



RESEARCH ARTICLE

Evaluation of fungicide combinations for the management of brown spot disease of rice

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Abstract

Rice is a primary food for more than half of the global population and plays a crucial role in sustainable food security worldwide. However, brown spot disease of rice caused by *Bipolaris oryzae* is increasingly threatening its production and productivity. To address this challenge, seven fungicide combinations were evaluated for their efficacy against *B. oryzae* under *in vitro* conditions using the poisoned food technique and field conditions during the kharif seasons of 2023 and 2024. *In vitro* studies showed that among seven fungicide combinations tested at four different concentrations (i.e. 100 ppm, 150 ppm, 200 ppm and 250 ppm) and three replications, azoxystrobin 5.1 % + tebuconazole 9.1 % + prochloraz 18.2 % EC was the most effective achieving complete fungal growth inhibition at 200 ppm, followed by tebuconazole 50 % + trifloxystrobin 25 % WG (complete inhibition at 250 ppm). Kasugamycin 5 % + copper oxychloride 45 % WP was the least effective with a maximum inhibition of 63.89 %. Field trials confirmed these results. Azoxystrobin + tebuconazole + prochloraz EC recorded the highest disease reduction (66.97 %) with the lowest PDI (16.67 %) and maximum yield (57.30 quintals per hectare (q ha⁻¹); 76.13 % increase over the control. Tebuconazole + trifloxystrobin WG performed similarly with 54.68 % disease reduction and a yield of 54.00 q ha⁻¹ (66.00 % increase in yield over the control). Kasugamycin + copper oxychloride WP showed the lowest efficacy (18.75 % disease reduction; 23.89 % increase in yield over the control). The results indicate that azoxystrobin + tebuconazole + prochloraz EC and tebuconazole + trifloxystrobin WG are promising combinations for effective management of brown spot disease in rice.

Keywords: *Bipolaris oryzae*; disease management; fungicide combinations; rice

Introduction

Rice (*Oryza sativa* L.) is a principal staple food for more than half of the world's population and plays a crucial role in food security, particularly in Asian countries (1). In India, rice occupies about 43.7 million hectares (Mha), accounting for about 22 % of the gross cropped area and contributing around 40–45 % of the total food grain production (2). Among Indian states, Bihar holds significant importance, with rice being a primary crop grown during the Kharif season. It covers around 3.2 Mha in Bihar and serves as a major source of livelihood for rural households (3). Ensuring sustainable rice production in this region is crucial for food security and socio-economic development. However, rice production is constrained by numerous biotic stresses, particularly pests and diseases caused by living organisms, which are one of the biggest challenges in rice production. Rice is affected by more than 60 different diseases, caused by different pathogens like fungi, bacteria, viruses, phytoplasmas, nematodes and some non-infectious factors. Among these, fungal pathogens are the most prevalent in stored seeds and are primarily responsible for seed-borne diseases. Fungal infections alone account for a major proportion of the seed-related problems in rice and contribute significantly to crop losses each year. The major seed-borne diseases of rice include brown spot, sheath

rot, blast, sheath blight, leaf scald, seedling blight and grain spot. Among these, brown spot disease, caused by *Bipolaris oryzae* (syn. *Helminthosporium oryzae*), is one of the most economically important constraints to rice cultivation (4). This disease affects leaves, glumes and grains, leading to poor grain filling and reduced yield quality. Brown spot disease is often severe in regions affected by water scarcity and nutrient deficiencies, particularly under low nitrogen content in the soil (5). These conditions are commonly associated with resource-limited farming systems, which have led to their characterisation as the “poor farmer’s disease” (6).

