



RESEARCH ARTICLE

Integrated disease management (IDM) for effective control of *Phomopsis vexans* causing blight and fruit rot in Brinjal (*Solanum melongena* L.) in Odisha

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Abstract

Phomopsis blight and fruit rot are major constraint to brinjal (*Solanum melongena* L.) cultivation, often causing substantial reductions in yield and market quality in Odisha. This two-year study evaluated integrated disease management (IDM) strategies combining cultural, biological and chemical components against *Phomopsis vexans* under both *in vitro* and field conditions. Treatments differed significantly in disease incidence, severity and yield. The most effective IDM treatment recorded the lowest disease incidence included Carbendazim at 2 g per kg of seed, seedling root dip with *Pseudomonas fluorescens* (2×10^8 cfu/g) @ 10 g/L water, foliar spray of Propiconazole 25 % EC @ 0.15 % at the vegetative stage (45 DAT) and Hexaconazole 5 % SC @ 0.1 % at the fruiting stage (75 DAT) resulted in the lowest disease incidence (8.74 %) and the highest fruit yield (377 q/ha). A comparable treatment comprising Carbendazim seed treatment, soil application of *P. fluorescens* (15 kg/ha) with vermicompost, turmeric extract (10 %) at the vegetative stage and Hexaconazole (0.1 %) at fruiting reduced disease incidence to 12.96 % and produced 362 q/ha. Overall, the findings underscore the integrated treatments were significantly more effective than those involving individual components and the untreated control. The findings underscore the effectiveness of IDM strategies for sustainable management of *Phomopsis* fruit rot in brinjal under Odisha's agro-climatic conditions.

Keywords: biological control; brinjal; fungicide efficacy; integrated disease management (IDM); Odisha; *Phomopsis vexans*

Introduction

Brinjal (*Solanum melongena* L.) is an important vegetable crop in India is believed to have originated in the Indian subcontinent. India is the world's second largest producer of brinjal, contributing about 9 % to the country's total vegetable production (1). In Odisha, brinjal is cultivated year-round and serves as an important cash crop for small and marginal farmers. Nutritionally, brinjal contains essential minerals and vitamins and is valued for its health benefits (2). Nationally, brinjal is grown on 0.68 million hectares, producing 12.99 million metric tonnes annually. In Odisha, the crop occupies about 0.13 million hectares, making the state the second-largest producer after West Bengal.

Despite these impressive figures, the yield in both India and Odisha remains lower than that of several other brinjal-producing countries mainly due to environmental stress and various diseases (3). Among these, *Phomopsis* fruit rot, caused by *Phomopsis vexans*, is one of the most destructive diseases as the pathogen infects the seed coat, cotyledons and embryo axis and can attack all above-ground parts of the plant (4). The disease initially appears as brownish to water-soaked lesions on fruits and under conducive conditions the spots enlarge and develop black pycnidia. As the infection sets in early during fruit development, the pathogen can cause a rapid progression of symptoms, especially in hot-wet weather (5). As a seed-borne pathogen

capable of surviving in crop debris, it can also cause damping-off, leaf spot and stem canker (6), resulting in substantial yield and market losses (7, 8) although several management strategies exist, *P. vexans* remains difficult to control.

The disease is difficult to manage partly because infected fruits exhibit poor spray adhesion, reducing the efficacy of chemical fungicides. Cultural practices like crop rotation have shown some success in minimizing disease incidence (9). In Odisha, *Phomopsis* fruit rot has been identified as a major constraint in brinjal cultivation, yet there is limited research on its integrated management under the agro-climatic conditions. Most studies so far have focused on the *in vitro* testing of individual fungicides, botanicals and biocontrol agents. However, field-based validation of IDM treatments tailored to local conditions is limited and information on the compatibility and timing of combined chemical, botanical and biological components is inadequate. Moreover, native strains of *Trichoderma* and *Bacillus* with potential antagonistic activity against *P. vexans* remain poorly characterized and no systematic monitoring of fungicide resistance has been conducted locally.

Therefore, this study aimed to evaluate integrated disease management (IDM) strategies combining chemical, botanical and biological components for effective and sustainable management of *P. vexans* in East and South-Eastern Coastal Plain of Odisha.

Methodology

A research trial was conducted in the *Kharif* season for two consecutive years 2022–23 and 2023–24 at Institute of Agriculture Science SOA University, Odisha in order to assess the effectiveness of new fungicides combined with botanicals and biocontrol agents against the causal pathogen under both laboratory and field conditions. The *P. vexans* isolate used in this study was obtained from naturally infected brinjal fruits collected from farmers' fields in Nayagarh district, Odisha. Small tissue pieces from the lesion margin were surface-sterilized (0.1 % NaOCl, 1 min), rinsed in sterile water and plated on PDA. After incubation at 25 ± 1 °C for 5–7 days, emerging colonies were purified by single-spore isolation. Identification was based on colony characteristics (white to grey mycelium with pycnidial formation) and the presence of typical hyaline, fusiform α-conidia and curved β-conidia, following the diagnostic descriptions of Sutton (10). The purified culture was maintained on PDA slants at 4 °C for subsequent experiments. In laboratory conditions, the efficacy of various treatments such as fungicides, botanicals and biocontrol agents was assessed through completely randomized design (CRD) and after successful evaluation, a suitable combination of treatments was selected for field evaluation. The efficacy of 10 systemic fungicides (T1 - Propiconazole, T2 - Carbendazim + Mancozeb, T3 - Azoxystrobin, T4 -Carbendazim, T5 - Difeconazole, T6 - Amistar Top, T7 - Tebuconazole, T8 - Chlorothalonil, T9 - Pencycuron) was tested at 50 and 100 ppm concentrations. Each fungicide was mixed with sterilized molten PDA to obtain the desired concentration and 20 mL of the medium was poured into sterilized petri plates, while PDA without any fungicide served as the control. From a ten-day-old fungal culture a 5 mm mycelial disc was taken and placed at the centre of each plate with three replications per treatment. The plates were kept at room temperature for seven days and fungal

growth was recorded when the control reached full growth. The percent inhibition of mycelial growth was calculated using Vincent's (1947) (11) formulae.

