Knowex Food and Agriculture
Vol.3, No.1, 33-49, 2026, ISSN 2682-728X (Online)

DOI: https://doi.org/10.17501/2682728X.2026.3104

Integration of Fungicides and Crop Cultivars for Management of Cowpea Root Rot in Batticaloa, Sri Lanka

Satheer S, Sahma ALFS and Prasannath K*

Department of Agricultural Biology, Faculty of Agriculture, Eastern University, Sri Lanka

Abstract: Cowpea is a major grain legume cultivated in the drier regions of Sri Lanka. Its plant stand and yield are adversely affected by root infections resulting from soil-borne pathogenic fungi. Cowpea production is severely constrained by Fusarium root rot caused by *Fusarium solani*. This study hypothesized that integrating resistant cowpea cultivars with fungicides could improve disease management under field conditions in Batticaloa. Experiments were conducted to evaluate the integrated use of four cowpea cultivars (*Bombay*, *Dhawala*, *Waruni*, and *Wijaya*) and three fungicides (captan, homai, and topsin) for managing Fusarium root rot. The study was arranged in a factorial randomized complete block design with 16 treatments and three replications. Before the field experiment, an *in vitro* study was conducted to culture *F. solani* on potato dextrose agar. After culturing, the pathogen was inoculated by soil drenching, followed by fungicide application to evaluate cultivar–fungicide interactions. Disease incidence, disease severity, total grain weight, 100-seed weight, and total dry pod weight were recorded. The *Bombay* × topsin combination significantly reduced disease severity. Among the cultivars, *Wijaya* recorded the lowest disease incidence and severity and the highest grain yield. Topsin and homai effectively reduced disease incidence and severity while improving grain yield. Overall, *Wijaya* combined with topsin or homai was identified as the most effective strategy for managing Fusarium root rot in cowpea under Batticaloa conditions. These findings provide a practical integrated disease management strategy to reduce yield losses and promote sustainable cowpea production in Sri Lanka.

Keywords: Cowpea, cultivar resistance, disease severity, fungicide, Fusarium root rot

1. Introduction

In rice-based cropping systems, grain legumes such as cowpea, mung bean, black gram, and groundnut are increasingly used as they do biological nitrogen fixation (BNF) and provide high-value food grains. Sri Lanka depends heavily on vegetables and legumes for nutrition, with about 75% of dietary protein sourced from plant-based foods (Jayathilake *et al*., 2018). Despite their importance, domestic production of pulses remains insufficient, requiring costly imports such as lentils and chickpeas. Cowpea, mung bean, black gram, and groundnut are the main pulses grown in approximately 80,000 acres; however, yields remain low (700–800 kg/ha) due to drought stress, inadequate N-P-K inputs, pest and disease damage, and lack of improved locally adapted varieties. Improving legume production is therefore vital to enhance national food security. Cowpea is cultivated on around 25,000 acres in dry zone of Sri Lanka (Senaratne *et al*., 1998; Hewavitharana *et al*., 2010). Cowpea improves soil fertility mainly through biological nitrogen fixation (BNF), while its deep root system also enhances the uptake and recycling of phosphorus (P) and potassium (K), contributing to improved soil nutrient availability (Stagnari *et al*.,

*Corresponding author's email: *prasannathk@esn.ac.lk*

2017; Goyal *et al*., 2021). It can fix 80–90 kg N/ha in association with effective rhizobia, improving soil fertility and increasing yields of subsequent cereal crops. This process occurs through the formation of root nodules, where *Rhizobium* bacteria establish a symbiotic association with the plant roots and convert atmospheric nitrogen through BNF. The root infections by *Fusarium solani* can damage the root system, reduce effective nodulation and nitrogen fixation, thereby affecting plant growth and yield. However, nitrogen benefits depend on the balance between BNF and grain nitrogen removal; soil nitrogen can be depleted if more N is taken away in harvested seeds (Eaglesham *et al*., 1982). Therefore, maximizing nitrogen fixation is necessary to support sustainable farming. *F. solani* and *Rhizoctonia solani* are the major soil-borne pathogens causing cowpea root rot, resulting in poor stand establishment and significant yield loss (Dubey *et al*., 2012). Fusarium root rot spreads through wind, irrigation water, machinery, and contaminated seed (Shrestha *et al*., 2016). Symptoms of fungal invasions appear with reddish-brown lesions on roots, leading to stunting, chlorosis, and reduction in lateral roots. Severe infections may reduce cowpea yields by 50–75% (Nakedde *et al*., 2016). The disease is favoured by soil compaction, poor drainage, drought stress, and high plant densities. Although fungicides are widely used to manage soil-borne diseases, their continuous use raises environmental and health concerns (Abd Allah *et al*., 2011). Thus, integrating resistant cultivars with effective chemical management is necessary for sustainable disease control. In the Batticaloa district, Fusarium root rot causes major productivity losses in cowpea. Therefore, identifying fungicide-cultivar combinations that reduce disease severity while supporting farmer-preferred varieties is essential for improved production.

Previous studies have evaluated resistant cowpea cultivars or fungicides separately for the management of Fusarium root rot (Namasaka *et al*., 2017; Ramusi *et al*., 2017). However, limited information is available on the combined performance of different cowpea cultivars and fungicides under field conditions in Sri Lanka, particularly in the Batticaloa district. Understanding cultivar-fungicide interactions is important for developing effective and economically feasible disease management strategies. It was hypothesized that integrating resistant cowpea cultivars with effective fungicides would significantly reduce Fusarium root rot incidence and severity while improving cowpea yield compared with susceptible cultivars or untreated plants. The objectives of this study are to evaluate the efficacy of selected fungicides in minimizing the impact of Fusarium root rot on different cowpea cultivars grown in Batticaloa, to determine the relative susceptibility of these cultivars to the disease, and to assess the interaction between fungicide treatments and cultivar performance in terms of reducing disease incidence and severity. The findings of this study will contribute to the development of integrated disease management practices that enhance sustainable cowpea production, reduce dependence on repeated fungicide applications, and improve food security in Sri Lanka.

