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Management of spot blotch using fungicidal combinations in wheat (*Triticum aestivum*)

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ABSTRACT

Spot blotch is a major constraint to wheat (*Triticum aestivum* L.) production in the Eastern Gangetic Plains (EGP) of India, where wheat cultivars express moderate resistance to susceptible reaction. Limited information available on yield penalties under varying disease severities. The present study was carried out during winter (*rabi*) seasons of 2021–22 and 2022–23 at Bihar Agricultural University, Sabour, Bihar to assess the efficacy of selected fungicidal combinations against wheat spot blotch under *in vitro* and *in vivo* conditions. A total of eight fungicidal combinations were evaluated, including tebuconazole 50% + trifloxystrobin 25% WG, propiconazole 13.9% + difenoconazole 13.9% EC, azoxystrobin 12.5% + tebuconazole 12.5% SC, picoxystrobin 7.05% + propiconazole 11.7% WSC, kresoxim-methyl 44.3% SC, propiconazole 25% EC, tebuconazole 22.9% EC, and mancozeb 75% WP, each tested at four concentration levels. *In vitro* activity was quantified using radial mycelial growth inhibition assays, while *in vivo* efficacy was examined through field trials conducted in a randomized block design. *In vitro* results showed complete fungal mycelial growth inhibition by all four combinations at 100 ppm, while at 75 ppm, tebuconazole 50% + trifloxystrobin 25% WG achieved the highest inhibition (91.84%). Field trials conducted over two years revealed that tebuconazole 50% + trifloxystrobin 25% WG at 1 g/Lwas the most effective in reducing disease severity, with the lowest infected plant, disease incidence and percent disease index. This treatment has also achieved maximum disease reduction (81.69% and 80.96%) resulting 28.91% and 27.46% yield increase over control during 2021–22 and 2022–23, respectively. Hence, it is concluded that, tebuconazole 50% + trifloxystrobin 25% WG belonging to two different chemical family group with broad mode of actions, is highly effective for managing spot blotch in wheat.

Keywords: *Bipolaris sorokiniana,* Fungicide, Management, Tebuconazole + trifloxystrobin

Wheat (*Triticum aestivum* L.) is the most widely cultivated crop globally and serves as a staple food for one quarter of the world's population. This crop is grown on 222.88 million hectares worldwide producing a record output of 788.95 million tonnes with an average productivity of 35.4 q/ha (ICAR-IIWBR 2024). Projections by the Food and Agriculture Organization (FAO) suggested that global wheat demand will reach approximately 840 million tonnes by 2050 (FAO 2009). Similarly, India's wheat production is expected to increase to 136 million tonnes by 2030, reflecting a rise of 24 million tonnes (FAO 2009). This growth is projected to stem from yield improvements, with an additional 0.7 t/ha and a one-million-hectare expansion in wheat cultivation (Kingsly *et al.* 2023). However, climate change and the emergence of plant diseases remain critical threats to sustaining wheat production and grain quality.

Paddy (*Oryza sativa*)-wheat cropping pattern is one of the prevalent cropping systems in Bihar which poses a challenge of delayed wheat planting due to late harvest of paddy and water stagnation resulting poor yield. Delayed wheat planting faces westerly wind and the occurrence of terminal heat stress and ultimately shrivelled grain and poor quality (Kumar *et al*. 2015). Despite these issues, Bihar contributes 6.34% to national wheat production. The state plays a significant role in wheat production, particularly within the Eastern Gangetic Plains (EGP). Over the last three years, the state's wheat acreage has remained steady at approximately 2.2 million hectares. However, productivity levels have driven a notable increase with yields rising from 27.8 q/ha in 2021–22 to 32.08 q/ha in 2023–24 (ICAR-IIWBR 2024).

EGP, classified as Mega Environment 5A (ME5A), are distinct due to their high humidity and elevated temperatures. These conditions favour proliferation of biotic stresses and abiotic stresses like terminal heat stresses (Villareal *et al.* 1995). Among the challenges faced by wheat growers in this area, spot blotch caused by *Bipolaris sorokiniana* (Sacc.) Shoem. (Teleomorph: *Cochliobolus sativus*), has emerged as a major concern due to conducive weather. The increased

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use of high-yielding wheat varieties of moderate resistant to moderate susceptible type has exacerbated the issue and promoted fungicidal spray and timely planting of the crop. Annual yield loss of 15–20% due to the spot blotch is a significant threat across South Asia (Duveiller and Sharma 2009). Under severe conditions, yield reductions can reach up to 80% (Aggarwal *et al.* 2019). In India, the disease impacts over 10 million hectares in the Gangetic plains, with losses ranging from 10–50%. These losses translate to a reduction in grain yield of up to 25% in severely affected areas (Nagarajan and Kumar 1998). Furthermore, Narayan (2004) observed yield losses of 2–30% due to foliar blight in Pusa (Bihar).