To evaluate the antifungal potential of botanicals (T1 - Neem leaf extract, T2 - Garlic clove extract, T3 - Turmeric rhizome extract, T4 - Ginger rhizome extract, T5 - Tulsi leaf extract. Fresh leaves of different botanicals surface-sterilized with 1 % sodium hypochlorite and rinsed with sterile distilled water. A 100 g sample was then crushed in a sterilized mortar and pestle with 100 mL sterile distilled water (1:1 w/v) and the extracts were filtered through muslin cloth and the filtrate served as the stock solution (12). The selection of these botanicals and their doses was based on earlier reports of their antifungal activity, preliminary *in vitro* screening and compatibility with bioagents and fungicides used under IDM programs. Final concentrations were standardized at 5 %, 10 % and 15 % based on extract strength and extraction efficiency, while alcohol ensured better solubility of active compounds without affecting assay results. Their antifungal effects are mainly attributed to bioactive constituents such as azadirachtin (neem), allicin (garlic), curcumin (turmeric), gingerols (ginger) and eugenol (Tulsi), which disrupt membrane integrity, inhibit enzymatic pathways or suppress fungal growth (13). Antifungal activity was tested using the poisoned food technique where stock solutions were mixed with molten sterilized PDA to obtain 5 %, 10 % and 15 % concentrations, poured (20 mL each) into sterilized petri plates and used for further study. Each plate was inoculated with a 5 mm mycelial disc from a seven-day old culture and incubated at 27 ± 1 °C until the control showed full growth. Three replications and suitable controls were maintained. Mean colony diameter was measured and percent inhibition of mycelial growth compared to the control was determined using Vincent's formula (11).

Antagonistic activity of the bio-agents was evaluated using the dual culture technique, which allows simultaneous interaction of the pathogen and antagonist and is widely used to assess mycoparasitism, competition and antibiotic production. Sterile petri plates were filled with 20 mL PDA. For fungal antagonists, a 5-mm disc of *P. vexans* and a 5-mm disc of the antagonist were placed on opposite sides of the plate, approximately 4 cm apart, to allow the two colonies to grow towards each other. For bacterial antagonists, the pathogen disc was placed near the periphery (1 cm from the plate edge) and the bacterium (standardized to 1 × 10⁸ CFU mL⁻¹) was streaked at the centre, ensuring uniform diffusion of metabolites. Plates were incubated at 25 ± 1 °C for 5–7 days (14). When the pathogen in the control plates reached 90 mm, radial growth of the pathogen in each treatment was measured and inhibition was expressed using Vincent's formula (11). The inhibition zone (mm) between colonies was also recorded wherever visible. Each treatment was replicated three times. The bio-agents tested included *Pseudomonas fluorescens* isolates 1 and 2, *Trichoderma harzianum*, *Trichoderma viride* and *Bacillus pumilus*. An untreated control (pathogen only) was maintained for comparison. The most effective antagonists identified *in vitro* were subsequently incorporated into ten integrated treatments for field evaluation. Treatment details are described in Table 1.

$$I = \frac{C - T}{C} \times 100$$

Table 1. Treatment details

Treatment details	Fungicides + Biopesticide
T1	Seed treatment with Carbendazim 50 % WP @ 2 g/kg seed + soil application of <i>Pseudomonas fluorescens</i> (2×10^8 cfu/g) @ 15 kg/ha along with vermicompost @ 12 q/ha + Turmeric rhizome extract @ 10 % at vegetative state (45 DAT) Foliar spray of Hexaconazole 5 % SC @ 0.1 % at fruiting stage (75 DAT)
T2	Seed treatment with <i>Pseudomonas fluorescens</i> isolate-1 (2×10^8 cfu/g) @ 15 g/L water + Foliar spray of Propiconazole 25 % EC @ 0.1 % at vegetative state (40 DAT) + Garlic clove extract @ 10 % at fruiting stage (75 DAT)
T3	Seed treatment with Carbendazim 50 % WP @ 2 g/kg seed + Seedling root dip with <i>Pseudomonas fluorescens</i> (2×10^8 cfu/g) @ 10 g/L water + Foliar spray of Propiconazole 25 % EC @ 0.15 % at vegetative state (45 DAT) + Foliar spray of Hexaconazole 5 % SC @ 0.1 % at fruiting stage (75 DAT)
T4	Seed treatment with <i>Pseudomonas fluorescens</i> isolate-1 (2×10^8 cfu/g) @ 15 g/L water + Foliar spray of Difenconazole 25 % EC @ 0.1 % + Turmeric rhizome extract @ 10 % at fruiting stage (75 DAT)
T5	Seed treatment with <i>Pseudomonas fluorescens</i> isolate-1 (2×10^8 cfu/g) @ 15 g/L water + Foliar spray of Propiconazole 25 % EC @ 0.1 % at vegetative state (40 DAT) + Turmeric rhizome extract @ 10 % at fruiting stage (75 DAT)
T6	Seed treatment with Carbendazim 50 % WP @ 2 g/kg seed + Seedling root dip with <i>Pseudomonas fluorescens</i> isolate-1 (2×10^8 cfu/g) @ 15 g/L water + Foliar spray of Propiconazole 25 % EC @ 0.1 % at vegetative state (40 DAT)
T7	Seed treatment with <i>Trichoderma harzianum</i> (1×10^7 cfu/g) @ 10 g/kg seed + Foliar spray of Carbendazim 50 % WP @ 0.1 % at vegetative state (45 DAT) + Foliar spray of <i>Pseudomonas fluorescens</i> (2×10^8 cfu/g) @ 0.1 % at fruiting stage (75 DAT)
T8	Seed treatment with Carbendazim 50 % WP @ 2 g/kg seed + Seedling root dip with <i>Pseudomonas fluorescens</i> (2×10^8 cfu/g) @ 10 g/L water + Foliar spray of Garlic clove extract @ 10 % at vegetative state (45 DAT) + Foliar spray of Hexaconazole 5 % SC @ 0.1 % at fruiting stage (75 DAT)
T9	Seedling root dip with <i>Trichoderma harzianum</i> (1×10^7 cfu/g) @ 15 g/L water + Foliar spray of Difenconazole 25 % EC @ 0.1 % at vegetative state (40 DAT) + Garlic clove extract @ 10 % at fruiting stage (75 DAT)
T10	Control (untreated)

