MTE*), had the lowest (15%). Fruit rot was the most widespread disease symptom, particularly affecting *terung bulat (MTE)* (47%) and *terung rapuh* (40%), while *terung telunjuk* showing the lowest incidence at only 5%. Anthracnose was the least common across all varieties, ranging between 2% and 8%. From these observations, *terung telunjuk* stands out as the most disease-resistant variety, while *terung* ulat (*MTE*) and *terung panjang* were more vulnerable to multiple diseases.

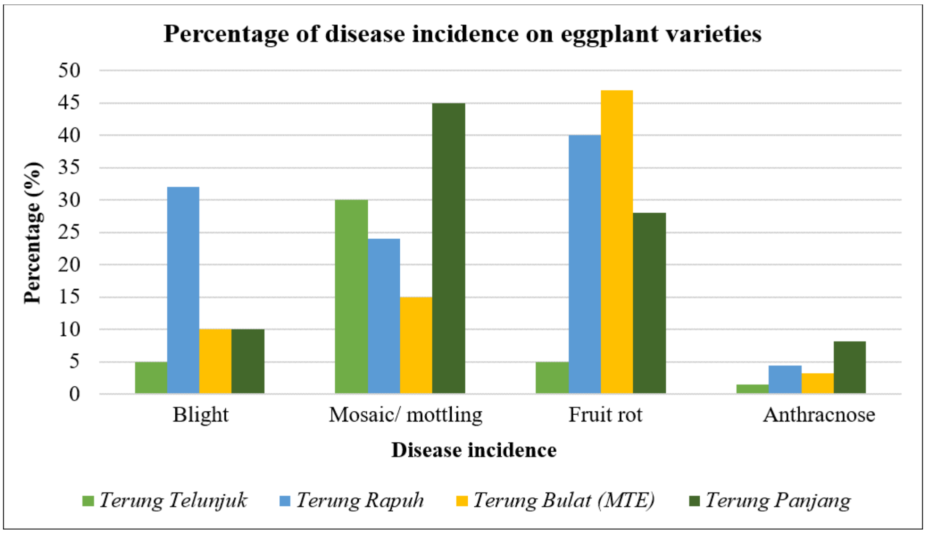

Fig. 3: The graph shows the percentage of disease incidence on eggplant varieties.

Dominant diseases recorded on traditional eggplant varieties (*terung telunjuk* and *terung rapuh*) are blight and fruit rot, which are caused by the fungal pathogen *P. vexans*, responsible for *Phomopsis* blight and brings a serious threat to eggplant production in tropical regions. The pathogen attacks stems, leaves, and fruits, often resulting in cankers, defoliation, and fruit rot. It survives in plant debris and seeds for extended periods, enabling recurrence across seasons (Islam et al., 2020b). In Malaysia and similar agroclimatic zones like India and Bangladesh, yield losses due to *Phomopsis* blight can range from 30% to 50%, particularly in susceptible cultivars under high humidity (Bhanushree et al., 2021; Gazipur et al., 2020). Without proper management, the disease not only reduces marketable yield but also affects seed viability and future crop performance.

Field observations on farmer plots have shown that disease can be transmitted through seeds and seedlings, and can persist in infected plant debris and soil. The pathogen produces a large number of conidia and survives as pycnidia, allowing it to infect plants from the vegetative stage through flowering and fruiting (Rohini et al., 2023). Symptoms on leaves usually begin as small, circular to irregular, water-soaked spots, which gradually enlarge and turn brown to dark brown with a characteristic concentric zonation (Figure 4). The lesions often coalesce, leading to extensive blighted areas and premature leaf senescence. In severe infections, the necrotic lesions cause leaf distortion, curling, and drying, especially on lower and older leaves. Pycnidia, appearing as minute black dots, are frequently visible within the necrotic tissue, serving as diagnostic features of *P. vexans* infection. The disease typically starts on older leaves and progresses upwards, significantly reducing photosynthetic efficiency (Bhat et al., 2019; Mahadevakumar et al., 2017).

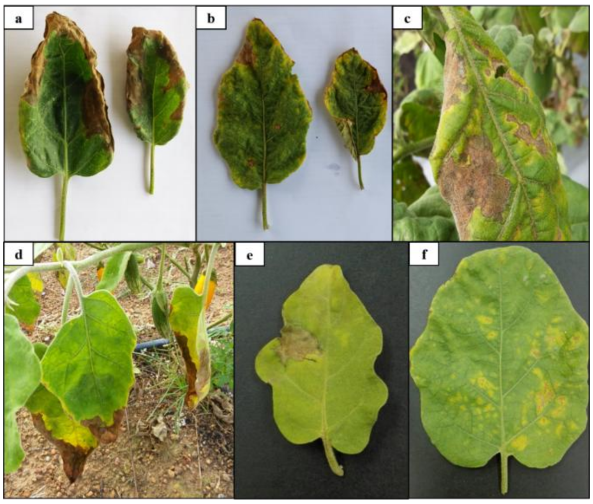

Fig. 4: Symptoms of leaf blight on (a–d) *terung telunjuk* and (e-f) terung rapuh leaves.

Fruit infection often begins at the calyx end or wounded areas as small, circular, sunken, pale brown spots that gradually expand to form large, dark, sunken lesions with a concentric ring pattern (Figure 5). The infected tissues soften and rot, causing the fruits to shrivel, shrink, and eventually mummify while still attached to the plant. In advanced stages, the lesions may cover the entire fruit surface. Numerous black pycnidia develop within the necrotic lesions, producing conidia that ooze out in creamy tendrils under humid conditions. These pycnidia are key diagnostic markers of *Phomopsis* fruit rot. Severe infection leads to premature fruit drop, rendering the crop unmarketable and causing significant post-harvest losses (Rohini et al., 2023; Udayashankar et al., 2019).

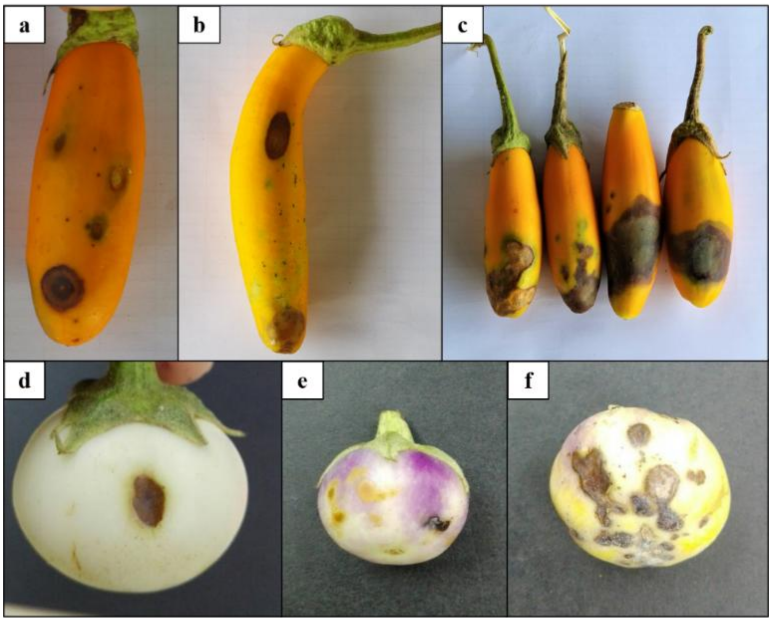

Fig. 5: Symptoms of fruit rot observed on *terung telunjuk* and terung rapuh fruit. (a-b) showing early and (c) late symptom on *terung telunjuk* fruit while (d-e) showing early and (f) late symptom on *terung rapuh* fruit.