Historically, the disease was implicated in two major epidemics in India. The first epidemic occurred during 1918–19 in the Krishna-Godavari delta region, while the second epidemic occurred in 1942 across present-day India and Bangladesh, with the latter being linked to the Great Bengal Famine (7). The causative fungus proliferates through intercellular and intracellular mycelial growth, forming a greyish-brown to dark brown mycelial mat on infected tissues. In culture, it produces olivaceous to grey or black mycelium (4). Symptomatically, the pathogen induces coleoptile blight, oval dark brown to purplish lesions on leaves and impairs photosynthetic activity, leading to scorching, premature leaf senescence, reduced tillering and stunted root and shoot development. The glume

blotching phase of *B. oryzae* has been identified as particularly detrimental (8). Recent reports suggest 5–90 % yield losses due to brown spot disease, depending on the severity of infection and climatic conditions (9). Warm and humid climates, poor soil fertility and inadequate management practices favour disease proliferation conditions that are prevalent in many rice-growing regions of Bihar (10). Despite Bihar being a significant rice-producing state, fluctuations in yield are frequently reported; the specific contribution of brown spot disease to these yield gaps remains underexplored. Therefore, establishing a clear relationship between disease pressure and regional production trends is essential. Host plant resistant against brown spot disease could serve as an important management strategy (11). Traditional single-fungicide treatments often provide inconsistent results due to the development of resistance and the limited spectrum of activity (12). Hence, integrated disease management approaches using fungicide combinations are gaining prominence, aiming to improve efficacy, delay resistance development and reduce the frequency of application (13). The application of combinations of systemic and contact fungicides has shown significant potential in controlling brown spot by targeting multiple stages of the pathogen's life cycle (14). Additionally, certain fungicide combinations may exhibit synergistic effects, whereby the combined action of two or more fungicides increases their overall effectiveness in disease management. Exploring these synergistic interactions could contribute to the development of more robust disease management strategies (15).

Materials and Methods

In vitro efficacy of the combination of fungicides against the brown spot of rice pathogen

The brown spot pathogen of rice, *B. oryzae*, was isolated from the diseased rice leaves collected from the Bihar Agricultural University, Sabour farm. Infected leaf portions along with adjacent healthy portions were cut into small pieces and placed on potato dextrose agar (PDA) media, followed by incubation at 26 ± 2 °C. Pathogen identification was carried out based on cultural and morphological characteristics. The fungal colonies developed on PDA medium were examined for colony colour, texture and growth pattern. For microscopic observations, fungal structures were stained with lactophenol cotton blue and observed under a compound microscope. The isolate was confirmed as *B. oryzae* based on its distinct features, including septate, olivaceous-brown mycelium and elongated, cylindrical to obclavate conidia with multiple septa and rounded ends. The hyphal tip method was used for sub-culturing the fungus in Petri plates to obtain a pure culture. The pure culture was maintained on PDA slants and stored in a refrigerator at 4 °C for further studies. Fungicide screening experiments against *B. oryzae* were conducted under *in-vitro* conditions using the poisoned food technique. Stock solutions of

each fungicide treatment were prepared using the following formula:

$$C_1V_1 = C_2V_2$$

Where,

C_1 = Concentration of stock solution (g mL⁻¹),

C_2 = Desired concentration (g mL⁻¹),

V_1 = Volume (mL) of the stock solution to be added

V_2 = Measured volume (mL) of the PDA medium.

The efficacy of seven fungicide combinations belonging to different groups, viz., mancozeb 50 % + thiophanate methyl 25 % WG, kasugamycin 5 % + copper oxychloride 45 % WP, azoxystrobin 5.1 % + tebuconazole 9.1 % + prochloraz 18.2 % EC, fenoxanil 5 % + isoprothiolane 30 % EC, azoxystrobin 14 % + epoxiconazole 9 % SC, picoxystrobin 7.05 % + propiconazole 11.7 % SC, tebuconazole 50 % + trifloxystrobin 25 % WG was tested against the test pathogen *B. oryzae* under *in vitro* conditions to find out their relative efficacy in inhibiting pathogen growth using the “poisoned food technique” at concentrations of 100 ppm, 150 ppm, 200 ppm and 250 ppm (Table 1). Fungicides were incorporated into PDA medium before solidification, then poured into sterile 90 mm petri plates. After solidification, 5 mm mycelial discs from a 7-day-old fungal culture were placed at the centre of each plate with the mycelial surface in direct contact with the medium. Control plates were maintained without fungicide treatment. Each treatment was replicated three times and incubated at 26 ± 2 °C. Radial mycelial growth was measured after 7 and 14 days of incubation. The percentage inhibition over control was calculated by the following formula (16):

$$\text{Per cent inhibition} = \frac{C - T}{C} \times 100$$

Where,

C = Radial fungal growth in control (mm)

T = Radial fungal growth in treatment (mm).