Where, I: Percent inhibition; C: Radial growth in control; T: Radial growth in treatment.

The field experiment was conducted using a randomized block design (RBD) comprising ten treatments with three replications. Each plot measured 5 m × 4 m, with brinjal seedlings transplanted at a spacing of 60 cm × 45 cm. The experimental site consisted of red *Alfisols*, sandy loam in texture, acidic in reaction (pH 5.58) and low in available N, P₂O₅ and K₂O, respectively. Seeds of the brinjal variety 'Utkal Anushree' were sown in raised nursery beds as per the treatment schedule and uniform seedlings (21–30 days old, 10–15 cm height) were transplanted into the main field. During main field preparation, 10–15 tons of FYM per hectare was incorporated at the final ploughing. Recommended agronomic practices, including drip irrigation and timely manual weeding, were followed throughout the cropping period. Fertilizer application was based on soil test recommendations of 110:87.5:62.5 kg ha⁻¹ N:P₂O₅:K₂O (compared to the general RDF of 110:70:50 kg ha⁻¹). The full doses of phosphorus and potassium, along with 50 % of nitrogen, were applied at transplanting, while the remaining nitrogen was supplied in two equal splits at 30 and 45 days after planting (15). A conidial suspension of *P. vexans* was prepared from 7 days old PDA cultures by flooding pycnidia with sterile water, filtering through muslin cloth and adjusting to 1×10^6 conidia mL⁻¹; Tween-20 (0.02 %) was added as a surfactant. Inoculation was done using a hand-held knapsack sprayer, applying 20–25 mL per plant to ensure uniform coverage. Spraying was carried out in the late afternoon under favourable temperature and humidity. To maintain consistent inoculum pressure, a second inoculation was performed three days later. Control plants received sterile water with surfactant.

Table 2. Efficacy of various bio-control agents under *in vitro* condition

Treatment	Mycelial growth (mm)			Average inhibition (%)
	72 hr	120 hr	168 hr	
T1 - <i>Pseudomonas fluorescens</i> isolates-1	17.27	27.86	42.27	53.03
T2 - <i>Pseudomonas fluorescens</i> isolates-2	19.80	34.72	50.16	44.27
T3 - <i>Trichoderma harzianum</i>	16.96	33.78	44.88	50.02
T4 - <i>Trichoderma viride</i>	21.29	39.99	54.83	39.08
T5 - <i>Bacillus pumilus</i>	26.16	41.44	62.34	30.73
T6 - Control	37.77	62.53	90.00	0.00
CD@	1.23	1.66	1.78	
SEm±	0.40	0.50	0.57	

Disease incidence (%)

Disease severity was recorded using the standard 0–5 scale, where 0 = no symptoms; 1 = 1–10 % leaf area infected; 2 = 11–25 %, 3 = 26–50 %, 4 = 51–75 % and 5 = >75 % leaf area infected. Percent disease index (PDI) was calculated using the formula (16):

$$PDI = \left[\frac{\sum (\text{rating} \times \text{number of leaves rated})}{(\text{maximum rating} \times \text{total leaves})} \right] \times 100.$$

Disease incidence (DI%) was expressed as the percentage of plants showing symptoms, but disease comparison across treatments was based on PDI and the terminology has been made consistent throughout the manuscript.

Statistical analysis

Data collected for the various parameters in this study were analysed using the analysis of variance (ANOVA) procedure outlined in previous study (17). Treatment effects were assessed using the F-test at the 5 % level of significance. All statistical analyses for individual parameters were carried out using R software (version 4.3.3) and Microsoft Excel 2016.