Common symptoms of the disease are most prominent on the lower leaves after heading, appearing as elongated brown-black lesions that reduce the photosynthetic area. This diminishes carbohydrate accumulation during the grain-filling stage, leading to lower kernel number and weight, ultimately affecting both yield and grain quality. During last two decades, information on impact and management practices of the disease is rare in the literature, especially for north-eastern states of India (Kumar *et al.* 2018). Till now, four resistance genes has been found which confer resistance against spot blotch i.e. *Sb1* (Lillemo *et al.* 2013), *Sb2* (Kumar *et al.* 2015), *Sb3* (Lu *et al.* 2016) and *Sb4* (Zhang *et al.* 2020). Gene *Sb1* is likely to present in a few Indian wheat varieties as it is linked with *Lr34/Yr18/Sr57*, a pleiotropic gene. Other genes have been restricted in breeding programmes due to lack of robust markers and/or limited resources. This disease can be effectively managed by fungicide combination to provide broader action, lower required doses and reduce the risk of resistance development. Therefore, this study aimd to evaluate the efficacy of fungicides with diverse modes of action to manage spot blotch effectively and estimate yield increase. Fungicide in combination are found efficient compared over solo applications, including broader activity, effective control at lower doses, and reduced risk of resistance in target pathogens. Combining active ingredients with different modes of action decreases selection pressure and delays the emergence of resistance. Such broad-spectrum combinations are therefore well suited for managing spot blotch (Kumar *et al.* 2023). This study was carried out to assess the efficacy of QoI, DMI, and benzimidazole fungicides, applied individually and in combination, against the disease.

MATERIALS AND METHODS

The present study was carried out during winter (*rabi*) seasons of 2021–22 and 2022–23 at Bihar Agricultural University, Sabour (86°57′E and 25°15′N; at an elevation of 46 m amsl), Bihar. Eight fungicides with unique modes of action were tested for efficacy against *Bipolaris sorokiniana* under *in vitro* and *in vivo* conditions. The treatment details comprised of, tebuconazole 50% + trifloxystrobin 25% WG (T_1), propiconazole 13.9% + difenoconazole 13.9% EC (T_2), azoxystrobin 12.5% + tebuconazole 12.5% SC (T_3), picoxystrobin 7.05% + propiconazole 11.7% WSC (T_4),

Table 1 Different concentration of fungicides tested *in vitro* and *in vivo* against *Bipolaris sorokiniana*

S.no.	Concentration of fungicides
1.	(Tebuconazole 50% + Trifloxystrobin 25% WG) Nativo @25 ppm
2.	(Tebuconazole 50% + Trifloxystrobin 25% WG) Nativo @50 ppm
3.	(Tebuconazole 50% + Trifloxystrobin 25% WG) Nativo @75 ppm
4.	(Tebuconazole 50% + Trifloxystrobin 25% WG) Nativo @100 ppm
5.	(Propiconazole 13.9% + Difenoconazole 13.9% EC) Prodizole @25 ppm
6.	(Propiconazole 13.9% + Difenoconazole 13.9% EC) Prodizole @50 ppm
7.	(Propiconazole 13.9% + Difenoconazole 13.9% EC) Peridiole @75ppm
8.	(Propiconazole 13.9% + Difenoconazole 13.9% EC) Prodizole @100 ppm
9.	(Azoxystrobin 12.5% + Tebuconazole 12.5% SC)Tebazo @25 ppm
10.	(Azoxystrobin 12.5% + Tebuconazole 12.5% SC)Tebazo @50 ppm
11.	(Azoxystrobin 12.5% + Tebuconazole 12.5% SC)Tebazo @75 ppm
12.	(Azoxystrobin 12.5% + Tebuconazole 12.5% SC)Tebazo @100 ppm
13.	(Picoxystrobin 7.05% + Propiconazole 11.7% WSC) Sayanka @25 ppm
14.	(Picoxystrobin 7.05% + Propiconazole 11.7% WSC) Sayanka @50 ppm
15.	(Picoxystrobin 7.05% + Propiconazole 11.7% WSC) Sayanka @75 ppm
16.	(Picoxystrobin 7.05% + Propiconazole 11.7% WSC) Sayanka @100 ppm
17.	(Kresoxin methyl 44.3% SC) Elona @25 ppm
18.	(Kresoxin methyl 44.3% SC) Elona @50 ppm
19.	(Kresoxin methyl 44.3% SC) Elona @75 ppm
20.	(Kresoxin methyl 44.3% SC) Elona @100 ppm
21.	(Propiconazole 25% EC) Tilt @25 ppm
22.	(Propiconazole 25% EC) Tilt @50 ppm
23.	(Propiconazole 25% EC) Tilt @75 ppm
24.	(Propiconazole 25% EC) Tilt @100 ppm
25.	(Tebuconazole 22.9% EC) Facure @25 ppm
26.	(Tebuconazole 22.9% EC) Facure @50 ppm
27.	(Tebuconazole 22.9% EC) Facure @75 ppm
28.	(Tebuconazole 22.9% EC) Facure @100 ppm
29.	(Mancozeb 75% WP) Agrofil M-45 @25 ppm
30.	(Mancozeb 75% WP) Agrofil M-45 @50 ppm
31.	(Mancozeb 75% WP) Agrofil M-45 @75 ppm
32.	(Mancozeb 75% WP) Agrofil M-45 @100 ppm