The mean radial fungal colony growth and percentage inhibition for each treatment were calculated and statistically examined.

Field evaluation of fungicide combinations against brown spot of rice

The study was conducted at Bihar Agricultural University, Sabour, using rice cultivar ‘Rajendra Sweta’ during two consecutive kharif seasons (2023 and 2024). The field experiment was laid out in a randomised block design (RBD) with eight treatments and three replications. The plot size was 4.8 x 2.4 square meters (m²) with a row-to-row spacing of 20 cm, plant-to-plant spacing of 15 cm and inter-plot spacing of 1.0 m. Recommended agronomic practices were followed throughout the experiment. All the treatments were applied twice: the first application was made at the initial appearance of symptoms, followed by a second application 15

Table 1. Treatment details of the experiment

Treatments	Fungicide composition	Trade name	Dose/liter of water
T ₁	Mancozeb 50 % + Thiophanate methyl 25 % WG	Juniper	3.0 g L ⁻¹
T ₂	Kasugamycin 5 % + copper oxychloride 45 % WP	Conika	1.5 g L ⁻¹
T ₃	Azoxystrobin 5.1 % + Tebuconazole 9.1 % + Prochloraz 18.2 % EC	Almagor	3.5 mL L ⁻¹
T ₄	Fenoxanil 5 % + Isoprothiolane 30 % EC	Capstone	2 mL L ⁻¹
T ₅	Azoxystrobin 14 % + Epoxiconazole 9 % SC	Mentor	1.5 mL L ⁻¹
T ₆	Picoxystrobin 7.05 % + Propiconazole 11.7 % SC	Galileo way	2 mL L ⁻¹
T ₇	Tebuconazole 50 % + Trifloxystrobin 25 % WG	Nativo	0.4 g L ⁻¹
T ₈	Untreated control	-	-

days later with the help of a knapsack sprayer. The control plots were sprayed with distilled water. A total of 25 randomly selected leaves were collected from each plot, before harvesting and disease severity was assessed using a 0–9 disease rating scale as outlined in Table 2 and Fig. 1 (17). The per cent disease index (PDI) was calculated using the formula (18):

Per cent disease index (PDI) =

$$\left\{ \frac{\text{Sum of all individual disease ratings}}{\text{Total number of leaves observed} \times \text{Maximum disease grade}} \right\} \times 100$$

Alternatively,

Per cent disease index =

$$\left\{ \frac{n(0) + n(1) + n(3) + n(5) + n(7) + n(9)}{t(n)} \right\} \times 100$$

Where,

$n(0)$, $n(1)$, $n(3)$, $n(5)$, $n(7)$, $n(9)$ = Number of leaves showing severity score of 0, 1, 3, 5, 7, 9

$t(n)$ = total number of leaves scored.

For grain yield estimation, a 1m x 1m area was randomly selected from each plot using a square wooden frame. The selected area was harvested and threshed separately and weighed after proper drying of seeds. The recorded weight (gm m^{-2}) was converted to quintals per hectare (q ha^{-1}) using the formula:

$$\text{Yield (weight q ha}^{-1}\text{)} = \frac{\text{Weight in gm}^{-2}}{10} \times 100$$

Statistical analysis was performed using OPSTAT software (CCSHAU, Hisar). The *F*-test was applied and critical differences (CD) were calculated at a 5 % level of significance.

Results

In vitro efficacy of fungicide combinations against the brown spot pathogen of rice

The efficacy of seven fungicide combinations was evaluated against the brown spot pathogen of rice, *B. oryzae*, under *in vitro* conditions during the kharif season of 2023. The data presented in Table 3 reveal that the evaluated fungicides significantly reduced the radial mycelial growth of the fungus. Azoxystrobin 5.1 % + tebuconazole 9.1 % + prochloraz 18.2 % EC was found superior, followed by tebuconazole 50 % + trifloxystrobin 25 % WG. These two fungicide combinations completely inhibited fungal growth at 200 ppm and 250 ppm respectively. These treatments were followed by azoxystrobin 14 % + epoxiconazole 9 % SC, which recorded a mean inhibition of 87.78 % at 250 ppm. Kasugamycin 5 % + copper oxychloride 45 % WP was the least effective treatment at all concentrations, with a maximum mean inhibition of 63.89 % at 250 ppm.