Fruit rot symptoms begin from early fruit formation and persist to maturity, often showing brown lesions that expand and destroy market value. Infected fruits may drop or harden after soft rot, becoming unsuitable for consumption (Pani et al., 2013). The combination of leaf blight and fruit rot symptoms drastically reduce eggplant yield and quality. Leaf blight diminishes canopy health and photosynthesis, while fruit rot directly reduces marketable yield and post-harvest storability. Under favorable warm and humid conditions, disease incidence may reach 30–50% or higher, making *P. vexans* one of the most destructive pathogens of eggplant worldwide (Pandey, 2010).

3.2 Microscopic and macroscopic morphological observation and molecular identification of fungal pathogen

The identification of fungal pathogens requires an integrated approach combining cultural features, microscopic characteristics, and molecular tools. In this study, the pathogen isolated from diseased brinjal tissue was identified as *P. vexans* based on its distinctive morphology, which was later confirmed through molecular analysis. Under microscopic observation in Figure 6, the conidia were found to be hyaline, aseptate, and typically biguttulate (containing two oil globules). They were single-celled observed under microscope. The pycnidia were observed as dark, pyriform, ostiolate, and either immersed or erumpent, becoming prominently visible during disease development similarly to characteristics of *P. vexans*. Such micromorphological features remain key taxonomic criteria for the identification of *Phomopsis* species, although they may vary slightly under different environmental conditions (Rohini et al., 2023).

The fungi macroscopic morphology was observed based on cultural features as shown in Figure 7. Colonies grown on PDA exhibited characteristics consistent with *Phomopsis* spp. culture morphology. On potato dextrose agar (PDA), colonies initially appeared white to greyish white with abundant aerial mycelia, which later turned dark grey to brown with age. Colonies generally showed cottony to floccose texture, with margins that were irregular but well-defined. Pycnidia developed after several days of incubation, usually scattered but sometimes aggregated, and appeared as small, black, globose to pyriform bodies immersed in the medium or erumpent on the colony surface.

When observed from the reverse side of PDA plates, colonies typically display yellowish-brown to dark brown pigmentation, with the intensity varying among isolates (Figure 8). Some isolates produced a pale-yellow halo around the colony margin, while others developed dark concentric zonation with prolonged incubation. The colony diameter ranged between 55–80 mm after 15 days of incubation at 25 ± 2 °C, depending on the isolate.

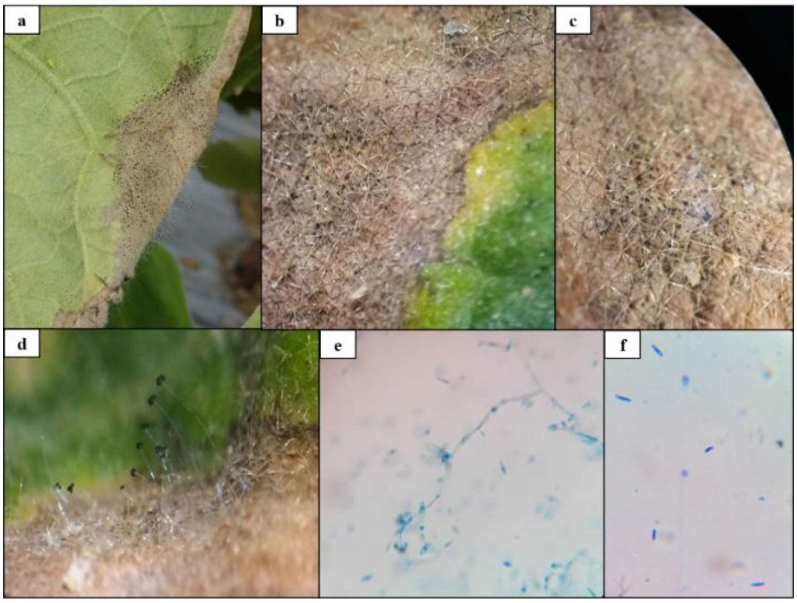

Fig. 6: (a)Pycnidia (asexual fruiting bodies) on necrotic leaves caused by leaf blight. (b-d) Clear pycnidia observed under dissecting microscope. (e-f) Fungal spore observed under compound microscope (1000 × magnification).

Fig. 7: Pathogenic fungus isolated on Potato Dextrose Agar (PDA) medium from a leaf exhibiting late-stage blight symptoms.

The grown cultures showed variation among isolates from infected leaf and fruit sample of *terung telunjuk* and *terung rapuh* (Figure 8, 9 and 10). Such variations in colony colour, texture, and growth rate have been documented in multiple studies, highlighting the morphological diversity within *P. vexans* populations (Bhat et al., 2019; Mahadevakumar et al., 2017). Importantly, sporulation on PDA was generally abundant, with pycnidia becoming visible on the colony surface between 10–20 days depending on the isolate, consistent with observations from Indian and Bangladeshi populations (Rohini et al., 2023).

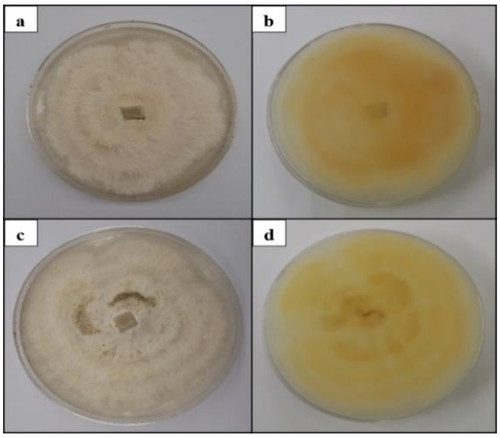

Fig. 8: Colony morphology of the pathogenic fungus *Phomopsis vexans* on PDA medium after 15 days of incubation. (a) Subculture from leaf sample (top view), (b) subculture from leaf sample (reverse view), (c) subculture from fruit sample (top view), and (d) subculture from fruit sample (reverse view).