2. Materials and Methods

The present study was conducted to evaluate the effectiveness of selected fungicides in controlling Fusarium root rot disease in cowpea cultivars grown under Batticaloa district conditions. The study consisted of *in vitro* experiments for pathogen isolation, purification and inoculum preparation, followed by *in vivo* experiments to evaluate fungicide–cultivar interactions under field conditions.

2.1 Experimental site

Laboratory activities including fungal isolation, purification, and pathogenicity confirmation, were carried out in the Laboratory of the Department of Agricultural Biology. The field study was carried out at the Field of the Department of Agricultural Biology, Faculty of Agriculture, Eastern University Sri Lanka at Palacholai in the Eastern Province of Sri Lanka, from September to November of 2022. The experiment site belongs to the Agro-Ecological Zone of the Low Country Dry Zone and is located at latitude 7° 73' N and longitude 81° 67' E (DL2). It is 8.52 m above sea level. The annual mean temperature in the location is 29.6 °C and ranges from 26 °C to 31.6 °C. The annual mean rainfall is 214 mm. The humidity in this area is 77%. The soil type is sandy regosol in this location.

2.2 Pathogen isolation and identification

Cowpea plants exhibiting typical Fusarium root rot symptoms (yellowing, stunted growth, and reddish-brown lesions on roots) were collected from infested fields in the Eastern University Research Farm. Root samples were washed under tap water to remove soil, surface-sterilized with 1% sodium hypochlorite for 1 minute, rinsed thrice with sterile distilled water, and blotted dry. Small pieces (5–7 mm) from the lesion margins were placed on Potato Dextrose Agar (PDA) plates amended with streptomycin (50 mg/L) to suppress bacterial contamination. Cultures were incubated at 28±2 °C for 5–7 days. Pure cultures were obtained through hyphal tip subculturing and identified by their cottony white to pinkish mycelium (Figure 1), curved 3–5 septate macroconidia, and chlamydospore formation. Microscopic examination was performed using lactophenol cotton blue staining. The pathogen was confirmed as *F. solani*.

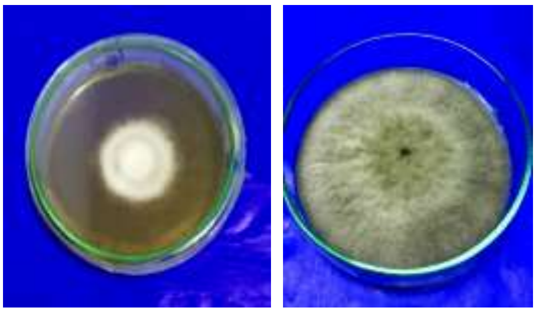

Figure 1. Pure culture of two-day-old (left) and five-day-old (right) F. solani

2.3 Preparation of conidial suspension

Seven-day-old fungal colonies were flooded with 10 mL sterile distilled water and gently scraped using a sterile spatula to release spores. The suspension was filtered through sterile muslin cloth and adjusted to 10^5 conidia/mL using a hemocytometer. This suspension served as the inoculum for field inoculation.

2.4 Collection of seeds

The four cultivars of cowpea, *Bombay*, *Dhawala*, *Waruni,* and *Wijaya*, were used for this study, and seeds were collected from the Seed Unit of the Research Farm, Eastern University, Sri Lanka.

2.5 Seed germination test

The four selected cowpea cultivars were subjected to a seed germination test by placing 20 seeds randomly on moist tissue paper in Petri dishes, which were then covered. Seeds were incubated at 28±2 °C for 7 days. Thereafter, the seed germination percentage was calculated.

2.6 Field experiment layout

Experimental soil was sandy loam with good drainage, pH 6.4–6.8, and moderate organic matter. The field experiment was conducted using a factorial Randomized Complete Block Design (RCBD) with 16 treatment combinations (four cultivars (C) × four fungicide (F) levels, including an untreated control), replicated three times, for a total of 48 plots (Figure 2). Each plot measured 1.5 m × 2.0 m, with plants spaced at 40 cm × 25 cm, accommodating 16 plants per plot. A border spacing of 0.5 m was maintained between plots to minimize treatment interference. Prior to sowing, seedbeds were thoroughly ploughed and levelled. Two seeds were sown per hill and later thinned to one healthy plant per hill after emergence.

2.7 Inoculation of fungal root rot pathogen to the plants

Three-week-old seedlings cultivated in a research field were inoculated by root drench with 5 mL of conidial suspension (10^5 conidia/mL) to assess pathogenicity. Following inoculation, the seedlings were grown in a field at ambient temperature 28±2 °C.

2.8 Preparation of fungicide solution and application

Based on the application rate and application interval prescribed by the manufacturer, 36 g of homai (Thiophanate-methyl + thiram) fungicide was dissolved in 36 L of water. Every cultivar of cowpea in three blocks was root drenched with the solution thrice at 10-day intervals. The first application was done seven days after the soil inoculation.