Field evaluation of fungicide combinations against brown spot of rice

The fungicide combinations were further evaluated under field conditions for their effect on brown leaf spot disease and grain yield. The data presented in Table 4 reveal that all fungicides significantly controlled the brown spot disease severity under field conditions during both kharif seasons (2023 and 2024). Azoxystrobin 5.1 % + tebuconazole 9.1 % + prochloraz 18.2 % EC was found to be the most effective treatment among all fungicide combinations, recording maximum mean disease reduction of 66.97 % and minimum mean PDI of 16.67 %. It was followed by tebuconazole 50 % + trifloxystrobin 25 % WG, which recorded a mean disease reduction of 54.68 % and a mean PDI of 22.87 %. Kasugamycin 5 % + copper oxychloride 45 % WP recorded the least average disease reduction (18.75 %) and maximum mean PDI (41.00 %) when compared with the untreated control (PDI 50.46 %).

The data presented in Table 5 reveal that all fungicide treatments significantly increased grain yield under field conditions during both kharif seasons (2023 and 2024). Azoxystrobin 5.1 % + tebuconazole 9.1 % + prochloraz 18.2 % EC was found to be the most effective treatment among all fungicide combinations, recording the highest mean yield increase (76.13 %) and maximum mean grain yield (57.30 q ha^{-1}). It was statistically at par with both the years with tebuconazole 50 % + trifloxystrobin 25 % WG, which recorded a mean yield increase of 66.00 % and a mean yield of 54.00 q ha^{-1} . The lowest average yield increase (23.89 %) and grain yield (40.30 q ha^{-1}) were observed in kasugamycin 5 % + copper oxychloride 45 % WP. The untreated control recorded the lowest mean yield (32.53 q ha^{-1}) (Fig.2).

Discussion

In vitro efficacy of fungicide combinations against the brown spot of rice pathogen

The present investigation is in agreement with previous findings, which reported complete inhibition of mycelial growth by tebuconazole + trifloxystrobin at different concentrations (0.05 %, 0.1 % and 0.2 %) (19). The fungicides were tested against *B. oryzae* and reported that among the combination fungicides, tebuconazole 50 % + trifloxystrobin 25 % WG completely inhibited the mycelial growth of the *B. oryzae* (20). The combination fungicides were tested and reported that, 100 % mycelial growth inhibition was recorded in azoxystrobin 20 % + difenoconazole 12.5 %, propiconazole 13.9 % + difenoconazole 13.9 % and tebuconazole 50 % + trifloxystrobin 25 % at 250 ppm followed by 85.39 %, 78.71 % and 78.65 % mycelial growth inhibition at 100 ppm, 76.30 %, 66.54 % and 60.22 % mycelial inhibition at 50ppm, 61.03 %, 49.76 % and 52.54 % inhibition at 25 ppm and 54.19 %, 48.12 % and 44.08 % inhibition at 10 ppm of azoxystrobin 20 % + difenoconazole 12.5 %, propiconazole 13.9 % + difenoconazole 13.9 % and tebuconazole 50 % + trifloxystrobin 25 %, respectively (21).

Table 2. Disease scoring scale for brown spot of rice

Disease score	Disease severity (% of leaf area diseased)	Disease reaction
0	No incidence	Immune
1	Less than 1 %	Resistant (R)
3	1–10 %	Moderately resistant (MR)
5	11–25 %	Moderately susceptible (MS)
7	26–50 %	Susceptible (S)
9	More than 50 %	Highly susceptible (HS)

Table 3. Per cent growth inhibition of *Bipolaris oryzae* mycelium on treated PDA media plates