Results and Discussion

The *in vitro* evaluation of bioagents against *P. vexans* showed a clear and consistent trend, with substantial variation in their ability to suppress mycelial growth (Table 2). Among all tested agents, *P. fluorescens* (Isolate-1) emerged as the most effective (inhibition of 53.03 %) of antagonist, recording the greatest reduction in pathogen growth of (42.27 mm). whereas *B. pumilus* showed comparatively lower inhibition (30.73 %). The control plates, as expected, exhibited unrestricted fungal growth. This superior performance of *P. fluorescens* (Isolate-1) may be due to its ability to

produce inhibitory metabolites such as siderophores, hydrogen cyanide and antibiotics that restrict mycelial expansion. Similarly, *T. harzianum* (inhibition of 50.02 %) is known to suppress pathogens through mycoparasitism and secretion of cell wall degrading enzymes, which aligns with earlier findings (18, 19). Across all concentrations, turmeric extract consistently showed the highest inhibition of *P. vexans* under *in vitro* conditions. A clear dose response trend was evident for all botanicals, with inhibition increasing as concentration increased from 5 %, 10 % and 15 %. At 15 % concentration (Tables 3-5), the performance followed a distinct pattern: Turmeric > Garlic > Tulsi > Ginger, confirming Turmeric as the most effective botanical but found at par with 10 %, respectively. The superior activity observed in turmeric and garlic extracts at higher concentrations may be attributed to the presence of curcumin and phenolic compounds in turmeric (20) and allicin and Sulphur compounds in garlic (21), which are known to interfere with fungal cell membrane integrity.

The *in vitro* efficacy of systemic fungicides was tested against *P. vexans* at 50 and 100 ppm concentrations (Table 6). The *in vitro* evaluation of systemic fungicides at 50 and 100 ppm

revealed significant differences in their ability to suppress the mycelial growth of *P. vexans* (Table 6). In the untreated control, radial growth reached 90 mm at 168 hr, confirming unrestricted fungal development. At 50 ppm, Carbendazim recorded the lowest mycelial growth (0.70–0.90 mm) with 99 % inhibition, followed closely by Tebuconazole, which also achieved >99 % inhibition. Propiconazole and Amistar Top were similarly effective, each producing more than 98 % inhibition. In contrast, Difeconazole showed comparatively weak activity at this concentration (79 % inhibition). The superior performance of Carbendazim, Tebuconazole and Propiconazole can be attributed to their systemic mode of action, particularly the inhibition of ergosterol biosynthesis or β -tubulin assembly, which disrupts membrane integrity and restricts mycelial growth (22). These results align with earlier findings reporting high inhibition levels for Carbendazim (87–100 %) and Propiconazole (86–93 %) against *P. vexans* (23). Increasing the concentration to 100 ppm enhanced the effectiveness of all fungicides. Tebuconazole again performed best, achieving up to 99.33 % inhibition, closely followed by Amistar Top (99.44 %).

Table 3. Efficacy of different botanical extract against *Phomopsis vexans* @ 5 % conc. under *in vitro* condition

Treatments detail	Mycelial growth of pathogen (mm) @ 5 %			Mycelial growth inhibition (%)
	72 hr	120 hr	168 hr	
T1 - Neem leaf extract	30.58	49.47	70.76	21.38
T2 - Garlic clove extract	30.72	51.53	72.13	19.86
T3 - Turmeric rhizome extract	23.82	41.49	55.03	38.86
T4 - Ginger rhizome extract	31.88	54.06	75.46	16.16
T5 - Tulsi leaf extract	22.43	40.87	58.43	35.08
T6 - Control	37.54	62.47	90.00	0.00
CD (0.05)	1.59	1.56	1.34	
SEm±	0.52	0.53	0.43	

Table 4. Efficacy of different botanical extract against *Phomopsis vexans* @ 10 % conc. under *in vitro* condition

Treatments detail	Mycelial growth of pathogen (mm) @ 10 %			Mycelial growth inhibition (%)
	72 hr	120 hr	168 hr	
T1 - Neem leaf extract	29.52	46.18	67.46	25.04
T2 - Garlic clove extract	21.26	36.38	53.54	40.49
T3 - Turmeric rhizome extract	12.91	24.83	34.17	62.03
T4 - Ginger rhizome extract	22.58	38.25	54.03	39.97
T5 - Tulsi leaf extract	19.32	32.84	48.76	45.82
T6 - Control	37.54	62.47	90.00	0.00
CD (0.05)	0.88	0.91	0.76	
SEm±	0.28	0.29	0.25	

Table 5. Efficacy of different botanical extract against *Phomopsis vexans* @ 15 % conc. under *in vitro* condition

Treatments detail	Mycelial growth of pathogen (mm) @ 15 %			Mycelial growth inhibition (%)
	72 hr	120 hr	168 hr	
T1 - Neem leaf extract	24.59	37.70	55.80	38.00
T2 - Garlic clove extract	17.48	27.85	36.40	59.56
T3 - Turmeric rhizome extract	10.16	20.66	28.30	68.56
T4 - Ginger rhizome extract	19.80	33.96	47.86	46.75
T5 - Tulsi leaf extract	16.08	27.61	41.64	53.73
T6 - Control	37.54	62.47	90.00	0.00
CD (0.05)	1.35	0.98	1.21	
SEm±	0.44	0.31	0.39	

Table 6. Efficacy of different fungicide against *Phomopsis vexans* @50 ppm and 100 ppm conc. under *in vitro* condition