According to the recommended application rate and application frequency prescribed by the manufacturer, 22 g of topsin (Thiophanate-methyl 70% WP) fungicide was dissolved in 36 L of water, and the solution was then applied by root drench to each cultivar of cowpea in three blocks thrice at 10-day intervals. The first application was done seven days after the soil inoculation.

The preparation and application of captan (N-trichloromethylthio- 4 –cyclohexane- 1,2- dicarboximide) solution followed a similar process. An amount of 44 g of fungicide was dissolved in 36 L of water to formulate the solution. The four cowpea cultivars were planted in three blocks, and the root drenching method was used to apply the solution to the plants thrice at 10-day intervals. The initial application was done seven days after soil inoculation.

2.9 Treatment structure

The field experiment consisted of a two-factor factorial arrangement using four cowpea cultivars and four fungicide treatments (Figure 2). The cultivars included *Bombay* (C_1), *Dhawala* (C_2), *Waruni* (C_3), and *Wijaya* (C_4), while the fungicide treatments comprised no fungicide application as the control (F_0), Homai (F_1), Topsin (F_2), and Captan (F_3). Each cultivar was combined with each fungicide treatment, resulting in a total of 16 treatment combinations, namely: C_1F_0 (*Bombay* without fungicide), C_2F_0 (*Dhawala* without fungicide), C_3F_0 (*Waruni* without fungicide), C_4F_0 (*Wijaya* without fungicide), C_1F_1 (*Bombay* with Homai), C_2F_1 (*Dhawala* with Homai), C_3F_1 (*Waruni* with Homai), C_4F_1 (*Wijaya* with Homai), C_1F_2 (*Bombay* with Topsin), C_2F_2 (*Dhawala* with Topsin), C_3F_2 (*Waruni* with Topsin), C_4F_2 (*Wijaya* with Topsin), C_1F_3 (*Bombay* with Captan), C_2F_3 (*Dhawala* with Captan), C_3F_3 (*Waruni* with Captan), and C_4F_3 (*Wijaya* with Captan).

C2F0	C4F2	C2F2	C1F1	BLOCK- 01
C4F3	C2F1	C1F0	C4F1	
C3F0	C1F2	C3F3	C3F2	
C2F3	C3F1	C1F3	C4F0	
C4F2	C3F0	C2F3	C4F1	BLOCK- 02
C3F1	C2F2	C1F1	C2F0	
C1F0	C4F3	C3F2	C1F3	
C3F3	C1F2	C4F0	C2F1	
C3F2	C1F1	C4F3	C3F0	BLOCK- 03
C2F0	C1F3	C3F3	C4F2	
C4F1	C2F2	C1F0	C3F1	
C1F2	C4F0	C2F3	C2F1	

Figure 2. Treatment structure

2.10 Data collection

The disease incidence in each experimental unit was recorded seven days after the first and second fungicide applications based on the number of plants in each plot exhibiting yellowing of the lower leaves. Seven days after the third fungicide application, the plants were uprooted, and disease incidence was estimated based on the number of plants in each plot showing visible sunken reddish-brown lesions on the roots. According to these symptoms, the incidence of Fusarium root rot was calculated using the following formula.

$$\text{Disease incidence}=\frac{\text{Number of infected plants in the experimental unit}}{\text{Total number of plants in the experimental unit}}\times 100\%$$

Disease severity was assessed individually for each plant within every experimental unit using two approaches: the proportion of yellowing lower leaves relative to the total number of leaves per plant (seven days after the first and second fungicide applications), and the ratio of taproot length to the length of the sunken, reddish-brown lesion in uprooted plants (seven days after the third fungicide application) (Figure 3).

Figure 3. Measuring length of sunken reddish-brown lesion on taproot

Based on these measurements, disease severity for each experimental unit was calculated using the severity values of infected individual plants based on the following formula.

$$\text{Disease severity}=\frac{\text{Sum of disease severity of infected plants in the experimental unit}}{\text{Total number of plants in the experimental unit}}\times 100\%$$

Growth and yield parameters were assessed to evaluate the performance of cowpea under different treatments. Growth parameters included plant height (cm), number of leaves per plant, and number of branches per plant. Yield parameters comprised total seed weight per plant, 100-seed weight, and dry weight of pods.

2.11 Statistical analysis

Data on percentage disease incidence and disease severity were subjected to arcsine square root transformation to stabilize variance. Interaction and significance of treatment effects on the measured variables were determined by analysis of variance (ANOVA) using MINITAB 19 statistical software. Treatment means were compared using Tukey's test at 5% significant level.

3. Results

3.1 Evaluation of disease incidence and severity seven days after the first application of fungicides

Seven days after the first fungicide application, disease incidence and severity did not show significant differences ($p > 0.05$) among the four cowpea cultivars, indicating a similar level of susceptibility at the early growth stage (Table 1). Disease incidence ranged from 9.9% in *Bombay* to 17.2% in *Wijaya*, while disease severity remained low across all cultivars (1.4–2.8%). A strong positive relationship was observed between disease incidence and disease severity ($R^2 = 0.805$; $r = 0.897$), indicating that 80% of disease incidence could be predicted by disease severity.