Treatments	100 ppm			150 ppm			200 ppm			250 ppm		
	7 DAI	14 DAI	Mean	7 DAI	14 DAI	Mean	7 DAI	14 DAI	Mean	7 DAI	14 DAI	Mean
Mancozeb 50 % + Thiophanate methyl 25 % WG	47.78 (43.73)	45.56 (42.45)	46.67	60.00 (50.77)	57.78 (49.48)	58.89	70.00 (56.81)	67.78 (55.43)	68.89	76.67 (61.16)	74.44 (59.67)	75.56
Kasugamycin 5 % + copper oxychloride 45 % WP	38.89 (38.58)	35.56 (36.60)	37.22	53.33 (46.91)	51.11 (45.64)	52.22	57.78 (49.48)	55.56 (48.19)	56.67	64.44 (53.41)	63.33 (52.74)	63.89
Azoxystrobin 5.1 % + Tebuconazole 9.1 % + Prochloraz 18.2 % EC	86.67 (68.74)	83.33 (66.06)	85.00	87.78 (69.72)	88.89 (70.75)	88.33	100.00 (90.00)	100.00 (90.00)	100.00	100.00 (90.00)	100.00 (90.00)	100.00
Fenoxanil 5 % + Isoprothiolane 30 % EC	51.11 (45.64)	48.89 (44.36)	50.00	56.67 (48.83)	54.44 (47.55)	55.56	61.11 (51.43)	57.78 (49.48)	59.44	68.89 (56.12)	67.78 (55.43)	68.33
Azoxystrobin 14 % + Epoxiconazole 9 % SC	62.22 (52.08)	58.89 (50.13)	60.56	74.44 (59.67)	71.11 (57.51)	72.78	82.22 (65.14)	80.00 (63.50)	81.11	88.89 (70.75)	86.67 (68.74)	87.78
Picoxystrobin 7.05 % + Propiconazole 11.7 % SC	57.78 (49.48)	54.44 (47.55)	56.11	65.56 (54.08)	68.89 (56.12)	67.22	76.67 (61.16)	75.56 (60.41)	76.11	83.33 (66.00)	82.22 (65.14)	82.78
Tebuconazole 50 % + Trifloxystrobin 25 % WG	76.67 (61.16)	74.44 (59.69)	75.56	81.11 (64.31)	80.00 (63.50)	80.56	91.11 (73.00)	88.89 (70.75)	90.00	100.00 (90.00)	100.00 (90.00)	100.00
Control	0.00 (0.00)	0.00 (0.00)	0.00	0.00 (0.00)	0.00 (0.00)	0.00	0.00 (0.00)	0.00 (0.00)	0.00	0.00 (0.00)	0.00 (0.00)	0.00
SE(m) ±	1.07	1.30	-	1.23	1.23	-	1.34	1.22	-	1.24	1.15	-
C.D (p = 0.01)	3.20	3.90	-	3.68	3.70	-	4.03	3.66	-	3.71	3.46	-
CV	4.12	5.19	-	4.32	4.38	-	4.17	3.86	-	3.52	3.32	-

DAI: Day after inoculation; Figures in parentheses represent angular transformed values.

Table 4. Effect of different fungicides on PDI and disease decrease over control of each treatment during kharif 2023 and 2024

Treatments	Fungicide composition	Dosage	Kharif 2023			Kharif 2024			Mean
			PDI 2023*	Disease reduction (%)	PDI 2024*	Disease reduction (%)	PDI	Reduction (%)	
T ₁	Mancozeb 50 % + Thiophanate methyl 25 % WG	3.0 g L ⁻¹	35.48	31.23	37.48	24.02	36.48	27.71	
T ₂	Kasugamycin 5 % + copper oxychloride 45 % WP	1.5 g L ⁻¹	41.56	19.44	40.44	18.02	41.00	18.75	
T ₃	Azoxystrobin 5.1 % + Tebuconazole 9.1 % + Prochloraz 18.2 % EC	3.5 mL L ⁻¹	16.74	67.55	16.59	66.37	16.67	66.97	
T ₄	Fenoxanil 5 % + Isoprothiolane 30 % EC	2 mL L ⁻¹	33.74	34.60	36.30	26.43	35.02	30.60	
T ₅	Azoxystrobin 14 % + Epoxiconazole 9 % SC	1.5 mL L ⁻¹	29.92	42.00	29.33	40.54	29.63	41.29	
T ₆	Picoxystrobin 7.05 % + Propiconazole 11.7 % SC	2 mL L ⁻¹	30.67	40.56	30.52	38.14	30.60	39.37	
T ₇	Tebuconazole 50 % + Trifloxystrobin 25 % WG	0.4 g L ⁻¹	23.37	54.71	22.37	54.65	22.87	54.68	
T ₈	Untreated control	-	51.59	0	49.33	0.00	50.46	0.00	
	CD (p = 0.05)	-	4.87	-	2.18	-	-	-	
	SEm (±)	-	1.61	-	0.72	-	-	-	
	CV	-	8.67	-	3.80	-	-	-	