kresoxim-methyl 44.3% SC (T_5), propiconazole 25% EC (T_6), tebuconazole 22.9% EC (T_7), and mancozeb 75% WP (T_8) and control (T_9). The study was carried out during 2021–22 under *in vitro* condition at Bihar Agricultural University, Sabour, Bihar using the Poisoned Food Technique (Schmitz 1930) to evaluate their effectiveness in managing spot blotch in wheat.

Four fungicide concentrations (25, 50, 75, and 100 ppm) were tested against *Bipolaris sorokiniana* using the Poisoned Food Technique (Table 1). Fungicides were mixed with Potato Dextrose Agar (PDA) before solidification, poured into sterilized petri plates, and solidified. A 5 mm mycelial plug from a 7-day-old fungal culture was placed at the center of each plate. Controls had PDA without fungicides but inoculated with the fungus. Each treatment was replicated five times and incubated at 26.2°C in a BOD incubator to assess fungal growth inhibition.

Mycelial growth (mm): Mycelial growth was measured at 5, 10, and 15 days after incubation. The average radial growth of the fungal mycelial colony was determined using a measuring scale.

Mycelial growth inhibition (%): The per cent inhibition over control will be calculated by Vincent's formula (1947):

$$I= [(C-T)/T] \times 100$$

Where I, Per cent inhibition; C, Radial growth of fungus in control; T, Radial growth of fungus in treatment.

Field experiment: The experiments were conducted during the winter (*rabi*) seasons of 2021–22 and 2022–23 at Bihar Agricultural University, Sabour, Bihar, using a randomized complete block design with three replicates and nine treatments including a control plot. Each plot measured 3 m × 1 m, with rows spaced 20 cm apart. The wheat variety used was HD2967 along with border rows of Agra Local, and standard agronomic practices were followed. To create epiphytotic conditions, artificial inoculation was performed using a virulent spore suspension (IIWBR Strain) at a concentration of 4×10^5 spores/µL. The suspension was sprayed at three crop growth stages: tillering (GS20), flag leaf emergence (GS37) and pre-anthesis (GS65) following the Zadoks scale (Zadoks *et al*. 1974). Inoculation was done during evening hours followed by frequent irrigation to maintain high humidity and promote disease development (Chaurasia *et al.* 1999).

Disease incidence was recorded at the hard dough stage by selecting a random 1 m² area within each plot. The number of total plants and infected plants (those showing symptoms on flag and penultimate leaves) were counted, and disease incidence was calculated using Singh and Dube (1998).

$$\text{Disease incidence (\%)} = (\text{Number of infected plants/Total number of plants}) \times 100$$

The Percent Disease Index (PDI) was determined using a 0–9 scale (DWR 2001), based on the disease severity

Table 2 Evaluation of different fungicides on mycelium growth (mm) of *Bipolaris sorokiniana* under *in vitro* condition