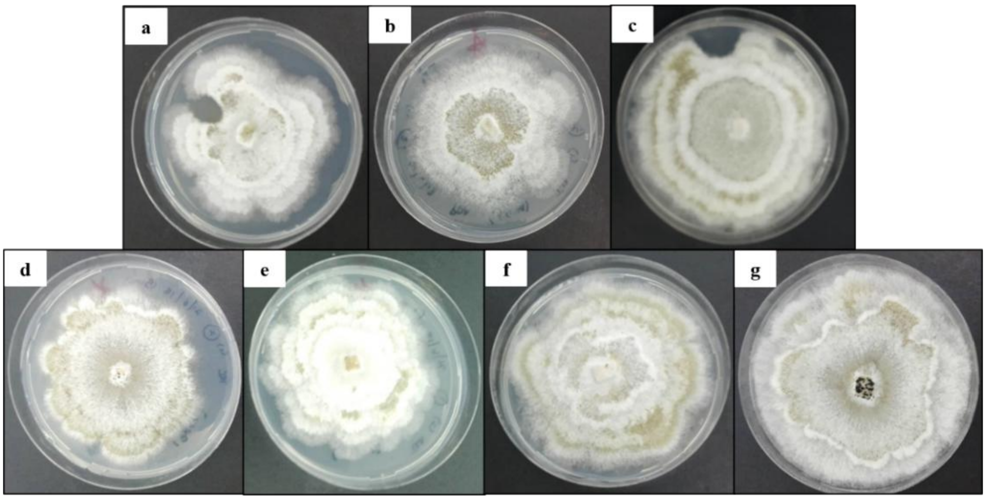

Fig. 9: Top view of full grow fungal isolates on PDA agar plate after 15 days. (a-c) Fungal isolates of TTAB, TTAL, TTBL from infected leaf and fruit sample of *terung telunjuk.* (d-f) Fungal isolates of TRCB, TRAL, TREB and TRHB from infected leaf and fruit sample of *terung rapuh.*

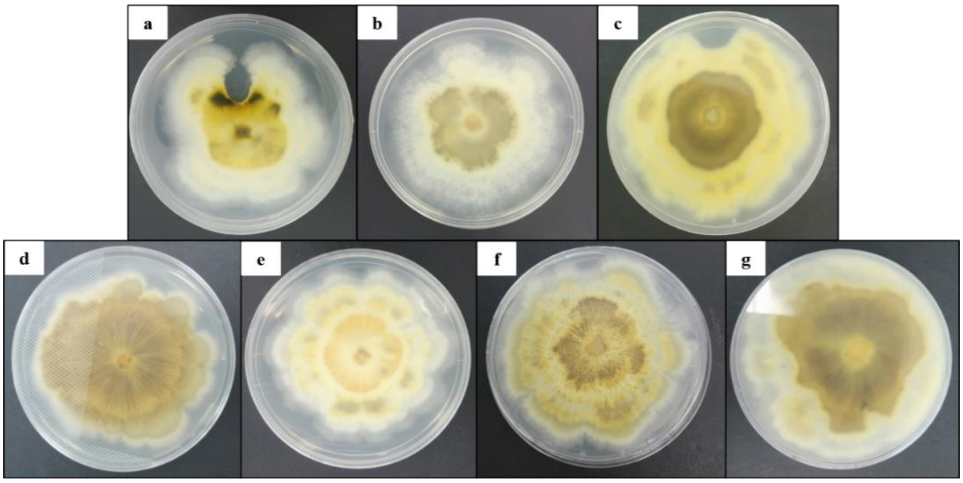

Fig. 10: Reverse view of full grow fungal isolates on PDA agar plate after 15 days. (a-c) Fungal isolates of TTAB, TTAL, TTBL from infected leaf and fruit sample of *terung telunjuk.* (d-f) Fungal isolates of TRCB, TRAL, TREB and TRHB from infected leaf and fruit sample of *terung rapuh.*

In this study, molecular identification using the internal transcribed spacer (ITS) region of rDNA confirmed all 7 isolates from infected leaf and fruit sample of *terung telunjuk* and *terung rapuh* were identified as *Phomopsis vexans (Table 4)*. ITS sequencing and phylogenetic analysis have been widely used to differentiate *P. vexans* from closely related species within *Diaporthe*, confirming the reliability of this approach (Santos et al., 2017, Udayanga et al., 2011).

Table 4: Molecular identification of fungal isolates based on ITS (internal transcribed spacer) gene sequencing.

Sample	Part	Fungal isolates	Identified Species Name	Similarity %	Accession numbers
Terung telunjuk	leaf	TTAB	*Phomopsis vexans*	99%	GU373631.1
	fruit	TTAL	*Phomopsis vexans*	99%	GU373631.1
		TTBL	*Phomopsis vexans*	99%	GU373631.1
Terung rapuh	leaf	TRCB	*Phomopsis vexans*	99%	GU373631.1
	fruit	TRAL	*Phomopsis vexans*	100%	GU373632.1
		TREB	*Phomopsis vexans*	99%	GU373633.1
		TRHB	*Phomopsis vexans*	99%	GU373631.1

3.3 In vitro evaluation of potential fungicides for their inhibitory activity against fungal pathogens

The efficacy of commercial biofungicides against *P. vexans* was evaluated *in vitro* using the poisoned food technique. Ten treaments comprising of commercial plant based (garlic oil, neem oil and Bio-Guard), plant base extract (moringa extract and lemon myrtle extract), commercial biofungicide (microbe based) (Tricho Care and Bacillus Care) and commercial chemical fungicide (Armada® 50 WDG, Amistar® and Kocide^{TM} 2000) (Table 1) were tested to see the inhibitory effect against *P. vexans* showed in Figure 11.

The results revealed significant variation in antifungal activity among treatments (Figure 12). Among all treatments, Tricho Care and Bacillus Care demonstrated the highest antifungal activity, with inhibition rates of 97.64% and 93.89%, respectively. This suggests that biological control agents may be highly effective, possibly due to mechanisms such as competition, antibiosis, or parasitism. Notably, Moringa extract also showed strong inhibitory effects (86.4%), outperforming several synthetic fungicides, indicating its potential as a natural alternative. Moderately effective treatments included Bioguard (80.17%), Amistar® (81.68%), Neem oil (76.15%), Garlic oil (73.71%), and Armada® 50 WDG (70.21%), showing that both biocontrol and some chemical agents can be comparably effective. However, KocideTM 2000 and Lemon myrtle extract exhibited the lowest inhibition percentages, 59.17% and 27.38% respectively, suggesting limited effectiveness against *P. vexans*. The variability in the efficacy of botanical treatments highlights the importance of selecting specific plant extracts with proven antifungal properties.

The superior performance of Tricho Care can be attributed to the antagonistic activity of *Trichoderma* spp., which suppress pathogens through mycoparasitism, competition for nutrients, and the secretion of hydrolytic enzymes and antifungal metabolites. Such mechanisms have made *Trichoderma* one of the most widely studied and effective biocontrol agents against soilborne fungi (Chowdhury et al., 2015). Similarly, Bacillus Care's strong inhibition is consistent with reports of *Bacillus amyloliquefaciens* producing bioactive lipopeptides such as fengycins and surfactins, which disrupt fungal membranes and reduce mycotoxin biosynthesis (Hanif et al., 2019; Li et al., 2014).

Among plant-based treatments, moringa extract and Bio-guard demonstrated notable antifungal activity, which is often linked to its phenolic compounds and bioactive isothiocyanates with known antimicrobial properties. Garlic oil also performed well, in line with evidence that allicin, a volatile sulfur compound produced by crushed garlic which exerts broad-spectrum antimicrobial action against fungi, bacteria, and oomycetes (Curtis et al., 2004). Neem oil showed moderate inhibition, consistent with its established role as a botanical biopesticide containing azadirachtin and other secondary metabolites that interfere with fungal growth.