* Mean value of three replications.

Table 5. Effect of different fungicides on grain yield and yield increase over control of each treatment during kharif 2023 and kharif 2024

Treatments	Fungicide composition	Dosage	Kharif 2023			Kharif 2024			Mean
			Yield 2023*	Yield increase (%)	Yield 2024*	Yield increase (%)	Yield	Yield increase (%)	
T ₁	Mancozeb 50 % + Thiophanate methyl 25 % WG	3.0 g L ⁻¹	42.27	34.61	44.27	31.52	43.27	33.02	
T ₂	Kasugamycin 5 % + copper oxychloride 45 % WP	1.5 g L ⁻¹	37.27	18.68	43.33	28.74	40.30	23.89	
T ₃	Azoxystrobin 5.1 % + Tebuconazole 9.1 % + Prochloraz 18.2 % EC	3.5 mL L ⁻¹	56.93	81.32	57.66	71.30	57.30	76.13	
T ₄	Fenoxanil 5 % + Isoprothiolane 30 % EC	2 mL L ⁻¹	42.75	36.15	44.00	30.72	43.38	33.34	
T ₅	Azoxystrobin 14 % + Epoxiconazole 9 % SC	1.5 mL L ⁻¹	44.03	40.23	47.67	41.62	45.85	40.95	
T ₆	Picoxystrobin 7.05 % + Propiconazole 11.7 % SC	2 mL L ⁻¹	44.67	42.25	46.33	37.65	45.50	39.87	
T ₇	Tebuconazole 50 % + Trifloxystrobin 25 % WG	0.4 g L ⁻¹	53.67	70.91	54.33	61.41	54.00	66.00	
T ₈	Untreated control	-	31.40	0.00	33.66	0.00	32.53	0.00	
	CD (p = 0.05)	-	5.73	-	5.75	-	-	-	
	SEm (±)	-	1.89	-	1.90	-	-	-	
	CV	-	7.41	-	7.08	-	-	-	

* Mean value of three replications; PDI: Per cent disease index.