Table 1. Disease incidence and severity seven days after the first fungicide application

Cultivar	Disease incidence (%)	Disease severity (%)
Bombay	9.9 ± 11.4	1.4 ± 1.9
Dhawala	13.5 ± 9.9	2.1 ± 1.4
Waruni	15.6 ± 10.1	2.4 ± 2.3
Wijaya	17.2 ± 10.3	2.8 ± 2.9

3.2 Effects of cultivars and fungicides on disease incidence and severity seven days after the second application of fungicides

Seven days after the second fungicide application, disease incidence based on yellowing of lower leaves showed no significant interaction ($p > 0.05$) between cultivars and fungicides; disease incidence showed no significant cultivar × fungicide interaction ($p > 0.05$), but the main effects of cultivar and fungicide were both significant ($p < 0.05$) (Table 2). Among cultivars, *Waruni*, *Dhawala*, and *Wijaya* disease incidence did not differ significantly, whereas *Bombay* exhibited significantly lower disease incidence. Under fungicide effects, application of homai significantly reduced disease incidence compared to the untreated control, while application of captan and topsin showed no significantly different outcomes. In contrast, disease severity showed a significant interaction between cultivars and fungicides ($p < 0.05$), along with significant main effects (Table 2).

Table 2. Disease incidence and severity seven days after the second fungicide application

		Disease incidence (%)	Disease severity (%)
Main effects			
Cultivars (C)	*Bombay*	5.2 ± 8.3^{b}	0.5 ± 0.6^{c}
	Dhawala	15.1 ± 9.4^{a}	2.9 ± 1.0^{a}
	Waruni	15.6 ± 8.6^{a}	2.8 ± 1.4^{a}
	Wijaya	9.4 ± 9.4^{ab}	1.4 ± 0.8^{b}
		*	*
Fungicides (F)	Homai	7.3 ± 7.4^{b}	1.1 ± 0.9^{c}
	Topsin	8.9 ± 9.0^{ab}	1.6 ± 1.5^{bc}
	Captan	11.5 ± 11.5^{ab}	2.7 ± 1.7^{a}
	Non- fungicidal	17.7 ± 7.9^{a}	2.1 ± 0.9^{ab}
		*	*
Interaction (C×F)			
Cultivars (C)	Fungicides (F)		
Bombay	Homai	2.1 ± 3.6	0.1 ± 0.1^{e}
	Topsin	0.0 ± 0.0	0.0 ± 0.0^{e}
	Captan	2.1 ± 0.0	0.6 ± 0.5^{de}
	Non- fungicidal	16.7± 9.5	1.1 ± o.8^{cde}
Dhawala	Homai	11.0 ± 9.5	1.9 ± 1.2^{bcde}
	Topsin	18.8 ± 6.2	3.6 ± 1.2^{ab}
	Captan	12.5 ± 12.5	2.8 ± 0.6^{bc}
	Non- fungicidal	18.8 ± 10.8	3.31± 0.1^{ab}
Waruni	Homai	10.4 ± 9.5	1.8 ± 0.3^{bcde}
	Topsin	10.4 ± 9.5	2.0 ± 0.4^{bcde}
	Captan	25.0 ± 0.0	5.1 ± 0.2^{a}
	Non – fungicidal	16.7 ± 3.6	2.2 ± 0.6^{bcd}
Wijaya	Homai	6.3 ± 6.2	0.7 ± 0.4^{de}
	Topsin	6.3 ± 6.2	0.8 ± 1.0^{de}
	Captan	6.3 ± 10.8	2.2 ± 0.1^{bcd}
	Non -fungicidal	18.8 ± 10.8	1.8 ± 0.2^{bcde}
		n.s	*

*Different letters indicate significant differences between means according to Tukey's test at the 5% significant level; n.s – not significant; * significant*

The highest severity was observed in *Waruni* with captan, *Dhawala* with topsin, and *Dhawala* under no fungicide application, while the lowest severity was recorded in *Bombay* treated with homai and topsin. This indicates that combining resistant cultivars with effective fungicides (homai and topsin) can significantly reduce disease severity.

3.3 Effects of cultivars and fungicides on disease incidence and severity seven days after the third application of fungicides

Seven days after the third fungicide application, disease incidence based on root rot lesions showed no significant cultivar × fungicide interaction ($p > 0.05$), whereas the main effects of cultivar and fungicide were significant ($p < 0.05$) (Table 3).

Table 3. Disease incidence and severity seven days after the third fungicide application

		Disease incidence (%)	Disease severity (%)
Main effects			
Cultivars (C)	*Bombay*	31.8 ± 10.8^{ab}	4.6 ± 1.3^{b}
	Dhawala	33.4 ± 22.8^{ab}	7.9 ± 4.1^{a}
	Waruni	44.8 ± 17.4^{a}	6.8 ± 2.7^{a}
	Wijaya	20.3 ± 8.0^{b}	3.9 ± 1.1^{b}
		*	*
Fungicides (F)	Homai	32.9 ± 15.6^{ab}	6.5 ± 2.6^{ab}
	Topsin	24.5 ± 15.4^{b}	3.3 ± 0.9^{c}
	Captan	30.7 ± 17.4^{ab}	5.9 ± 1.8^{b}
	Non- fungicidal	42.2 ± 21.1^{a}	7.5 ± 4.1^{a}
		*	*
Interaction (C×F)			
Cultivars (C)	Fungicides (F)		
Bombay	Homai	33.3 ± 9.5	4.7 ± 0.4^{cde}
	Topsin	29.2 ± 15.7	3.4 ± 0.2^{de}
	Captan	27.1 ± 13.0	4.7 ± 1.4^{cde}
	Non- fungicidal	37.5 ± 6.2	5.3 ± 2.1^{cde}
Dhawala	Homai	43.9 ± 20.1	10.8 ± 0.4^{ab}
	Topsin	14.6 ± 9.5	2.2 ± 0.9^{e}
	Captan	25.0 ± 6.2	6.4 ± 0.7^{cd}
	Non- fungicidal	50.0 ± 31.3	12.1 ± 1.7^{a}
Waruni	Homai	29.2 ± 19.1	5.1 ± 1.4^{cde}
	Topsin	41.7 ± 9.5	4.1 ± 0.5^{de}
	Captan	47.9 ± 19.1	8.1 ± 1.6^{bc}
	Non – fungicidal	60.4 ± 9.5	10.1 ± 1.7^{ab}
Wijaya	Homai	25.0 ± 6.2	5.3 ± 0.5^{cde}
	Topsin	12.5 ± 6.2	3.6 ± 0.3^{de}
	Captan	22.9 ± 9.5	4.3 ± 0.5^{de}
	Non -fungicidal	20.8 ± 7.2	2.6 ± 0.2^{e}
		n.s	*