Treatments detail	Mycelial growth of pathogen (mm) @ 50 ppm			Mycelial growth inhibition (%)	Mycelial growth of pathogen (mm) @ 100 ppm			Mycelial growth inhibition (%)
	72 hr	120 hr	168 hr		72 hr	120 hr	168 hr	
T1 - Propiconazole	1.30	1.10	1.20	98.67	1.30	1.10	1.20	98.67
T2 - Carbendazim + Mancozeb	1.10	1.20	1.30	98.56	1.10	1.20	1.30	98.56
T3 - Azoxystrobin	16.37	23.82	37.40	58.44	15.50	21.70	32.10	64.33
T4 - Carbendazim	0.70	0.80	0.90	99.00	0.90	1.00	1.10	98.78
T5 - Difeconazole	6.10	13.97	18.90	79.00	0.80	0.90	1.00	98.89
T6 - Amistar Top	1.20	1.30	1.40	98.44	1.20	1.30	0.50	99.44
T7 - Tebuconazole	1.40	0.70	0.80	99.11	0.70	0.50	0.60	99.33
T8 - Chlorothalonil	18.68	27.22	43.30	51.90	18.60	27.03	37.86	57.93
T9 - Pencycuron	21.01	35.95	50.80	43.56	19.04	35.23	46.36	48.59
T10 - Control	37.54	62.47	90.00	0.00	37.54	62.47	90.00	
CD (0.05)	1.741	0.921	0.632		0.88	0.97	0.61	
SEm±	0.57	0.305	0.209		0.28	0.31	0.19	

Carbendazim and Propiconazole maintained high levels of suppression (98–99 %). Notably, Difenoconazole, which was least effective at 50 ppm, exhibited a substantial improvement at 100 ppm, recording 98.89 % inhibition, consistent with earlier findings of strong inhibitory activity at higher doses (24). Overall, the fungicides Tebuconazole, Amistar Top, Carbendazim and Propiconazole consistently demonstrated the highest efficacy, each achieving more than 98 % inhibition of *P. vexans* under *in vitro* conditions.

The integrated disease management (IDM) treatments evaluated for controlling *Phomopsis* blight (*P. vexans*) in brinjal demonstrated varying levels of efficacy across two consecutive growing seasons (2022–23 and 2023–24) in field condition (Table 7 & 8). The treatment T3 recorded the lowest PDI (8.74 %) and the highest disease control (74.67 %), making it the most effective IDM treatment under field conditions. T1 performed comparably, with a mean PDI of 12.96 % and 71.45 % disease control (22, 24). Treatments involving only a single biocontrol or chemical component, such as T2, T4 and T5, showed moderate suppression of the disease, further indicating that integrated approaches provided superior management. The enhanced performance of T3 and T1 can be attributed to the synergistic action of systemic fungicides (Carbendazim, Propiconazole, Hexaconazole) in combination with *P. fluorescens*, which suppresses *P. vexans*

through mechanisms such as competition (25), antibiotic production (26) and induced systemic resistance (27). Comparable studies have also reported improved disease suppression when fungicides are integrated with antagonistic microorganisms, supporting the present findings. IDM treatments significantly improved fruit size, fruit number and overall yield compared with the untreated control (Table 9). Among all treatments, T3 produced the highest performance, with the greatest fruit size, maximum number of fruits per plant and the highest yield (377 q/ha) (15). T1 followed closely, also recording substantial improvements in all yield attributes (362 q/ha). Treatments such as T6 and T7 yielded moderate improvements, whereas the control (T10) consistently recorded the lowest fruit size, fruit number and yield.

The superior productivity observed in T3 and T1 is largely attributed to the combined effects of systemic fungicides (Carbendazim, Propiconazole, Hexaconazole) and *P. fluorescens*, which enhance plant growth and yield through disease suppression, induced systemic resistance and improved plant vigour (16, 28). Treatments involving *T. harzianum* also produced higher yields than the control, supporting its role in stimulating growth and resistance responses (26). In contrast, treatments based primarily on botanical extracts showed only moderate yield benefits, likely due to their limited persistence and shorter residual activity compared to systemic fungicides (29).

Table 7. Effect of IDM treatments on percent disease intensity and percent disease control under field condition

Treatment	Percent disease intensity (PDI)		Mean
	2021–22	2022–23	
T1 - Seed treatment with Carbendazim 50 % WP @ 2 g/kg seed + soil application of <i>Pseudomonas fluorescens</i> (2×10^8 cfu/g) @ 15 kg/ha along with vermicompost @ 12 q/ha + Turmeric rhizome extract @ 10 % at Vegetative stage (45 DAT) Foliar spray of Hexaconazole 5 % SC @ 0.1 % at fruiting stage (75 DAT)	11.43	14.48	12.96
T2 - Seed treatment with <i>Pseudomonas fluorescens</i> isolate-1 (2×10^8 cfu/g) @ 15 g/L water + Foliar spray of Propiconazole 25 % EC @ 0.1 % at vegetative state (40 DAT) + Garlic clove extract @ 10 % at fruiting stage (75 DAT)	16.86	18.80	17.83
T3 - Seed treatment with Carbendazim 50 % WP @ 2 g/kg seed + Seedling root dip with <i>Pseudomonas fluorescens</i> 1 (cfu 2×10^8 /g) @ 10 g/L water + Foliar spray of Propiconazole 25 % EC @ 0.15 % at vegetative state (45 DAT) + Foliar spray of Hexaconazole 5 % SC @ 0.1 % at fruiting stage (75 DAT)	9.28	8.20	8.74
T4 - Seed treatment with <i>Pseudomonas fluorescens</i> isolate-1 (2×10^8 cfu/g) @ 15 g/L water + Foliar spray of Difenoconazole 25 % EC @ 0.1 % + Turmeric rhizome extract @ 10 % at fruiting stage (75 DAT)	20.67	18.94	19.8
T5 - Seed treatment with <i>Pseudomonas fluorescens</i> isolate-1 (2×10^8 cfu/g) @ 15 g/L water + Foliar spray of Propiconazole 25 % EC @ 0.1 % at vegetative state (40 DAT) + Turmeric rhizome extract @ 10 % at fruiting stage (75 DAT)	17.82	24.59	21.21
T6 - Seed treatment with Carbendazim 50 % WP @ 2 g/kg seed + Seedling root dip with <i>Pseudomonas fluorescens</i> isolate-1 (2×10^8 cfu/g) @ 15 g/L water + Foliar spray of Propiconazole 25 % EC @ 0.1 % at vegetative state (40 DAT)	17.34	19.69	18.51
T7 - Seed treatment with <i>Trichoderma harzianum</i> (cfu 1×10^7 /g) @ 10 g/kg seed + Foliar spray of Carbendazim 50 % WP @ 0.1 % at vegetative state (45 DAT) + Foliar spray of <i>Pseudomonas fluorescens</i> (cfu 2×10^8 /g) @ 0.1 % at fruiting stage (75 DAT)	15.35	13.13	14.24
T8 - Seed treatment with Carbendazim 50 % WP @ 2 g/kg seed + Seedling root dip with <i>Pseudomonas fluorescens</i> (2×10^8 cfu/g) @ 10 g/L water + Foliar spray of Garlic clove extract @ 10 % at vegetative stage (45 DAT) + Foliar spray of Hexaconazole 5 % SC @ 0.1 % at fruiting stage (75 DAT)	17.47	19.83	18.65
T9 - Seedling root dip with <i>Trichoderma harzianum</i> (1×10^7 cfu/g) @ 15 g/L water + Foliar spray of Difenoconazole 25 % EC @ 0.1 % at vegetative state (40 DAT) + Garlic clove extract @ 10 % at fruiting stage (75 DAT)	14.31	20.67	17.49
T10 - Control (untreated)	28.83	33.13	30.98
CD@	4.63	4.2	3.9
SEm±	1.53	1.4	1.3