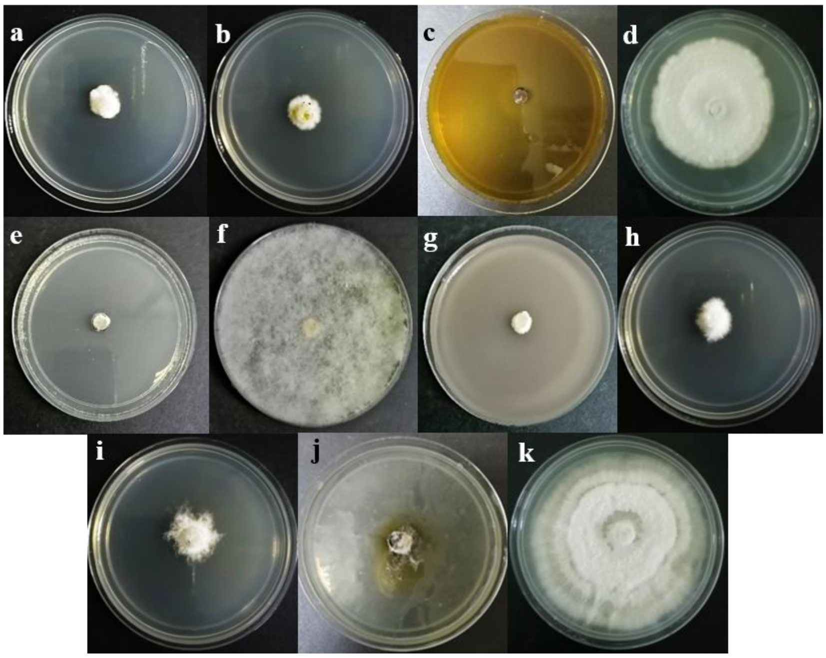

Fig. 11: Poisoning agar result of *Phomopsis vexans* against 9 different treatments of fungicides after 7 days incubations. The following treaments are (a) garlic oil, (b) neem oil, (c) moringa extract, (d) lemon myrtle, (e) Bioguard, (f) Tricho Care, (g) Bacillus Care, (h) Armada®, (i) 50 WDG Amistar®, (j) Kocide^{TM} 2000 and (k) control.

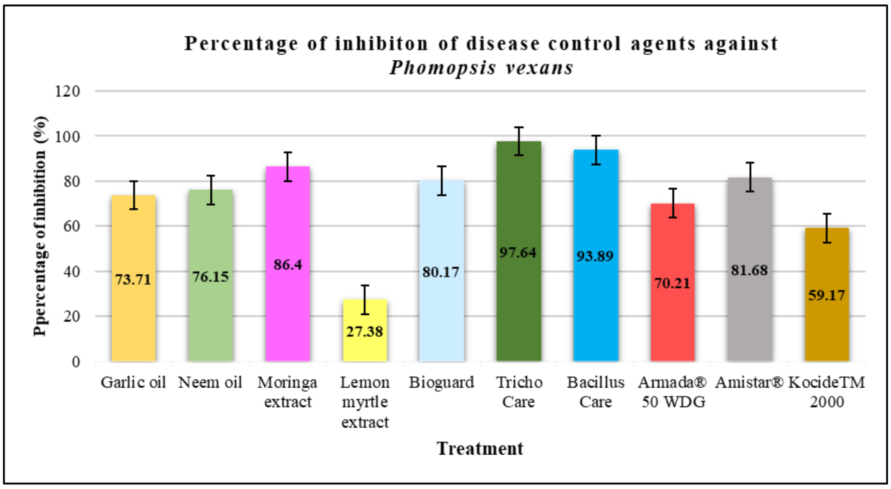

Fig. 12: Percent inhibition on mycelia growth of *Phomopsis vexans* on 9 different types of treatments.

The relatively weak inhibition observed with lemon myrtle extract suggests that its essential oils may be less effective against *P. vexans*. Likewise, the efficacy of chemical fungicides such as Armada® 50 WDG (trifloxystrobin + triadimefon), Amistar® (azoxystrobin) and Kocide^{TM} 2000 (copper hydroxide) *in vitro* may reflect differences in pathogen sensitivity, solubility, or their mode of action compared to different active ingredient. Overall, the results indicate that biofungicides particularly based on *Trichoderma* and *Bacillus* provide superior suppression of *P. vexans* compared to conventional fungicides and certain plant extracts. This supports the broader shift towards integrating microbial and botanical products as sustainable alternatives for managing fungal diseases on eggplant cultivation.

3.4 Evaluation of the effectiveness potential fungicide in fungal disease control on field trial

3.4.1 Leaf blight disease control on *terung telunjuk*

Leaf blight and fruit rot disease caused by *P. vexans* remains one of the most destructive fungal diseases affecting eggplant, particularly traditional varieties like *terung telunjuk* and *terung rapuh*. This disease can severely reduce photosynthetic surface area, plant vigor, and yield if unmanaged. The results presented here provide insight into the comparative efficacy of various fungicides and biocontrol treatments under natural field infection conditions.

Disease incidence reflects how widespread the infection becomes in a crop. As shown in Figure 13, the untreated control (T10) showed the highest incidence, exceeding 85%, reaffirming the high susceptibility of *terung telunjuk* to *P. vexans*. In contrast, T6 (Amistar®) and T5 (KocideTM 2000) significantly reduced incidence, maintaining levels below 30%. Combination treatments such as T8 (Bacillus Care alternating with Amistar®) and T7 (Tricho Care alternating with Kocide) also reduced incidence, though less effectively. These findings align with previous studies where fungicides like azoxystrobin and copper hydroxide significantly reduced foliar blight in eggplant crops (Hossain et al., 2013).

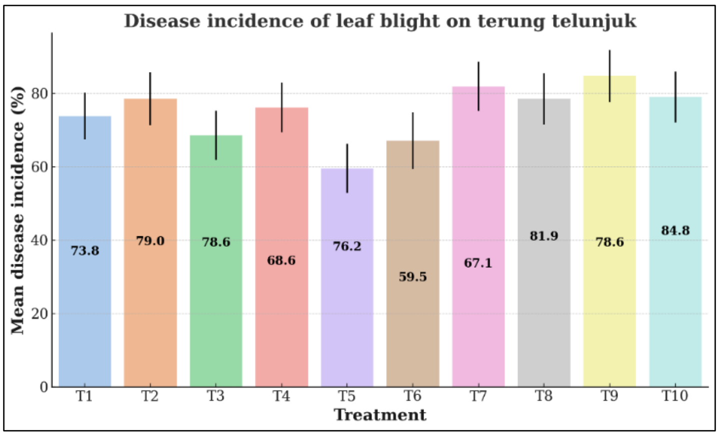

Fig. 13: Mean percentage of disease leaf blight incidence on *terung telunjuk* across ten treatment groups. The bars represent the average incidence across all weeks, with error bars indicating the standard error of the mean (SEM). (Notes: T1 = Garlic oil, T2 = Neem oil, T3 = Tricho Care, T4 = Bacillus Care, T5 = KocideTM 2000, T6 = Amistar®, T7 = Tricho Care / KocideTM 2000, T8 = Bacillus Care / Amistar®, T9 = Plant Protect & T10 = Control)

Disease severity progression, illustrated in Figure 14, reveals differences in how treatments suppressed disease symptoms over time. The untreated plots showed the steepest increase in severity, reaching over 75% by week 12. In contrast, T6, T5, and T8 consistently kept severity below 20%, while T3 (Bacillus Care) and T4 (Tricho Care) held severity around 45–50%. These trends support findings that both chemical and biological treatments can substantially reduce foliar disease symptoms, with biocontrol agents such as Trichoderma and Bacillus contributing to partial suppression (Rohini et al., 2016).