Fungicides	Mycelium Growth (mm)*											
	5 DAI				10 DAI				15 DAI			
	25 ppm	50 ppm	75 ppm	100 ppm	25 ppm	50 ppm	75 ppm	100 ppm	25 ppm	50 ppm	75 ppm	100 ppm
Tebuconazole 50% + Trifloxystrobin 25% WG	5.70 (2.49)	4.25 (2.18)	3.35 (1.96)	0.00 (0.00)	8.75 (3.04)	6.90 (2.72)	5.15 (2.38)	0.00 (0.00)	10.95 (3.38)	10.20 (3.27)	7.20 (2.77)	0.00 (0.00)
Propiconazole 13.9% + Difenoconazole 13.9% EC	9.20 (3.11)	7.00 (2.74)	6.20 (2.59)	0.00 (0.00)	11.90 (3.52)	9.90 (3.22)	8.95 (3.07)	0.00 (0.00)	14.20 (3.83)	11.95 (3.53)	11.20 (3.42)	0.00 (0.00)
Azoxystrobin 12.5% + Tebuconazole 12.5% SC	9.95 (3.23)	9.00 (3.08)	6.95 (2.73)	0.00 (0.00)	12.20 (3.56)	11.90 (3.52)	9.70 (3.19)	0.00 (0.00)	15.20 (3.96)	12.45 (3.60)	12.20 (3.56)	0.00 (0.00)
Picoxystrobin 7.05% + Propiconazole 11.7% WSC	5.95 (2.54)	5.25 (2.40)	4.20 (2.17)	0.00 (0.00)	9.35 (3.14)	7.90 (2.90)	6.65 (2.67)	0.00 (0.00)	11.70 (3.49)	10.95 (3.38)	9.25 (3.12)	0.00 (0.00)
Kresoxin methyl 44.3% SC	13.45 (3.73)	11.50 (3.46)	10.20 (3.27)	5.95 (2.54)	16.25 (4.09)	14.15 (3.83)	12.95 (3.67)	8.70 (3.03)	19.45 (4.47)	17.95 (4.30)	16.20 (4.09)	11.95 (3.53)
Propiconazole 25% EC	10.15 (3.26)	9.75 (3.20)	7.05 (2.75)	4.95 (2.33)	12.60 (3.62)	12.40 (3.59)	8.70 (3.03)	7.70 (2.86)	15.95 (4.06)	13.95 (3.80)	12.95 (3.67)	10.95 (3.38)
Tebuconazole 22.9% EC	15.70 (4.02)	15.25 (3.97)	13.95 (3.80)	6.45 (2.64)	19.25 (4.44)	17.90 (4.29)	16.70 (4.15)	9.20 (3.11)	22.45 (4.79)	21.20 (4.66)	19.95 (4.52)	12.45 (3.60)
Mancozeb 75% WP	18.45 (4.35)	17.00 (4.18)	15.45 (3.99)	8.70 (3.03)	21.25 (4.66)	19.65 (4.49)	18.20 (4.32)	11.45 (3.46)	24.45 (4.99)	22.95 (4.84)	21.45 (4.69)	14.70 (3.90)
Control	33.75 (5.85)	33.75 (5.85)	33.75 (5.85)	33.75 (5.85)	65.45 (8.12)	65.45 (8.12)	65.45 (8.12)	65.45 (8.12)	88.25 (9.42)	88.25 (9.42)	88.25 (9.42)	88.25 (9.42)
CD (*p*=0.01%)	0.53	0.31	0.43	0.28	0.51	0.35	0.39	0.28	0.40	0.40	0.40	0.28
SEM (±)	0.18	0.10	0.15	0.10	0.18	0.12	0.14	0.10	0.14	0.14	0.14	0.10
CV	3.18	2.01	3.06	3.51	2.20	1.62	2.04	2.29	1.32	1.43	1.49	1.57

*- Mean values of five replications, DAI- Date after Inoculation, () under parenthesis transformed values.

observed on flag and penultimate leaves:

PDI (%) = (Sum of all disease ratings / Total number of leaves × Maximum rating) × 100

The grain yield obtained from each net plot was recorded in kg and the grain yield/plot was converted into q/ha and statistically analyzed using Microsoft Excel and R environment (R Core Team 2020). Duncan's Multiple Range Test (DMRT) test was performed to differentiate responses of different fungicidal combinations in terms of number of infected plants, disease incidence level, percent disease index and yield (q/ha) (Duncan 1955).

RESULTS AND DISCUSSION

The experiment aimed to assess the efficacy of various fungicides and their concentrations in inhibiting the mycelial growth of *B. sorokiniana* (Table 2). All the fungicides tested demonstrated a significant reduction in the mycelial growth of *B. sorokiniana* compared to the untreated control (Table 3).