*Different letters indicate significant differences between means according to Tukey's test at the 5% significant level; n.s – not significant; * significant.*

Among cultivars, *Waruni* recorded the highest disease incidence, whereas *Wijaya* showed the lowest, although *Bombay*, *Dhawala*, and *Wijaya* were statistically similar. Under fungicide effects, topsin caused a significant reduction in disease incidence compared to the untreated control, recording the lowest incidence, while the effects of homai and captan were statistically similar to the control.

In contrast, disease severity assessed seven days after the third fungicide application showed a significant cultivar × fungicide interaction ($p < 0.05$), as well as significant main effects of cultivar and fungicide (Table 3). The highest disease severity was observed in *Dhawala* under non-fungicidal treatment, while lower severity was recorded in treatments combining effective fungicides with relatively resistant cultivars. *Wijaya* under non-fungicidal treatment and *Dhawala* under topsin showed comparable effects but differed significantly from *Dhawala* without fungicide application. Overall, cultivars *Bombay* and *Wijaya* exhibited lower disease severity, whereas cultivars *Waruni* and *Dhawala* showed higher severity. Among fungicides, topsin was the most effective in reducing disease severity, showing notable differences from captan and the untreated control.

3.4 Yield and yield components

Total seed weight after three harvestings showed no significant cultivar × fungicide interaction ($p > 0.05$), whereas the main effects of cultivar and fungicide were significant ($p < 0.05$) (Table 4). Among cultivars, *Wijaya* recorded the highest total seed weight and differed significantly from the others, whereas *Dhawala* and *Waruni* were statistically similar but significantly higher than *Bombay*, which showed the lowest yield. Results of treatments of fungicides, topsin, captan, and homai were statistically similar, but all produced significantly higher yields (seed weight) than the control.

In contrast, 100-seed weight showed a significant cultivar × fungicide interaction ($p < 0.05$), as well as significant main effects of cultivar and fungicide (Table 4). *Dhawala* treated with topsin and homai recorded the highest seed weight, while *Bombay* under all fungicide treatments, showed consistently lower values. Among cultivars, *Dhawala* had the highest 100-seed weight, followed by *Wijaya* and *Waruni*, whereas *Bombay* recorded the lowest. Under fungicide effects, homai and topsin performed similarly and produced higher seed weights, while captan resulted in comparatively lower values.

Similarly, the total dry weight of pods showed significant differences ($p < 0.05$) among cultivars, with *Dhawala*, *Waruni*, and *Wijaya* performing significantly better than *Bombay*, which recorded the lowest values (Table 4).

Table 4. Evaluation of 100-seed weight, total seed weight and total dry weight of pods after three harvestings

		100-seed weight (g)	Total seed weight (g)	Total dry weight of pods (g)
Main effects				
Cultivars (C)	*Bombay*	9.7 ± 0.6[c]	130.0 ± 19.2[c]	316.7 ± 63.4[b]
	Dhawala	20.2 ± 1.3[a]	216.5 ± 23.3[b]	556.6 ± 50.4[a]
	Waruni	13.8 ± 0.7[b]	211.2 ± 38.4[b]	593.8 ± 84.0[a]
	Wijaya	14.3 ± 0.7[b]	265.1 ± 29.6[a]	579.2 ± 109.7[a]
		*	*	*
Fungicides (F)	Homai	14.9 ± 3.9[a]	213.6 ± 55.9[a]	508.7 ± 121.8
	Topsin	14.9 ± 4.6[a]	219.5 ± 23.3[a]	522.9 ± 143.6
	Captan	13.9 ± 3.8[b]	214.2 ± 38.4[a]	489.6 ± 142.4
	Non- fungicidal	14.2 ± 3.2[ab]	175.4 ± 46.7[b]	525.0 ± 158.8
		*	*	n.s
Interaction (C×F)				
Cultivars (C)	Fungicides (F)			
Bombay	Homai	9.9 ± 0.7[e]	139.1 ± 32.6	341.7 ± 57.7
	Topsin	9.4 ± 0.4[e]	125.6 ± 20.6	308.3 ± 38.2
	Captan	9.2 ± 0.5[e]	135.7 ± 13.8	333.3 ± 112.7
	Non- fungicidal	10.3± 0.6[e]	119.6 ± 2.40	283.3 ± 38.2
Dhawala	Homai	20.7 ± 0.5[ab]	204.7 ± 16.1	559.8 ± 52.0
	Topsin	21.6 ± 1.3[a]	232.2 ± 15.7	575.0 ± 43.3
	Captan	19.4 ± 0.9[b]	236.3 ± 11.4	550.0 ± 50.0
	Non- fungicidal	19.0 ± 0.5[b]	192.8 ± 21.4	541.7 ± 76.4
Waruni	Homai	14.5 ± 0.1[cd]	235.3 ± 16.3	583.3 ± 125.8
	Topsin	13.5 ± 0.5[cd]	242.6 ± 16.2	625.0 ± 75.0
	Captan	13.0 ± 0.7[d]	206.7 ± 5.5	541.7 ± 76.4
	Non – fungicidal	14.0 ± 0.5[cd]	160.0 ± 35.1	625.0 ± 66.1
Wijaya	Homai	14.5 ± 0.4[cd]	275.4 ± 27.9	550.0 ± 43.3
	Topsin	15.1 ± 0.5[c]	277.7 ± 26.5	583.3 ± 101.0
	Captan	13.8 ± 0.8[cd]	278.3 ± 15.1	533.3 ± 204.0
	Non -fungicidal	13.7 ± 0.4[cd]	229.0 ± 22.7	650.0 ± 25.0
		*	n.s	n.s