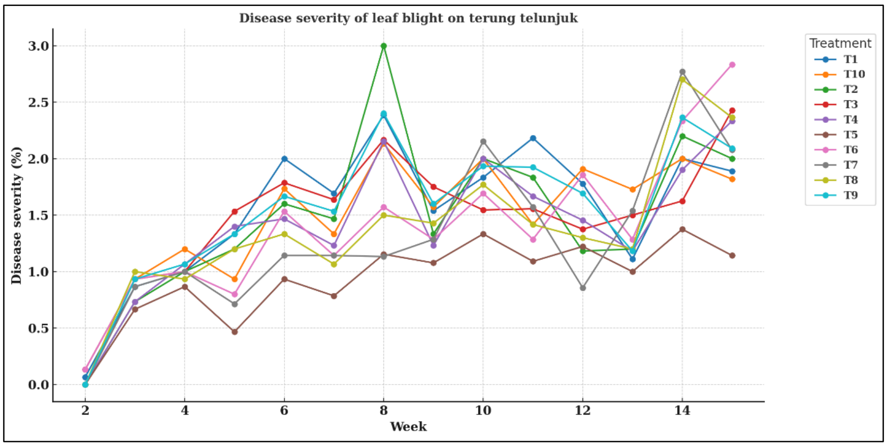

Fig. 14. Disease severity of leaf blight on *terung telunjuk* over 15 weeks following treatment application. Each line represents the mean disease severity (%) for a treatment group (T1–T10), averaged across replicates. (Notes: T1 = Garlic oil, T2 = Neem oil, T3 = Tricho Care, T4 = Bacillus Care, T5 = KocideTM 2000, T6 = Amistar®, T7 = Tricho Care / KocideTM 2000, T8 = Bacillus Care / Amistar®, T9 = Plant Protect & T10 = Negative control)

The cumulative impact of disease over time is reflected in AUDPC values (Figure 15). Treatment T6 (Amistar®) and T5 (KocideTM 2000) had the lowest AUDPC, followed closely by T8 (combined treatment of Bacillus Care and Amistar®,), indicating effective disease suppression. The control (T10) recorded the highest AUDPC, indicating uncontrolled disease progression. Similar reductions in AUDPC were reported in integrated management programs where both fungicides and biopesticides were employed (Singh et al., 2012).

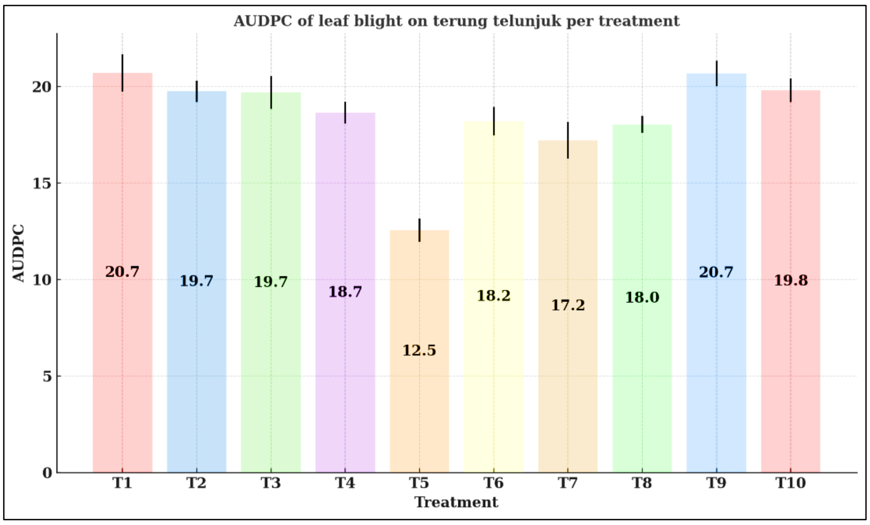

Fig. 15: The mean Area Under the Disease Progress Curve (AUDPC) for leaf blight on *terung telunjuk* across different treatment groups. Bars indicate the mean AUDPC values, while error bars represent the standard error of the mean (SEM). Higher AUDPC values reflect greater disease progression, indicating less effective treatments.

Distribution of disease severity (Figure 16) further supports treatment efficacy. Statistical analysis revealed that T6, T5, and T8 clustered in the lowest severity group, indicating consistently high performance. In contrast, untreated plots and single biocontrol treatments showed higher variability and greater median severity. These patterns are supported by field trials that observed lower variability in disease pressure when synthetic fungicides were used in combination with microbial agents (Rohini et al., 2023; Mahadevakumar & Janardhana, 2016).

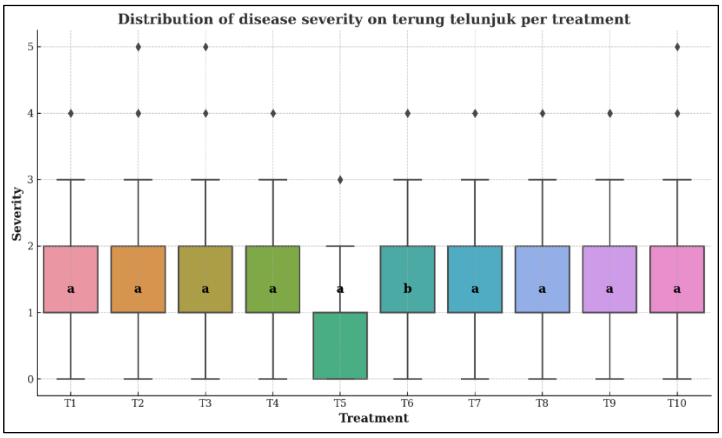

Fig. 16: The distribution of disease severity on *terung telunjuk* across different treatment groups. Each box represents the interquartile range (IQR), with the horizontal line indicating the median. Group letters indicate statistical differences based on Tukey's HSD test at $p < 0.05$; treatments sharing the same letter are not significantly different from one another.

Although synthetic fungicides provided the strongest control, biocontrol agents still demonstrated potential. For instance, *Trichoderma harzianum* and *Bacillus subtilis* have been shown to produce antifungal metabolites and induce plant resistance, offering more sustainable, long-term disease management options (Reddy et al., 2018). Moreover, combining these agents with fungicides could lead to synergistic effects, improving control while reducing chemical input and resistance pressure (Balai & Kumar, 2022). In summary, *P. vexans* leaf blight presents a serious risk to traditional eggplant varieties like *terung telunjuk*, but effective control can be achieved through integrated strategies. Treatments involving systemic fungicides such as Amistar® and KocideTM 2000 alone or combined with microbial biocontrol agents had offered the most effective suppression. These findings reinforce the importance of IDM approaches for sustainable and efficient crop protection (Singh et al., 2012; Hossain et al., 2013; Rohini et al., 2023).