The inhibition of *B. sorokiniana* mycelial growth increased with higher fungicide concentrations. At 25 ppm, the colony diameter ranged from 10.95–24.45 mm, with the minimum diameter (10.95 mm) observed in tebuconazole 50% + trifloxystrobin 25% WG and the maximum diameter (24.45 mm) in carbendazim 75% WP, measured 15 days after inoculation (Table 3). The highest inhibition rate (91.84%) was recorded with tebuconazole 50% WG + trifloxystrobin 25% WG at 75 ppm. Conversely, mancozeb 75% WP showed the lowest inhibition (75.69%) at the same concentration, while the control exhibited 85.22 mm of growth after 15 days. At 100 ppm, all fungicidal combinations achieved 100% inhibition of fungal mycelial growth at 5, 10, and 15 DAI (days after inoculation) (Table 3). Fungicides combining triazole and strobilurin groups consistently showed more than 70% inhibition at all concentrations.

These findings were similar to previous studies of Samia *et al.* (2015) and Kumari (2020). Samia *et al.* (2015) reported no mycelial growth in plates treated with propiconazole, except in controls, across all *B. sorokiniana* isolates. Similarly, Kumari *et al.* (2020) demonstrated that azoxystrobin 12.5% SC + tebuconazole 12.5% SC inhibited 85.77% of growth at 25 ppm followed by propiconazole 25 EC (83.72%).

The table data revealed that all fungicides significantly reduced the number of infected plants/m^2 and disease incidence compared to the control during 2021–22 and 2022–23 seasons (Table 4, Fig. 1). Tebuconazole 50% + trifloxystrobin 25% WG @1 g/L was the most effective with the minimum infected plants (35.33 and 38.67) and the

Table 3 Evaluation of fungicides on mycelial growth inhibition (%) of *Bipolaris sorokiniana* under *in vitro* condition

Fungicides	Mycelial Growth Inhibition (%)*											
	5 DAI				10 DAI				15 DAI			
	25 ppm	50 ppm	75 ppm	100 ppm	25 ppm	50 ppm	75 ppm	100 ppm	25 ppm	50 ppm	75 ppm	100 ppm
Tebuconazole 50% + Trifloxystrobin 25% WG	83.11 (65.73)	87.41 (69.22)	90.07 (71.63)	100.00 (90.00)	86.63 (68.55)	89.46 (71.06)	92.13 (73.71)	100.00 (90.00)	87.59 (69.37)	88.44 (70.12)	91.84 (73.40)	100.00 (90.00)
Propiconazole 13.9% + Difenoconazole 13.9% EC	72.74 (58.53)	79.26 (62.91)	81.63 (64.62)	100.00 (90.00)	81.82 (64.76)	84.87 (67.11)	86.33 (68.30)	100.00 (90.00)	83.91 (66.35)	86.46 (68.41)	87.31 (69.13)	100.00 (90.00)
Azoxystrobin 12.5% + Tebuconazole 12.5 % SC	70.52 (57.11)	73.33 (58.91)	79.41 (63.01)	100.00 (90.00)	81.36 (64.42)	81.82 (64.76)	85.18 (67.36)	100.00 (90.00)	82.78 (65.48)	85.89 (67.94)	86.18 (68.18)	100.00 (90.00)
Picoxystrobin 7.05% + Propiconazole 11.7% WSC	82.37 (65.17)	84.44 (66.77)	87.56 (69.35)	100.00 (90.00)	85.71 (67.79)	87.93 (69.67)	89.84 (71.41)	100.00 (90.00)	86.74 (68.65)	87.59 (69.37)	89.51 (71.10)	100.00 (90.00)
Kresoxin methyl 44.3% SC	60.15 (50.86)	65.93 (54.29)	69.78 (56.65)	82.37 (65.67)	75.17 (60.11)	78.38 (62.29)	80.21 (63.59)	86.71 (68.62)	77.96 (62.00)	79.66 (63.19)	81.64 (64.63)	86.46 (68.41)
Propiconazole 25 % EC	69.93 (56.75)	71.11 (57.49)	79.11 (62.80)	85.33 (67.48)	80.75 (63.98)	81.05 (64.19)	86.70 (68.61)	88.24 (69.94)	81.93 (64.84)	85.33 (67.48)	85.33 (67.48)	87.59 (69.37)
Tebuconazole 22.9 % EC	53.48 (47.00)	54.81 (47.76)	58.67 (49.99)	80.89 (64.08)	70.59 (57.16)	72.65 (58.47)	74.48 (59.66)	85.94 (67.98)	74.56 (59.71)	75.98 (60.65)	77.39 (61.61)	85.89 (67.94)
Mancozeb 75 % WP	45.33 (42.32)	49.63 (44.79)	54.22 (47.42)	74.22 (59.49)	67.53 (55.26)	69.98 (56.78)	72.19 (58.17)	82.51 (65.28)	72.29 (58.24)	73.99 (59.34)	75.69 (60.46)	83.34 (65.91)
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)	0.00 (0.00)	0.00 (0.00)
CD (1%)	1.81	1.05	1.43	0.94	1.04	0.71	0.80	0.58	0.53	0.53	0.53	0.52
SEm (±)	0.63	0.37	0.50	0.33	0.36	0.25	0.28	0.20	0.19	0.18	0.18	0.17
CV	2.52	1.38	1.74	0.92	1.28	0.84	0.90	0.56	0.60	0.58	0.57	0.56

*Mean values of five replications; DAI, Date after inoculation; Values under parenthesis are transformed values.