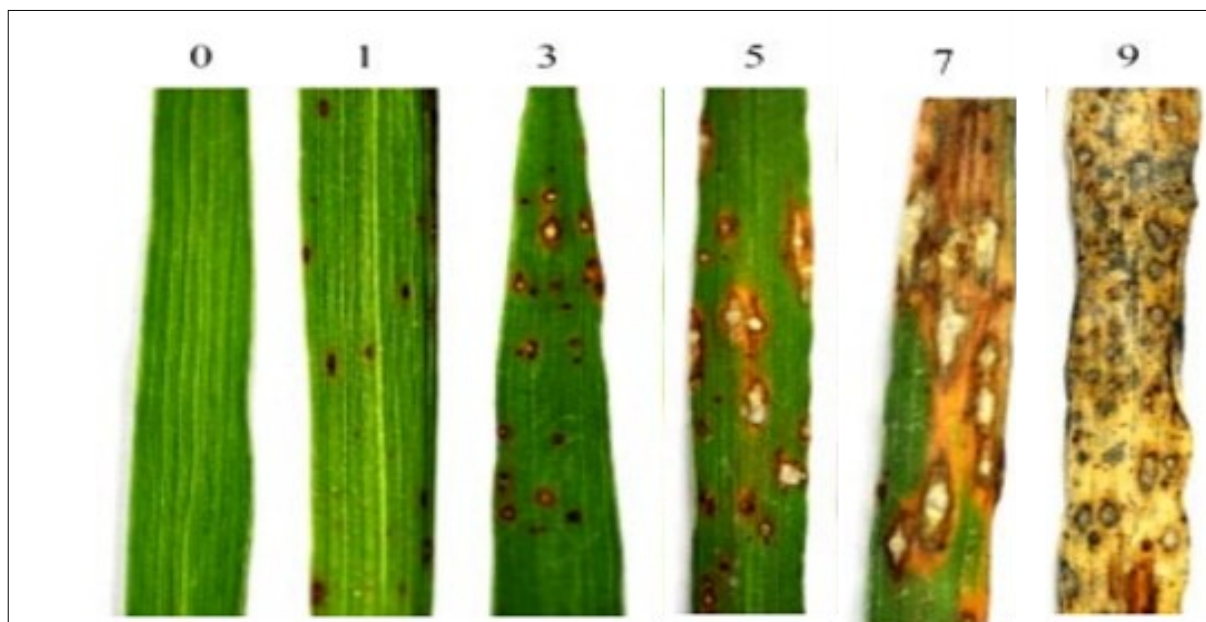


Fig. 1. Pictorial scale for brown spot of rice disease scoring.

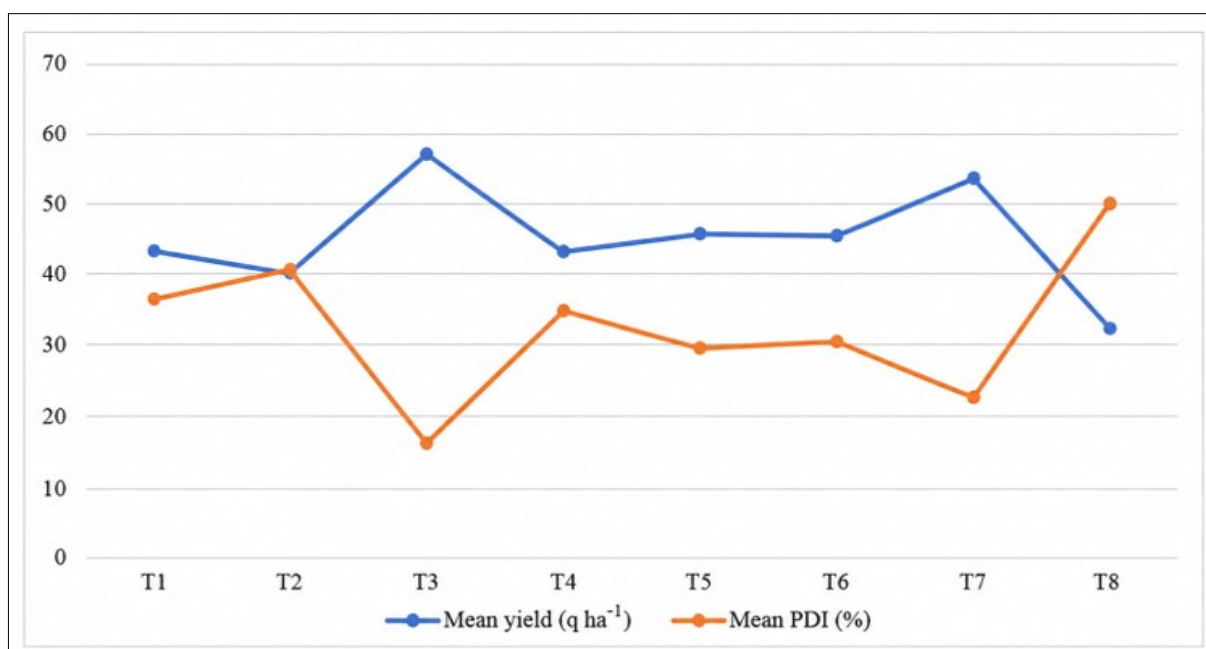


Fig. 2. Effect of different fungicides on Per cent disease index and grain yield of each treatment during kharif 2023 and 2024.