3.4.2 Leaf blight disease control on *terung rapuh*

The progression and intensity of leaf blight on *terung rapuh* were evaluated through disease incidence, severity progression, and area under the disease progress curve (AUDPC). The bar chart illustrating mean disease incidence (%) revealed significant differences among treatments (Figure 17). The synthetic fungicide Amistar® (T9) and its combination with Bio-Guard (T8) resulted in the lowest disease incidence, indicating their high efficacy in reducing initial infection rates. Meanwhile, the untreated control (T10) exhibited the highest incidence, confirming the need for disease management interventions. Botanical treatments such as Bio-Guard (T1), neem oil (T2), and garlic oil (T3) moderately reduced disease incidence compared to the control but were less effective than synthetic-based treatments. Notably, treatments combining botanicals with synthetic fungicides such as T7 (garlic oil alternating with Amistar®)—demonstrated improved efficacy, suggesting potential synergistic effects.

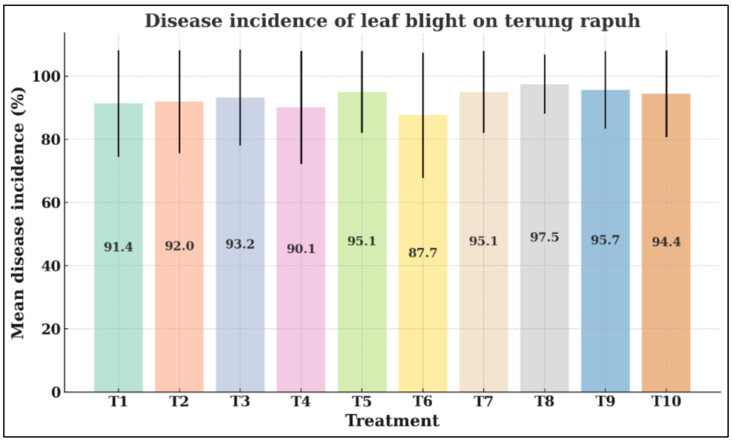

Fig. 17: Mean percentage of disease leaf blight incidence on *terung rapuh* across ten treatment groups. The bars represent the average incidence across all weeks, with error bars indicating the standard error of the mean (SEM). (Notes: T1 = Bio-Guard, T2 = Neem oil, T3 = garlic oil, T4 = Garlic oil / Bio-Guard, T5 = Garlic oil / Neem oil, T6 = Neem oil / Bio-Guard, T7 = Garlic oil / Amistar®, T8 = Bio-Guard / Amistar®, T9 = Amistar® & T10 = Negative control)

The disease severity progression curves further illustrated treatment efficacy on *terung rapuh* over time (Figure 18). In the untreated plots (T10), disease severity increased rapidly and continuously across the 15-week observation period, reflecting high disease pressure in the absence of control. In contrast, T8 and T9 maintained consistently low severity levels, indicating effective suppression of disease development. Among botanical treatments, disease progression was slower than in the control, though severity eventually increased, suggesting limited residual activity. Combination treatments such as T6 (neem oil and Bio-Guard) and T7 (Garlic oil and Amistar®) provided intermediate control, slowing disease buildup and extending protection. These trends imply that while botanicals alone may offer partial protection, their integration with synthetic fungicides can enhance durability and efficacy. This is in line with the known systemic and translaminar properties of strobilurin fungicides like azoxystrobin, which inhibit mitochondrial respiration in pathogens and provide broad-spectrum, curative and protective action (Bartlett et al., 2002).

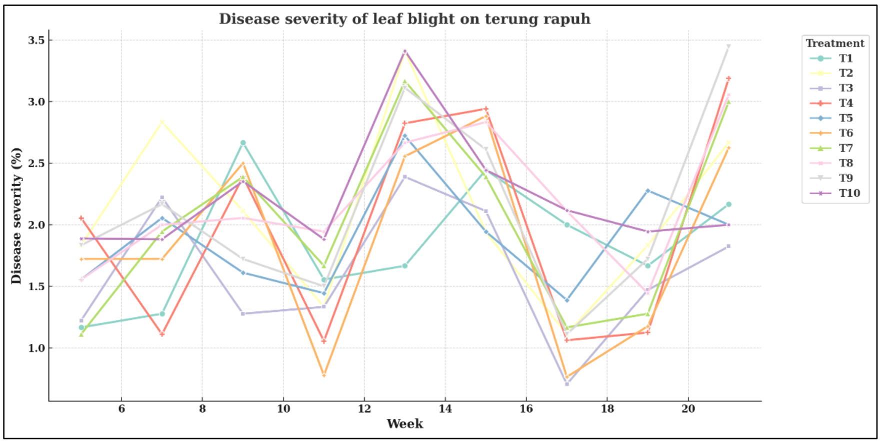

Fig. 18: Disease severity of leaf blight on *terung rapuh* over 20 weeks following treatment application. Each line represents the mean disease severity (%) for a treatment group (T1–T10), averaged across replicates. (Notes: T1 = Bio-Guard, T2 = Neem oil, T3 = garlic oil, T4 = Garlic oil / Bio-Guard, T5 = Garlic oil / Neem oil,

T6 = Neem oil / Bio-Guard, T7 = Garlic oil / Amistar®, T8 = Bio-Guard / Amistar®, T9 = Amistar® & T10 = Negative control)

Cumulative disease pressure on *terung rapuh* was captured via the AUDPC values (Figure 19). Consistent with earlier findings, the control (T10) showed the highest AUDPC, denoting prolonged and intense disease presence. The lowest AUDPC values were recorded for T8 and T9, confirming their superior long-term performance. Treatments like T5 (garlic oil and neem oil) and T7 also achieved relatively low AUDPCs, demonstrating the benefit of botanical combinations. These results indicate that combining fungicides particularly integrating botanical and synthetic products, can reduce not only initial infection but also overall disease development across the growing season. This performance supports earlier findings by Kagale et al. (2004), who reported that plant extracts can trigger induced resistance and antimicrobial activity with variable efficacy depending on environmental conditions.

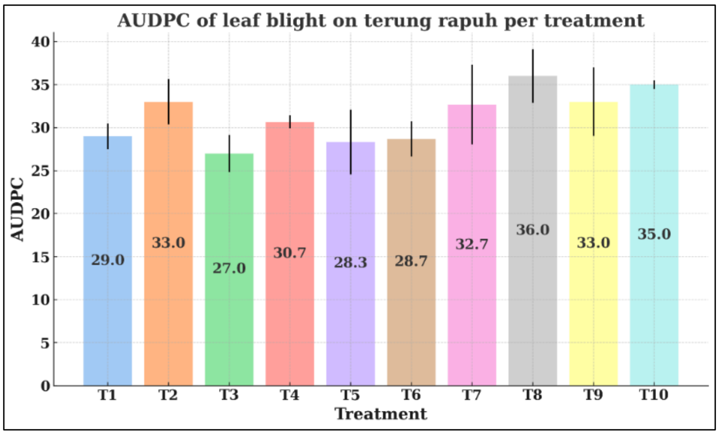

Fig. 19: The mean Area Under the Disease Progress Curve (AUDPC) for leaf blight on *terung rapuh* across different treatment groups. Bars indicate the mean AUDPC values, while error bars represent the standard error of the mean (SEM). Higher AUDPC values reflect greater disease progression, indicating less effective treatments.