Table 4 Effect of fungicides on number of infected plant/m^2, disease incidence (%) and percent disease index against spot blotch in wheat during 2021–22 and 2022–23

Fungicides	*No. of infected plant/m^2			*Disease incidence (%)			*Percent disease index		
	2021–22	2022–23	Mean	2021–22	2022–23	Mean	2021–22	2022–23	Mean
Tebuconazole 50% + Trifloxystrobin. 25% WG @0.1%	35.33^{e*} (5.99)	38.67^{e} (6.26)	37.00	10.76^{e} (19.15)	12.23^{e} (20.47)	11.49	9.63^{e} (18.08)	10.33^{e} (18.75)	9.98
Propiconazole 13.9% + Difenoconazole 13.9% EC @0.1%	46.00^{d} (6.82)	49.00^{cd} (7.04)	47.50	15.30^{c} (23.03)	15.51^{de} (23.19)	15.40	24.56^{d} (29.71)	26.11^{d} (30.73)	25.33
Azoxystrobin 12.5% + Tebuconazole 12.5% SC @0.1 %	40.33^{e} (6.39)	43.33^{de} (6.62)	41.83	12.28^{de} (20.51)	13.28^{e} (21.37)	12.78	11.48^{e} (19.81)	12.22^{e} (20.46)	11.85
Picoxystrobin 7.05% + Propiconazole 11.7% WSC @0.1%	46.67^{cd} (6.87)	50.00^{cd} (7.11)	48.33	14.18^{cd} (22.12)	15.19^{de} (22.94)	14.68	20.37^{d} (26.83)	20.96^{d} (27.25)	20.66
Kresoxin methyl 44.3% SC @0.1%	64.33^{b} (8.05)	65.33^{b} (8.11)	64.83	21.76^{b} (27.81)	21.96^{b} (27.94)	21.86	46.78^{b} (43.15)	48.33^{b} (44.04)	47.55
Propiconazole 25% EC @0.1%	51.67^{c} (7.22)	52.33^{c} (7.27)	52.00	15.88^{c} (23.48)	20.18^{bc} (26.69)	18.03	42.33^{bc} (40.59)	44.93^{b} (42.09)	43.63
Tebuconazole 22.9% EC @0.1%	49.33^{cd} (7.06)	53.67^{c} (7.36)	51.50	15.77^{c} (23.40)	17.52^{cd} (24.74)	16.65	38.30^{c} (38.23)	39.59^{c} (38.99)	38.94
Mancozeb 75 % WP @0.1 %	59.67^{b} (7.76)	64.33^{b} (8.05)	62.00	21.13^{b} (23.37)	21.50^{b} (27.62)	21.31	44.26^{b} (41.70)	46.33^{b} (42.90)	45.29
Control	159.00^{a} (12.63)	168.33^{a} (12.99)	163.33	50.70^{a} (45.40)	54.06^{a} (47.33)	52.38	52.59^{a} (46.48)	54.26^{a} (47.44)	53.42
CD (p=0.05%)	5.15	6.89	-	2.12	3.35	-	5.37	5.01	-
SEM (±)	1.70	2.31	-	0.70	1.10	-	1.77	1.66	-
CV	4.81	6.16	-	6.16	8.98	-	9.14	8.97	-

*Mean values of three replication, values under parenthesis are transformed values. *represents Duncan's Multiple Range Test (DMRT) significance level (a-e).

lowest disease incidence (10.76% and 12.33%). In contrast, kresoxim-methyl 44.3% SC @1 mL/L had the highest number of infected plants (64.33 and 65.33) and higher disease incidence (21.76% and 21.96%) among treated plots, following the control which recorded 159.00 and 168.33 infected plants and 50.70% and 54.06% disease incidence (Table 4, Fig. 1). The present findings are in congruent with the findings of Singh *et al.* (1998) who found Tilt 25 EC and Indofil M-45 effective against wheat leaf blight. Tadess *et al.* (2019) reported reduced disease incidence in treated plots, and Hijim (2022) confirmed that fungicides substantially lowered spot blotch infection compared to untreated controls.