Table 8. Effect of IDM treatments on percent disease control under field condition

Treatment	% Disease control		Mean
	2021-22	2022-23	
T1 - Seed treatment with Carbendazim 50 % WP @ 2 g/kg seed + soil application of <i>Pseudomonas fluorescens</i> (2×10^8 cfu/g) @ 15 kg/ha along with vermicompost @ 12 q/ha + Turmeric rhizome extract @ 10 % at vegetative stage (45 DAT) Foliar spray of Hexaconazole 5 % SC @ 0.1 % at fruiting stage (75 DAT)	73.75	69.14	71.45
T2 - Seed treatment with <i>Pseudomonas fluorescens</i> isolate-1 (2×10^8 cfu/g) @ 15 g/L water + Foliar spray of Propiconazole 25 % EC @ 0.1 % at vegetative state (40 DAT) + Garlic clove extract @ 10 % at fruiting stage (75 DAT)	36.03	36.43	36.23
T3 - Seed treatment with Carbendazim 50 % WP @ 2 g/kg seed + Seedling root dip with <i>Pseudomonas fluorescens</i> 1 (cfu 2×10^8 /g) @ 10 g/L water + Foliar spray of Propiconazole 25 % EC @ 0.15 % at vegetative state (45 DAT) + Foliar spray of Hexaconazole 5 % SC @ 0.1 % at fruiting stage (75 DAT)	79.89	69.46	74.67
T4 - Seed treatment with <i>Pseudomonas fluorescens</i> isolate-1 (2×10^8 cfu/g) @ 15 g/L water + Foliar spray of Difenconazole 25 % EC @ 0.1 % + Turmeric rhizome extract @ 10 % at fruiting stage (75 DAT)	46.10	35.69	40.89
T5 - Seed treatment with <i>Pseudomonas fluorescens</i> isolate-1 (2×10^8 cfu/g) @ 15 g/L water + Foliar spray of Propiconazole 25 % EC @ 0.1 % at vegetative state (40 DAT) + Turmeric rhizome extract @ 10 % at fruiting stage (75 DAT)	35.13	32.00	33.56
T6 - Seed treatment with Carbendazim 50 % WP @ 2 g/kg seed + Seedling root dip with <i>Pseudomonas fluorescens</i> isolate-1 (2×10^8 cfu/g) @ 15 g/L water + Foliar spray of Propiconazole 25 % EC @ 0.1 % at vegetative state (40 DAT)	57.71	46.29	52.00
T7 - Seed treatment with <i>Trichoderma harzianum</i> (cfu 1×10^7 /g) @ 10 g/kg seed + Foliar spray of Carbendazim 50 % WP @ 0.1 % at vegetative state (45 DAT) + Foliar spray of <i>Pseudomonas fluorescens</i> (cfu 2×10^8 /g) @ 0.1 % at fruiting stage (75 DAT)	52.94	50.99	51.96
T8 - Seed treatment with Carbendazim 50 % WP @ 2 g/kg seed + Seedling root dip with <i>Pseudomonas fluorescens</i> (2×10^8 cfu/g) @ 10 g/L water + Foliar spray of Garlic clove extract @ 10 % at vegetative stage (45 DAT) + Foliar spray of Hexaconazole 5 % SC @ 0.1 % at fruiting stage (75 DAT)	50.03	51.10	50.57
T9 - Seedling root dip with <i>Trichoderma harzianum</i> (1×10^7 cfu/g) @ 15 g/L water + Foliar spray of Difenconazole 25 % EC @ 0.1 % at vegetative state (40 DAT) + Garlic clove extract @ 10 % at fruiting stage (75 DAT)	42.38	50.26	46.32
T10 - Control (untreated)	0.00	0.00	0.00
CD@	6.02	8.88	6.4
SEm±	2	2.9	2.13