*Different letters indicate significant differences between means according to Tukey's test at the 5% significant level; n.s – not significant; * significant.*

4. Discussion

Disease incidence and severity assessed seven days after the first fungicide application did not differ significantly among the four cowpea cultivars, indicating that all cultivars exhibited a similar level of susceptibility during the early growth stage. The absence of significant variation suggests that resistance mechanisms were not fully expressed immediately after infection and that environmental conditions may have contributed to a uniform disease response among cultivars. During the early stages of infection, resistance mechanisms such as cell wall reinforcement, activation of defense-related enzymes, and antimicrobial compound production may not be fully expressed (Andersen *et al*., 2018), resulting in similar disease responses among cultivars. As host–pathogen interactions progress, genetic differences in resistance become more evident, leading to greater variation in disease development among cultivars. Similar observations have been reported by Snapp *et al.* (2003), who noted that varietal differences in disease response often become more evident at later stages of plant growth. Furthermore, the strong positive relationship observed between disease incidence and severity ($R^2 = 0.805$; $r = 0.897$) indicates that increased infection levels were directly associated with greater disease damage, supporting previous findings on disease progression in legume crops (Bock *et al.,* 2010).

After the second fungicide application, considerable variations in treatment response were observed among the cultivars and the treatments. *Bombay* was found to be considerably less infected and diseased than the other cultivars, an indication of its resistance to Fusarium root rot. Host resistance was identified as a significant method of controlling the disease. Boukar *et al.* (2019) demonstrated that resistant cultivars play a pivotal role in the management of Fusarium root rot by lowering the levels of infection and disease severity. The present study also revealed that homai and topsin reduced disease levels more effectively than captan and the untreated. Topsin is a systemic fungicide that inhibits fungal cell division by disrupting microtubule formation, allowing protection of newly developing roots. Homai also effectively suppresses soil-borne pathogens through its broad-spectrum fungicidal activity, reducing pathogen establishment and disease progression (Abdulhassan and Abass, 2025). The interaction effect between cultivar and treatment was also significant, an indication that the level of effectiveness of a particular fungicide depended on the susceptibility of the cultivar to the disease. The best combination of treatment and resistant cultivar recorded the lowest percentage of disease severity. The combined effect of using resistant cultivars and effective fungicides in the management of Fusarium root rot was established by Carolan *et al.* (2017). They demonstrated that the integration of both control measures reduced the rate of infection and inoculum production.

The results obtained after repeated fungicide applications further demonstrated the importance of integrated disease management. Significant differences in disease incidence and severity were observed among cultivars and fungicides, with *Bombay* and *Wijaya* generally exhibiting lower disease severity than *Dhawala* and *Waruni*. These differences may be associated with variations in root structure.

Resistant cultivars often have stronger root architecture, greater lignification, and increased production of defense-related metabolites, which restrict fungal penetration and colonization (Cardoni *et al.*, 2022). As plants mature, these defense mechanisms become more effective, contributing to lower disease incidence and severity. Thangavelu and Mustapha (2010) reported that resistance to root diseases often increases with plant age and root development. Among the fungicides, topsin was the most effective treatment, significantly reducing disease incidence and severity compared with captan and the untreated control. The superior performance of topsin agrees with the findings of Vatchev and Maneva (2012), who reported its effectiveness in controlling root rot diseases and reducing plant mortality. The results also indicate that repeated fungicide applications improve disease suppression under field conditions; however, fungicides alone cannot fully compensate for highly susceptible cultivars, emphasizing the importance of cultivar selection.

Yield and yield-related parameters were notably influenced by both cultivar and fungicide application. *Wijaya* produced the highest total seed weight, which corresponded with its relatively lower disease incidence and severity. This relationship suggests that reduced disease pressure contributes directly to improved crop productivity. Similar observations were reported by Rouse (1998), who demonstrated the negative impact of disease development on crop yield. The significant differences observed in hundred-seed weight among cultivars and fungicide treatments indicate that both genetic factors and disease intensity influence seed development. *Dhawala* treated with topsin and homai produced the highest seed weights, indicating that effective disease management increases seed filling and improves the allocation of assimilates to developing seeds. Similarly, Olorunwa *et al.* (2023) reported that plant health and physiological resource allocation play important roles in seed development and final seed weight. Likewise, the higher pod dry weight observed in *Dhawala*, *Waruni*, and *Wijaya* compared with *Bombay* may be attributed to genetic characteristics and environmental factors affecting pod development. Barros *et al*. (2022) reported that environmental conditions during pod formation play a major role in determining pod growth and final yield, with temperature being one of the key climatic factors influencing cowpea growth, development, and grain yield.