All fungicides significantly reduced the percent disease

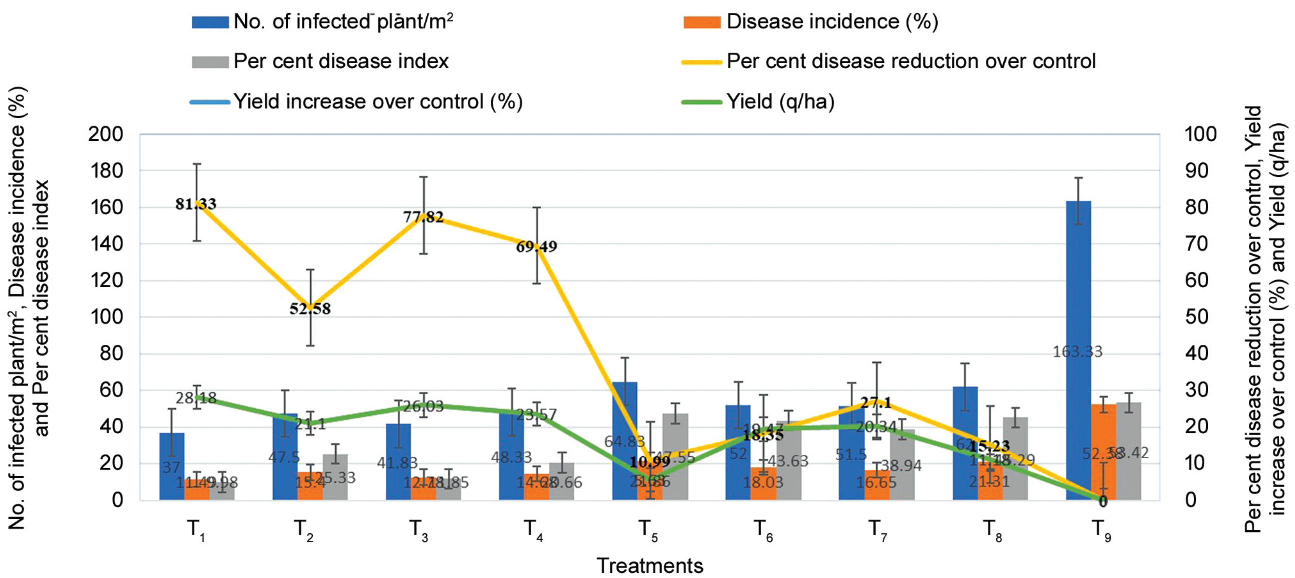

Fig. 1 Effect of fungicides on disease infection and yield potential against spot blotch of wheat during 2021–22 and 2022–23. Treatment details are given under Materials and Methods.

index (PDI) compared to the control (Table 4, Fig. 1). Tebuconazole 50% + Trifloxystrobin 25% WG @1 g/L was the most effective, achieving the lowest PDI (9.63% and 10.33%). Conversely, kresoxim-methyl 44.3% SC @1 mL/L recorded the highest PDI (46.78% and 48.33%) among treatments following the control figures of 52.59% and 54.26% during the 2021–22 and 2022–23 seasons, respectively (Table 4, Fig. 1). These findings aligned with Kumar (2018) who reported that applying propiconazole at 0.1% at 15 days interval was highly effective against spot blotch achieving the lowest PDI (29.08% and 25.75%) and the highest disease control (63.73% and 68.62%). Similarly, Tiwari *et al.* (2022) demonstrated that propiconazole (Tilt 25 EC) at 1% concentration achieved low PDI (29.02% and 25.80%) and high disease control (63.74% and 68.40%).

The study demonstrated that the combination of tebuconazole 50% + trifloxystrobin 25% WG at 1 g/L applied three times after seven days of flowering, resulted in the highest disease reductions (81.69% and 80.96%) compared to the control group (Table 5, Fig. 1). In contrast, kresoxim-methyl 44.3% SC at 1 mL/L achieved the least reduction with only 11.05% and 10.93% decreases in disease severity (Table 5, Fig. 1). These findings coincided with Patsa *et al.* (2020) who reported a 60.18% reduction in spot blotch with propiconazole; Tiwari *et al.* (2022) reported that propiconazole (Tilt 25 EC) at 1% concentration effectively controlled the disease achieving the lowest disease index (29.02% and 25.80%).