Table 9. Effect of IDM treatments on fruit size (cm) and no. of fruits/plant and yield (q/ha) under field condition

Treatment	Fruit size (cm)			No. of fruits/plant			Yield (q/ha)		
	2022-23	2023-24	Mean	2022-23	2023-24	Mean	2022-23	2023-24	Mean
T1	16.7	17.7	17.2	16.9	17.2	17	361	363	362
T2	9.8	9.5	9.7	16.1	17.1	16.6	198	203	201
T3	18.3	19.3	18.8	18.0	19.5	18.7	373	381	377
T4	10.2	11.4	10.8	15.4	17.73	16.5	237	240	239
T5	9.0	9.0	9.0	16.5	14.7	15.6	189	216	202
T6	14.9	14.0	14.5	15.8	16.0	15.9	294	308	301
T7	13.1	13.7	13.4	16.9	16.3	16.6	301	318	309
T8	11.7	11.3	11.5	16.1	14.8	15.4	291	300	296
T9	10.7	10.3	10.5	15.9	15.3	15.6	244	269	257
T10	8.0	8.4	8.2	13.0	14.3	13.6	167	170	168
CD (0.05)	0.89	1.05	0.72	1.46	1.58	1.25	36.19	37.62	32.8
SEm±	0.3	0.352	0.234	0.46	0.53	0.42	12.18	12.6	10.9

Conclusion

This two-year field study demonstrated the stage- and time-specific integrated disease management (IDM) practices are significantly more effective than stand-alone chemical or biological treatments for managing *Phomopsis* blight and fruit rot in brinjal (*S. melongena* L.). The most effective treatments, combining Carbendazim seed treatment, *P. fluorescens* root dip and stage specific foliar applications of Propiconazole and Hexaconazole, successfully reduced disease incidence to a low of 8.74 % while achieving the maximum fruit yield of 377 q/ha. Overall, the findings highlight the potential of IDM as an effective and environmentally compatible strategy for managing *P. vexans* under the agro-climatic conditions of Odisha however to minimise risks associated with fungicide use, rotating fungicides with different modes of action, integrating botanicals and biocontrol agents, applying fungicides only when necessary, following recommended doses, maintaining proper pre-harvest intervals (PHI) and regularly monitoring residues are essential for ensuring environmental and consumer safety.

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Authors' contributions

EP and BRS¹ conducted the experiment and were responsible for writing the original manuscript draft. BRS¹ conceptualized the research idea and provided overall direction and supervision throughout the study. RK contributed to field investigation and data collection. AD co-conceptualized the study and guided the research execution and manuscript development. DM helped in the experimental investigation and offered suggestions during manuscript revision. PD supported the investigation field evaluation and assisted with editing the manuscript. KM reviewed and refined the manuscript. AR provides input during the manuscript editing phase. BRS² performed the formal data analysis and contributed to critical revisions and corrections of the manuscript. All authors read and approved the final version of the manuscript. [BRS¹ and BRS² stands for Bidwan Ranjan Sahoo and Bignyan Ranjan Sahoo.]