Overall, the findings demonstrate that both genetic resistance and chemical control play important roles in the management of Fusarium root rot in cowpea. Although all cultivars exhibited similar susceptibility during the early stages following inoculation, differences became more apparent after fungicide application and disease progression. Among all the cultivars tested, *Wijaya* had a lower incidence of disease along with good yields, suggesting higher adaptability under disease conditions. The application of fungicides on a recurring basis further increased disease suppression. The integration of resistant cultivars with effective fungicides, particularly topsin and homai, provides a more sustainable and effective strategy for managing Fusarium root rot and improving cowpea productivity under field conditions. Similar conclusions were reported by Moparthi (2016), who highlighted the superiority of integrated disease management approaches over individual control measures. Higher disease severity was associated with reduced yield, confirming the negative impact of Fusarium root rot on crop productivity. Cultivar *Wijaya* produced the highest grain yield, supporting its dual advantage of moderate resistance and better yield potential under field conditions.

5. Conclusions and Future Prospects

The study demonstrated that integrating fungicides with cowpea cultivars effectively reduced Fusarium root rot under field conditions in Batticaloa. Significant interaction effects between cultivars and fungicides influenced disease incidence, severity, and grain yield. Among the cultivars, *Wijaya* exhibited the best overall performance, with lower disease incidence and severity and the highest grain yield under disease pressure, while homai and topsin were more effective than captan in disease suppression. These findings indicate that integrating the *Wijaya* cultivar with homai or topsin is effective for managing Fusarium root rot in cowpea. The *Wijaya* cultivar combined with homai or topsin fungicide is recommended for effective and sustainable management of Fusarium root rot of cowpea under field conditions in Batticaloa, Sri Lanka. Future research should also assess the economic feasibility of these management practices and their long-term effects on crop productivity and soil health.

Declaration of Generative AI and AI-Assisted Technologies

The authors declare that no generative AI or AI-assisted technologies were used in the preparation, writing, or editing of this manuscript. The authors maintained complete responsibility and oversight throughout the research and writing process, and assume full accountability for the content of the published work.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

Financial support from the Department of Agricultural Biology, Faculty of Agriculture, Eastern University, Sri Lanka, is acknowledged.

Author Contributions

Satheer S: Experimental Work (100%) and Data analysis (70%)
Sahma ALFS: Data Analysis (30%) and Writing (70%)
Prasannath K: Conceptualization (100%) and Writing (30%)

References

Abd Allah, E. F., Hashem, A., Bahkali, A. H., & Al-Huqail, A. (2011). First report of black root rot disease (*Thielaviopsis basicola*) of carrot in Saudi Arabia. *African Journal of Microbiology Research, 5*(18), 2867–2869. https://doi.org/10.5897/AJMR11.107

Abdulhassan, H. A., & Abass, M. H. (2025). Pathogenic and molecular characterization of *Rhizoctonia solani* Kühn from wheat (*Triticum aestivum* L.) plants with assessment of Topsin-M fungicide as a control agent. *Basrah Journal of Science, 43*(3), 589–613. https://doi.org/10.29072/basjs.20250303

Andersen, E. J., Ali, S., Byamukama, E., Yen, Y., & Nepal, M. P. (2018). Disease resistance mechanisms in plants. *Genes, 9*(7), Article 339. https://doi.org/10.3390/genes9070339

Barros, J. R. A., Guimarães, M. J. M., Simões, W. L., Melo, N. F. de, & Angelotti, F. (2022). Temperature: A major climatic determinant of cowpea production. *Acta Scientiarum. Agronomy, 45*, e56812. https://doi.org/10.4025/actasciagron.v45i1.56812

Bock, C. H., Poole, G. H., Parker, P. E., & Gottwald, T. R. (2010). Plant disease severity estimated visually, by digital photography and image analysis, and by hyperspectral imaging. *Critical Reviews in Plant Sciences, 29*(2), 59–107. https://doi.org/10.1080/07352681003617285

Boukar, O., Belko, N., Chamarthi, S., Togola, A., Batieno, J., Owusu, E., Fatokun, C., *et al.* (2019). Cowpea (*Vigna unguiculata*): Genetics, genomics and breeding. *Plant Breeding, 138*(4), 415–424. https://doi.org/10.1111/pbr.12589

Cardoni, M., Gómez-Lama Cabanás, C., Valverde-Corredor, A., Villar, R., & Mercado-Blanco, J. (2022). Unveiling differences in root defense mechanisms between tolerant and susceptible olive cultivars to *Verticillium dahliae*. *Frontiers in Plant Science, 13,* 863055. https://doi.org/10.3389/fpls.2022.863055

Carolan, K., Helps, J., van den Berg, F., Bain, R., Paveley, N., & van den Bosch, F. (2017). Extending the durability of cultivar resistance by limiting epidemic growth rates. *Proceedings of the Royal Society B: Biological Sciences, 284*(1863), 20170828. https://doi.org/10.1098/rspb.2017.0828

Dubey, S. C., Tripathi, A., Upadhyay, B. K., & Singh, B. (2012). Influence of weather and soil parameters on development of wet root rot in pulse crops and virulence analysis of *Rhizoctonia solani* isolates. *Journal of Agricultural Science, 4*(11), 195–207. https://doi.org/10.5539/jas.v4n11p195

Eaglesham, A. R. J., Ayanaba, A., Ranga Rao, V., *et al.* (1982). Mineral N effects on cowpea and soybean crops in a Nigerian soil. *Plant and Soil, 68*, 171–181. https://doi.org/10.1007/BF02373703