The results data indicated that the highest grain yields in both years were obtained with tebuconazole 50% + trifloxystrobin 25% WG at 1 g/L, applied three times at seven-day intervals after flowering, which recorded 47.13 and 46.68 q/ha, respectively (Table 5, Fig. 1). Considering both years' data, non-significant differences were observed in terms of yield. Grain yields from azoxystrobin 12.5% + tebuconazole 12.5% SC at 1 mL/L were comparable, with 46.23 q/ha and 44.87 q/ha were recorded. In contrast, the untreated control recorded the lowest yield, 37.91 q/ha in 2021–22 and 36.37 q/ha in 2022–23. The tebuconazole + trifloxystrobin treatment resulted in the highest yield increase over the control (28.91% and 27.64%), whereas kresoxim-methyl produced the lowest increase (6.54% and 4.73%) (Table 5, Fig. 1). These results were consistent with Patsa *et al.* (2020), who found that propiconazole effectively reduced wheat diseases and improved crop yield. Tiwari *et al.* (2022) also reported higher yield (42.83 and 41.60 q/ha) and increased 1000-grain weight with propiconazole, revealing its role in higher wheat productivity.

Spot blotch disease in wheat was successfully controlled by spraying fungicides three times at intervals of seven days following flowering. Among these, the combination of tebuconazole and trifloxystrobin has a broader mode of action and belongs to separate chemical families considered effective. From the oximino-acetate family, trifloxystrobin was extracted from the fungus *Strobilurus tenacellus*. Trifloxystrobin is a strong inhibitor at the Quinone "outside" site of the bc1 complex, which is complex III in the electron transport chain (Kumar *et al.* 2023). This interference halts fungal respiration by preventing electron transfer and ATP synthesis. Trifloxystrobin, a strobilurin, also promotes enhanced crop growth through its trans-laminar movement within leaves (Kumar *et al.* 2023). In contrast, tebuconazole,

Table 5 Effect of fungicides on disease reduction, yield (q/ha) and increase yield over control against spot blotch in wheat during 2021–22 and 2022–23

Fungicides	% disease reduction over control			Yield (q/ha)			Yield increases over control (%)		
	2021–22	2022–23	Mean	2021–22	2022–23	Mean	2021–22	2022–23	Mean
Tebuconazole 50% + Trifloxystrobin. 25 % WG @0.1%	81.69	80.96	81.33	47.13[a*]	46.23[a]	46.68	28.91	27.46	28.18
Propiconazole 13.9% + Difenoconazole 13.9% EC @0.1%	53.29	51.87	52.58	44.67[a]	44.10[a]	44.38	22.18	20.02	21.10
Azoxystrobin 12.5% + Tebuconazole 12.5% SC @0.1%	78.17	77.48	77.82	46.33[a]	44.87[a]	45.60	26.74	25.33	26.03
Picoxystrobin 7.05% + Propiconazole 11.7% WSC @0.1%	69.71	69.28	69.49	45.33[a]	44.70[a]	45.02	24.01	23.12	23.57
Kresoxin methyl 44.3% SC @0.1%	11.05	10.93	10.99	38.95[c]	38.57[bc]	38.76	6.54	4.73	5.63
Propiconazole 25% EC @0.1%	19.51	17.19	18.35	43.90[ab]	43.30[ab]	43.60	20.07	18.87	19.47
Tebuconazole 22.9% EC @0.1%	27.17	27.04	27.10	44.37[ab]	43.50[ab]	43.93	21.35	19.34	20.34
Mancozeb 75% WP @0.1%	15.84	14.61	15.23	40.93[bc]	40.75[abc]	40.84	11.96	10.40	11.18
Control	0.00	0.00	0.00	37.91[c]	36.37[c]	37.14	0.00	0.00	0.00
CD (*p*=0.05%)	-	-	-	3.36	4.78	-	-	-	-
SEM (±)	-	-	-	1.11	1.58	-	-	-	-
CV	-	-	-	4.44	6.43	-	-	-	-

*represents Duncan's Multiple Range Test (DMRT) significance level (a-c).

a member of the triazole chemical family, functions as a demethylation inhibitor (DMI). It inhibits the enzyme C-14 demethylase which is crucial for the synthesis of sterols, particularly ergosterol, essential for the structure and function of fungal cell walls. This inhibition leads to abnormal fungal growth and cell wall death, distinguishing it from benzimidazole fungicides. The combined action of these two broad-spectrum fungicides effectively controls *B. sorokiniana* infection. As a result, trifloxystrobin 25% + tebuconazole 50%, a combination of demethylation and quinone outside inhibitors showed consistence in the management of spot blotch in wheat.

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