Field evaluation of fungicide combinations against brown spot of rice

The findings of the present investigation were also supported by earlier studies, which evaluated the field performance of different fungicides and reported that tebuconazole at a concentration of 2000 ppm (0.20 %) produced the lowest incidence of brown spot disease, observed just 15.25 % PDI, when compared with other fungicides and control treatments (22). Similarly, it was reported that most enhanced grain yield in trifloxystrobin 25 % + tebuconazole at 0.4 g L⁻¹ across the three tested varieties, with maximum grain yield (61.5 q/ha) recorded in BPT 5204 (23). Studies showing the effect of different fungicides combination against brown spot disease of rice under field conditions states that azoxystrobin + difenoconazol at 500 mL ha⁻¹ is the most effective treatment, recording PDI values of 6.14 % and 8.90 % with disease reduction of 84.6 % and 81.7 % over control during kharif 2018 and 2019 respectively. This was followed by trifloxystrobin + tubeconazole at 160 g ha⁻¹ which recorded PDI values of 10.10% and 12.50 % with disease reduction of 74.8 % and 74.3 % in the

respective years (24). Other researchers also supported that hexaconazole 5 % EC at 0.125mL L⁻¹ has maximum disease reduction over control (71.11 %) with PDI of 14.67 %, followed by tebuconazole 50 % + trifloxystrobin 25 % WG at 0.4 g L⁻¹ which recorded a PDI of 22.67 % and 68.12 % disease reduction over control (25).

The present findings are also supported by previous reports on the effectiveness of different fungicides against brown leaf spot of rice. Foliar spray with difenoconazole 25 % EC at 0.5 mL L⁻¹ recorded maximum yield of 41.68 q ha⁻¹ and per cent yield increase of 28.24 %, followed by tebuconazole 25.9 % EC at 1.5 mL L⁻¹ with 40.25 q ha⁻¹ and per cent yield increase of 23.84 % as compared to control (26). Per cent increase in yield over control in propiconazole 25 % EC was 18.56 % with the highest yield of 20.38 q ha⁻¹ (27). It was followed by a combination of fungicide pyraclostrobin + epoxyconazole at 0.12 % with a yield of 19.86 q ha⁻¹ and 15.53 % yield increase over control. A three-year pooled data (2009, 2010, 2011) shows significantly higher grain yield (33.69 q ha⁻¹) with a 90.57 % increase in yield following application of propiconazole (0.1 %) (28). Further, propiconazole was

followed by carbendazim (0.1 %) and bitertanol (0.25 %), which recorded grain yields of 31.73 and 29.76 q ha⁻¹ respectively. Azoxystrobin is categorised under the strobilurin group of fungicides and acts as a quinone outside inhibitor (QoI), disrupting mitochondrial respiration in fungal cells and thereby restricting the growth and spread of *B. oryzae*. In contrast, triazole fungicides such as tebuconazole and imidazole fungicides like prochloraz interfere with ergosterol biosynthesis, which is essential for fungal cell membrane integrity. Thus, strobilurins primarily affect energy production, whereas triazoles target membrane formation. Their combined application offers both preventive and curative effects, improving disease management efficacy.

Conclusion

Brown leaf spot disease of rice has been an important constraint in rice production historically and is currently gaining attention in several parts of India. The collective activity of the fungicide mixtures may provide greater efficacy than the individual effects of their components, due to a synergistic effect. This approach is essential for delaying the development of resistance and minimising fungicide usage (14, 28). Under both *in vitro* and field conditions, azoxystrobin 5.1 % + tebuconazole 9.1 % + prochloraz 18.2 % EC was found to be the most effective treatment among the tested fungicides, followed by tebuconazole 50 % + trifloxystrobin 25 % WG. The present study demonstrates that for effective management of brown spot disease in rice, a combination of azoxystrobin 5.1 % + tebuconazole 9.1 % + prochloraz 18.2 % EC should be applied twice, with the first spray at the appearance of disease symptoms and the second spray 15 days after the first application. This treatment could be a viable option for managing brown spot disease of rice and enhancing grain yield.

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Authors' contributions

VK carried out the research work and participated in data collection. UK contributed to data analysis and manuscript drafting. AK conceived the study and participated in its design, data collection, analysis and manuscript drafting. MN, BD and SB participated in manuscript writing and proofreading. All the authors read and approved the final manuscript.

Compliance with ethical standards

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

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