Ellison, A. M. (2001). Interspecific and intraspecific variation in seed size and germination requirements of *Sarracenia* (Sarraceniaceae). *American Journal of Botany*, *88*(3), 429–437. https://doi.org/10.2307/2657107

Gent, M. P. N. (1983). Rate of increase in size and dry weight of individual pods of field-grown soybean plants. *Annals of Botany*, *51*(3), 317–329. https://doi.org/10.1093/oxfordjournals.aob.a086472

Goyal, R. K., Schmidt, M. A., & Hynes, M. F. (2021). Molecular biology in the improvement of biological nitrogen fixation by rhizobia and extending the scope to cereals. *Microorganisms*, *9*(1), Article 125. https://doi.org/10.3390/microorganisms9010125

Hewavitharane, H. V. C., Warnakulasooriya, H. U., & Wajira Kumara, G. B. S. (2010). Constraints to expansion of cowpea and mungbean under rain-fed farming in Anuradhapura district. *Annals of the Sri Lanka Department of Agriculture*, *12*, 91–104. https://doi.org/10.22004/ag.econ.95541

Jayathilake, C., Visvanathan, R., Deen, A., Bangamuwage, R., Jayawardana, B. C., Nammi, S., & Liyanage, R. (2018). Cowpea: An overview on its nutritional facts and health benefits. *Journal of the Science of Food and Agriculture*, *98*(13), 4793–4806. https://doi.org/10.1002/jsfa.9074

Moparthi, S. (2016). *Epidemiology and management of sweet cherry powdery mildew in Washington nurseries* (Doctoral dissertation, Washington State University).

Nakedde, T., Ibarra-Pérez, F. J., Mukankusi, C., Waines, J. G., & Kelly, J. D. (2016). Mapping of QTL associated with *Fusarium* root rot resistance and root architecture traits in black beans. *Euphytica*, *212*(1), 51–63. https://doi.org/10.1007/s10681-016-1755-6

Namasaka, R., Tusiime, G., Orawu, M., Gibson, P., Nyiramugisha, J., & Edema, R. (2017). Evaluation of cowpea genotypes for resistance to *Fusarium redolens* in Uganda. *American Journal of Plant Sciences*, *8*, 2296–2314. https://doi.org/10.4236/ajps.2017.89154

Olorunwa, O. J., Adhikari, B., Brazel, S., Bheemanahalli, R., Barickman, T. C., & Reddy, K. R. (2023). Waterlogging stress reduces cowpea (*Vigna unguiculata* L.) genotypes growth, seed yield, and quality at different growth stages: Implications for developing tolerant cultivars under field conditions. *Agricultural Water Management*, *284*, 108336. https://doi.org/10.1016/j.agwat.2023.108336

Ramusi, T. M., van der Waals, J. E., Labuschagne, N., & Aveling, T. A. (2017). Evaluation of mefenoxam and fludioxonil for control of *Rhizoctonia solani*, *Pythium ultimum* and *Fusarium solani* on cowpea. *South African Journal of Plant and Soil*, *34*(1), 27–33. https://doi.org/10.1080/02571862.2016.1155764

Reis, E. M., & Carmona, M. A. (2013). Integrated disease management of *Fusarium* head blight. In T. M. Alconada Magliano & S. N. Chulze (Eds.), *Fusarium head blight in Latin America* (pp. 159–173). Springer. https://doi.org/10.1007/978-94-007-7091-1_10

Rouse, D. I. (1988). Use of crop growth models to predict the effects of disease. *Annual Review of Phytopathology, 26*, 183–201. https://doi.org/10.1146/annurev.py.26.090188.001151

Schneider, R. W., Hollier, C. A., Whitam, H. K., Palm, M. E., McKemy, J. M., Hernandez, J. R., Levy, L., & DeVries-Paterson, R. (2005). First report of soybean rust caused by *Phakopsora pachyrhizi* in the continental United States. *Plant Disease, 89*(7), 774. https://doi.org/10.1094/PD-89-0774A

Senaratne, R., Dayatilake, G. A., & Subasinghe, S. (1998). Studies in Sri Lanka on cowpea: N_2 fixation, growth, yield, and effects on cereals. In *Improving yield and nitrogen fixation of grain legumes in the tropics and sub-tropics of Asia*.

Shrestha, U., Ownley, B. H., & Butler, D. M. (2016). First report of stem and root rot of cowpea caused by *Fusarium oxysporum* in Tennessee. *Plant Disease, 100*(3), 649. https://doi.org/10.1094/PDIS-08-15-0934-PDN

Snapp, S., Kirk, W., Román-Avilés, B., & Kelly, J. (2003). Root traits play a role in integrated management of *Fusarium* root rot in snap beans. *HortScience, 38*(2), 187–191. https://doi.org/10.21273/HORTSCI.38.2.187

Stagnari, F., Maggio, A., Galieni, A., & Pisante, M. (2017). Multiple benefits of legumes for agriculture sustainability: An overview. *Chemical and Biological Technologies in Agriculture, 4*(1), Article 2. https://doi.org/10.1186/s40538-016-0085-1

Thangavelu, R., and Mustaffa, M. M. (2010). First report of corm rot disease caused by *Sclerotium rolfsii* in banana. *Australasian Plant Disease Notes, 5*(1), 30–33. https://doi.org/10.1071/DN10012

Vatchev, T., and Maneva, S. (2012). Chemical control of root rot complex and stem rot of greenhouse cucumber in straw-bale culture. *Crop Protection, 42*, 16–23. https://doi.org/10.1016/j.cropro.2012.08.001