Visualized by using a boxplot, treatments T8, T9, and T5 had significantly lower median severity scores and smaller interquartile ranges, indicating both efficacy and consistency across replicates (Figure 20). In contrast, the control group displayed the highest median severity with wide variability, underscoring the uncontrolled nature of disease in untreated plants. These findings collectively highlight the effectiveness of integrated disease management approaches, particularly those that combine synthetic fungicides with bio-based alternatives, in managing leaf blight in *terung rapuh* (Kumar et al., 2020).

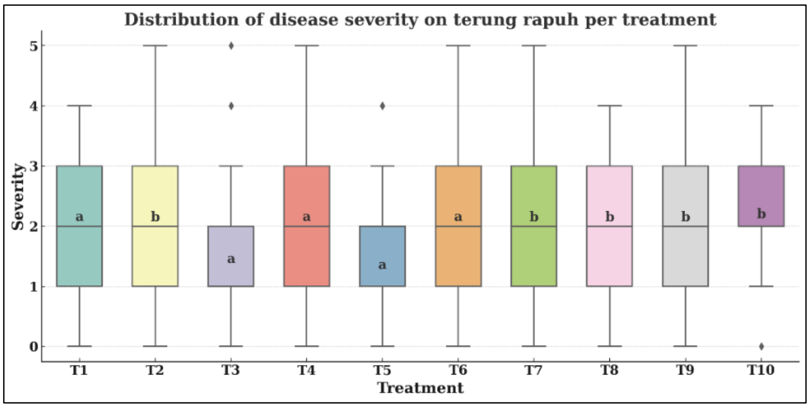

Fig. 20: The distribution of disease severity on *terung rapuh* across different treatment groups. Each box represents the interquartile range (IQR), with the horizontal line indicating the median. Group letters indicate statistical differences based on Tukey's HSD test at $p < 0.05$; treatments sharing the same letter are not significantly different from one another.

The present study revealed substantial variation in disease severity and incidence of leaf blight across different treatments applied to *terung rapuh*. Among the tested treatments, the synthetic fungicide Amistar® (azoxystrobin) and its combination with Bio-Guard consistently recorded the lowest disease severity and AUDPC values, demonstrating superior efficacy in suppressing disease progression. The integration of chemical and biological controls, as in the Bio-Guard and Amistar® treatment, outperformed single application treatments. Such combinations potentially control the systemic action of synthetic fungicides alongside the biostimulant or antagonistic effects of biological products, resulting in additive or synergistic disease suppression. This is in agreement with the principles of Integrated Pest Management (IPM), which promote reduced chemical inputs and sustainable control strategies (Kumar et al., 2020).

Although botanical treatments such as neem oil, garlic oil, and Bio-Guard alone were less effective than Amistar®, they still significantly reduced disease severity compared to the untreated control. These botanicals may activate host resistance or interfere with fungal growth through antifungal metabolites. Kagale et al. (2004) reported that extracts of *Datura metel* induced systemic resistance in rice, and similar effects may be hypothesized for garlic or neem extracts in eggplant. However, the lower and more variable efficacy of botanicals observed in this study is consistent with findings by Dubey et al. (2011), who emphasized the inconsistent performance of plant derived pesticides under field conditions due to their rapid degradation and sensitivity to environmental factors.

The untreated control (T10) displayed the highest disease severity and incidence throughout the observation period. This reinforces the idea that *terung rapuh* is highly susceptible to leaf blight under conducive conditions. Environmental factors such as humidity and temperature may have also accelerated disease development, particularly in tropical field conditions. As noted by Chakraborty and Newton (2011), tropical climates favor rapid disease cycles and intensify epidemic risk.

From a broader perspective, these findings underscore the importance of integrating multiple disease management strategies. While synthetic fungicides offer the highest efficacy, their repeated use can lead to environmental contamination and resistance development (Aktar et al., 2009). Therefore, combining synthetic and biobased product, balancing effectiveness with ecological safety. Long-term studies, such as this, are crucial for evaluating disease control under field conditions, and contribute valuable insights into sustainable production systems (Jeger & Pautasso, 2008).

3.4.3 Fruit rot disease control on *terung telunjuk* and *terung rapuh*

In this study, yield was assessed based on the mean number of fruits and mean fruit weight, further categorized into marketable and non-marketable fruits, across four harvest periods (Weeks 8, 10, 12, and 14) for *terung telunjuk* and three harvest periods (Week 12, Week 17, and Week 20) for *terung rapuh*. Harvest period for both eggplants traditional varieties were different depend on their fruiting season. Non-marketable fruits were defined as those showing symptoms of fruit rot disease.

The results demonstrated that fungicide treatments had a substantial effect on improving both the quantity and quality of eggplant yield on both eggplants traditional varieties. For *terung telunjuk*, chemical treatments, particularly T5 (Kocide™ 2000) and T6 (Amistar®), consistently produced the highest number and weight of marketable fruits, especially during Week 10, which showed peak production. These treatments also significantly suppressed the occurrence of fruit rot, resulting in lower non-marketable yields (Figure 21). These outcomes were supported by their corresponding to low leaf blight disease severity levels which indicate strong disease suppression during critical crop growth stages. The relationship between disease severity and yield was clearly evident. As disease severity decreased, particularly in T5 and T6, marketable yield increased substantially. This aligns with findings by Ishii (2006), who emphasized the efficacy of strobilurin fungicides like azoxystrobin in managing foliar fungal diseases, as well as the resistance management benefits of copper-based fungicides.

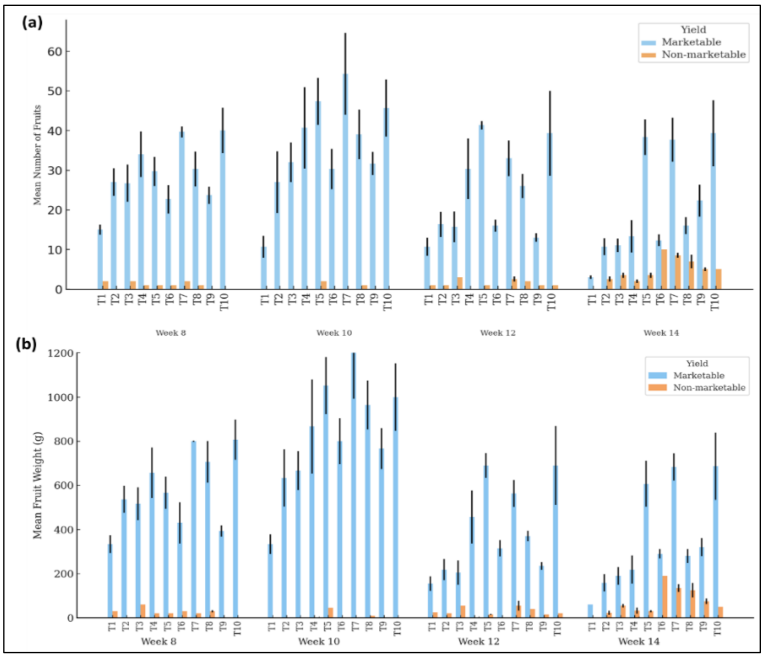

Fig. 21: Mean number of fruits (a) and mean fruit weight (b) of *Terung Telunjuk* under different fungicide treatments (T1–T10) across four harvest weeks. Yields are categorized into marketable (blue) and non-marketable (orange) fruits. Error bars indicate standard error.