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

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References

- Dash SR, Mishra PJ, Swain SK, Dhal A. Indigenous brinjal variety gobindpali brinjal: A ray of hope for the tribal farmers of malkangiri district — a case study. *Progressive Horticulture*. 2022;54(2):211–6. <https://doi.org/10.5958/2249-5258.2022.00033.1>
- Hasan MM, Chowdhury MA, Saha BK, Islam MR. Major nutrient contents and their uptake by brinjal as influenced by phosphorus and sulphur. *Journal of the Bangladesh Agricultural University*. 2013;11(1):41–6. <https://doi.org/10.3329/jbau.v11i1.18206>
- Kaniyassery A, Thorat SA, Kiran KR, Murali TS, Muthusamy A. Fungal diseases of eggplant (*Solanum melongena* L.) and components of the disease triangle: A review. *Journal of Crop Improvement*. 2023;37(4):543–94. <https://doi.org/10.1080/15427528.2022.2120145>
- Udayashankar AC, Chandra Nayaka S, Archana B, Lakshmeesha TR, Niranjana SR, Lund OS, et al. Specific PCR-based detection of *Phomopsis vexans*, the cause of leaf blight and fruit rot of *Solanum melongena* L. *Letters in Applied Microbiology*. 2019;69(5):358–65. <https://doi.org/10.1111/lam.13214>
- Keinath AP. Differences in susceptibility to *Phomopsis* blight of seven eggplant cultivars with different fruit types. *Plant Health Progress*. 2021;23(1):57–64. <https://doi.org/10.1094/PHP-07-21-0100-RS>
- Sherf AF, MacNab AA. *Vegetable diseases and their control*. New York: John Wiley & Sons; 1986.
- Beura SK, Mahanta IC, Mohapatra KB. Economics and chemical control of *Phomopsis* twig blight and fruit rot of brinjal. *Journal of Mycopathological Research*. 2008;46(1):73–6.
- Pandey AP. Studies on fungal diseases of eggplant in relation to statistical analysis and making of a disease calendar. *Recent Research in Science and Technology* 2010;2(9):01–03.
- Hossain MT, Hossain S, Islam MA, Khan MA, Hossain SM. Awareness of the farmers on the use of hot water seed treatment device for controlling *phomopsis* blight of eggplant (*Solanum melongena* L.). *Bangladesh Journal of Agricultural Research*. 2009;34(4):723–7. <https://doi.org/10.3329/bjar.v34i4.5847>
- Sutton BC. *The Coelomycetes: fungi imperfecti with pycnidia, acervuli and stromata*. Kew: Commonwealth Mycological Institute; 1980.
- Vincent JM. Distortion of fungal hyphae in the presence of certain inhibitors. *Nature*. 1947;159(4051):850. <https://doi.org/10.1038/159850b0>
- Begum FB, Bhuiyan MK. Integrated control of seedling mortality of lentil caused by *Sclerotium rolfsii*. *Agricultural and Food Sciences*. 2007:17–24.
- Pun LB, Chhetri K, Pandey A, Poudel R. *In vitro* evaluation of botanical extracts, chemical fungicides and *Trichoderma harzianum* against *Alternaria brassicicola* causing leaf spot of cabbage. *Nepalese Horticulture*. 2020;14(1):68–76. <https://doi.org/10.3126/nh.v14i1.30612>
- Wamani AO. Screening of microbial antagonists and plant extracts against selected tomato pathogens and their potential in the management of bacterial wilt. Nairobi: University of Nairobi; 2014.
- Prusty M, Panda N, Dash AK, Mishra N. Nutrient management modules for eggplant (*Solanum melongena* L.): Yield, quality, economics, nutrient uptake and post-harvest soil properties. *Journal of the Indian Society of Coastal Agricultural Research*. 2022;40(1). <https://doi.org/10.54894/JISCAR.40.1.2022.112565>
- Dar MS, Ganaie SA, Raja W, Teeli RA. *In vivo* investigation on antifungal properties of leaf extracts of certain medicinal plants through seed treatment and foliar sprays against rice blast disease (*Magnaporthe grisea*) in Kashmir, India. *Annals of Agrarian Science*. 2018;16(3):267–71. <https://doi.org/10.1016/j.aasci.2018.04.002>
- Gomez KA, Gomez AA. *Statistical Procedures for Agricultural Research*. 2nd ed. New York: John Wiley & Sons; 1984.
- Raaijmakers JM, Mazzola M. Diversity and natural functions of antibiotics produced by beneficial and plant pathogenic bacteria. *Annual Review of Phytopathology*. 2012;50(1):403–24. <https://doi.org/10.1146/annurev-phyto-081211-172908>
- Guzmán-Guzmán P, Kumar A, de Los Santos-Villalobos S, Parra-Cota FI, Orozco-Mosqueda MD, Fadiji AE, et al. *Trichoderma* species: Our best fungal allies in the biocontrol of plant diseases — a review. *Plants*. 2023;12(3):432. <https://doi.org/10.3390/plants12030432>
- Wsain SM, Attiya HJ, Al-Zubaidi LA. Antifungal activity of turmeric phenolic extract and turmeric silver nanoparticles on aflatoxin B1 producing fungi. *Biochemical and Cellular Archives*. 2020;20(1).
- Sarfraz M, Nasim MJ, Jacob C, Gruhlke MC. Efficacy of allicin against plant pathogenic fungi and unveiling the underlying mode of action employing yeast-based chemogenetic profiling approach. *Applied Sciences*. 2020;10(7):2563. <https://doi.org/10.3390/app10072563>
- Chaukhe AN, Patil MJ, Tekale AG, Borude VA. *In vitro* efficacy of fungicides against *Phomopsis vexans* causing *phomopsis* blight in brinjal. *International Journal of Chemical Studies*. 2020;8(4):2054–5. <https://doi.org/10.22271/chemi.2020.v8.i4v.9930>
- Jakatimath SP, Mesta RK, Mushrif SK, Biradar IB, Ajjappalavar PS. *In vitro* evaluation of fungicides, botanicals and bio-agents against *Phomopsis vexans*, the causal agent of fruit rot of brinjal. *Journal of Pure and Applied Microbiology*. 2017;11(1):229–35. <https://doi.org/10.22207/JPAM.11.1.29>
- Sushree A, Beura SK, Muthu MC. Evaluation of efficacy of various fungicides against *Phomopsis vexans*, the incident of fruit rot of brinjal (*Solanum melongena* L.). *International Journal of Current Microbiology and Applied Sciences*. 2018;7(8):684–7. <https://doi.org/10.20546/ijcmas.2018.708.074>
- Ons L, Bylemans D, Thevissen K, Cammue BP. Combining biocontrol agents with chemical fungicides for integrated plant fungal disease control. *Microorganisms*. 2020;8(12):1930. <https://doi.org/10.3390/microorganisms8121930>
- Gikas GD, Parlakidis P, Mavropoulos T, Vryzas Z. Particularities of fungicides and factors affecting their fate and removal efficacy: A review. *Sustainability*. 2022;14(7):4056. <https://doi.org/10.3390/su14074056>
- Ahmed SH, Sharma SH, Kumar AD, Sharma AD, Rana TA. The perspectives of induced resistance in brinjal against *Phomopsis vexans* causing *phomopsis* blight: A review. *Biopesticides International*. 2022;18(1):9–21.
- Ekka S, Kumar M, Lal HC, Chakravarty MK, Soren A. Management of fruit rot of brinjal caused by *Phomopsis vexans* through fungicides, plant extract and host plant resistance. *International Journal of Current Microbiology and Applied Sciences*. 2018;7:5119–24. <https://doi.org/10.20546/ijcmas.2018.706.332>
- Deresá EM, Diriba TF. Phytochemicals as alternative fungicides for controlling plant diseases: A comprehensive review of their efficacy, commercial representatives, advantages, challenges for adoption and possible solutions. *Heliyon*. 2023;9(3). <https://doi.org/10.1016/j.heliyon.2023.e13810>

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