Integrated treatments such as T7 (Trichoderma spp. alternating with Kocide™) and T8 (Bacillus spp. alternating with Amistar®) also performed well, suggesting that alternating biological and chemical fungicides can offer effective disease control while maintaining good yield performance (Fravel, 2005; Calvo et al., 2014). Biological treatments alone, such as T3 (*Trichoderma* base) and T4 (*Bacillus* base), led to moderate improvements over the untreated control (T10), though they were less effective compared to chemical fungicides.

Throughout the first three harvests (Weeks 8, 10, and 12), the non-marketable yield remained consistently low across nearly all treatments, suggesting effective early disease suppression. Most treatments recorded only minimal fruit losses during these periods, including the untreated control (T10), likely due to low initial disease pressure. However, by Week 14, a notable increase in non-marketable yield was observed under several treatments. Specifically, T4 (Bacillus Care), T6 (Amistar®), T7 (Tricho Care/Kocide), T8 (Bacillus Care alternating with Amistar®), and particularly the untreated control (T10) exhibited visibly higher levels of non-marketable fruits, both in terms of number and weight. This suggests that these treatments were less effective in controlling fruit rot symptoms during the later stages of the crop cycle when disease pressure may have increased. In contrast, treatments such as T1 (Garlic oil), T2 (Neem oil), T3 (Tricho Care), and T5 (Kocide™ 2000) maintained low non-marketable yields even in Week 14, indicating stronger or more persistent disease control capabilities. This pattern highlights the importance of sustained disease management to prevent late season rot, which can otherwise reduce overall marketable yield.

The yield performance of *Terung Rapuh* under ten different fungicide treatments indicate that, among all the treatments, T1 (Bio-Guard) showed the most prominent result, producing the highest number of marketable fruits and heaviest fruit weight in Week 17**,** while maintaining moderate performance in Weeks 12 and 20 (Figure 22). This suggests that Bio-Guard may be particularly effective during the peak fruiting stage. Treatment T6 (Neem oil + Bio-Guard) also showed a stable yield pattern across all weeks, with moderate to high fruit counts and weights, indicating consistent disease suppression and yield potential.

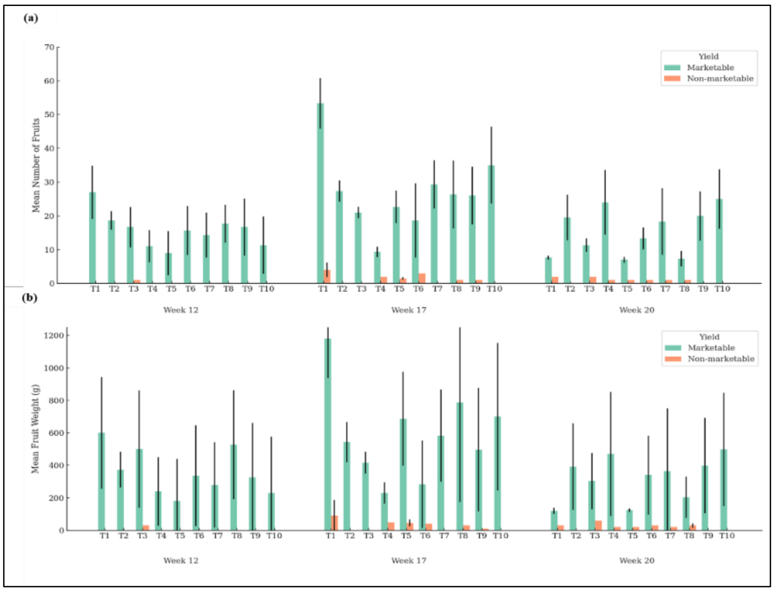

Fig. 22: Mean number of fruits (a) and mean fruit weight (b) of *Terung Rapuh* under different fungicide treatments (T1–T10) across three harvest weeks. Yields are categorized into marketable (green) and non-marketable (orange) fruits. Error bars indicate standard error.

In addition, integrated treatments such as T7 (Garlic oil alternating with Amistar®) and T8 (Bio-Guard alternating with Amistar®) performed consistently across the three weeks, particularly in terms of maintaining fruit weight and keeping non-marketable yield low. These results highlight the benefit of combining biocontrol agents with systemic fungicides for sustained crop protection. Additionally, integrated treatments T7 and T8 also demonstrated moderate to low leaf blight disease severity throughout the season. These results support the growing body of research promoting IDM strategies, which combine biological and chemical control methods to reduce disease pressure while minimizing environmental risks (Fravel, 2005; Calvo et al., 2014). Surprisingly, T9 (Amistar®) alone did not show strong yield performance in this yield dataset, suggesting that while it may be effective in leaf blight disease control, it may not always translate to yield gains when used alone under field conditions. Non-marketable yields, representing fruits affected by disease symptoms such as rot, remained low across most treatments. The lowest non-marketable yields were observed in T2, T6, T7, and T9, suggesting strong disease suppression.

The comparison between disease severity and yield across treatments reveals a strong inverse relationship between treatments that effectively controlled foliar blight also achieved better yield outcomes. This relationship aligns with previous findings that foliar diseases in eggplant, particularly those caused by *P. vexans*, can reduce photosynthetic area and promote fruit rot, leading to losses of up to 40–70% if unmanaged (Dhariwal et al., 2021). Therefore, fungicide treatments especially those combining systemic chemical agents with natural biocontrol are vital not only to control leaf blight but also to ensure high marketable yield and fruit quality.

Overall, the study confirms a strong inverse relationship between disease severity and marketable yield in eggplant cultivation. Chemical fungicides and integrated approaches were most effective in reducing fruit rot and leaf blight symptoms, thus improving yield outcomes. Sustainable disease management practices incorporating both efficacy and environmental considerations remain critical for long-term crop productivity

4.0 Conclusion

This study confirms that *P. vexans* is the primary fungal pathogen affecting traditional Malaysian eggplant varieties, *terung telunjuk* and *terung rapuh*, causing significant leaf blight and fruit rot. *In vitro* tests showed that biofungicides containing *Trichoderma* spp. and *Bacillus* spp. were most effective, while botanical extracts like moringa, neem, and garlic also demonstrated strong antifungal activity. Field trials revealed that integrated treatments particularly combinations of biofungicides with azoxystrobin or copper hydroxide had significantly reduced disease severity and improved yield. These findings highlight the importance of IDM as a sustainable and effective approach for protecting traditional eggplant cultivars and ensuring long-term crop productivity. These results support the adoption of IDM approaches as sustainable and effective alternatives to chemical-only disease control, especially for preserving traditional eggplant cultivars. Future research should explore long-term field evaluations and the development of resistant varieties.

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Conflict of Interest

The authors declare no conflict of interest.

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