Research Article

Field evaluation of an Integrated disease management for sustainable suppression of pearl millet downy mildew caused by *Sclerospora graminicola*

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Abstract

Pearl millet downy mildew, caused by *Sclerospora graminicola*, is one of the most destructive diseases limiting pearl millet productivity in India. The disease causes severe yield losses under favourable conditions, necessitating the identification of effective, eco-friendly management strategies. Hence, the present study aimed to evaluate various chemical, biological, and organic treatments under field conditions for sustainable management of the disease. The study was conducted in field conditions for two growing seasons, during *Kharif* 2019-20 and 2020-21 at the National Agriculture Research Project, Aurangabad, Maharashtra (India), to evaluate chemicals, organic amendments, bio-control agents, and plant extracts under field conditions against pearl millet downy mildew caused by *Sclerospora graminicola*. In the study, disease incidence (DI) and severity (DS) were recorded at 30 and 60 days after sowing, along with grain yield. The two years pooled mean revealed that the foliar application of Trifloxystrobin 50 % WG @ 1ml/L was most effective at 30 DAS in respect of reducing DI and DS (1.66 % and 0.57 %) which was at par with Azoxystrobin 23 % SC @ 2ml/L (1.99 % and 0.73 %) compared to untreated control (7.00% and 3.96%) respectively, while DI and DS was (0.00 % each) compared to untreated control (8.83 % and 6.48 %) at 60 DAS respectively. The same fungicides were found to be superior in terms of yield and economics compared with the control.

Keywords: Bioagents, Downy mildew, Fungicides, Organic amendment, Pearl millet, Plant extract

INTRODUCTION

Pearl millet, scientifically known as *Pennisetum glaucum L.,* belongs to the *Poaceae* family and is recognized for its ability to withstand drought and high temperatures, thanks to its C4 photosynthetic mechanism. In India, it is widely known as Bajra, while internationally, it is also called Cat tail, Bulrush or Spiked millet, African millet, and barbed millet. %. Among many constraints in pearl millet production, disease is the most important yield reducing factor. (Aakash *et al*., 2024). Downy mildew caused by *Sclerospora graminicola* is the major disease of pearl millet, which can reduce yield by up to 60% and, in some fields, losses can reach nearly 100%. The organism that causes downy mildew disease in pearl millet was initially identified in India in 1907 (Butler, 1907). The highest average downy mildew incidence of 4.05% and 5.7% was observed in Beed district at 30 days after sowing and 60 days after sowing, respectively, followed by Chh. Sam-

bhaji nagar district (3.98% and 5.61%), Jalna (1.51% and 2.25%) (Waghmare *et al*., 2023).Meanwhile, in Rajasthan, the average incidence of downy mildew across districts such as Bikaner, Jodhpur, Sikar, Jaipur, and Alwar ranged from 9.87 % to 17.95% (Saini *et al*., 2020).The repeated use of fungicides poses significant risks due to their unintended effects, including the emergence of resistant pathogen strains, reduced effectiveness, increased production costs, and environmental pollution (Heil *et al*., 2000; Yoon *et al*., 2013)

To effectively manage downy mildew disease in pearl millet over the long term and mitigate these negative impacts—such as environmental contamination, residual toxicity, pathogen resistance, and cost inefficiency—integrated disease management is essential (Gora *et al*., 2025) Keeping in view the importance of the disease and lack of systematic work on the integrated disease management, the present study was aimed to evaluate chemicals, organic amendments, bio-control agents and plant extracts under field condition against pearl millet downy mildew caused by *Sclerospora graminicola*.

MATERIALS AND METHODS

Materials

Seeds of pearl millet (*Pennisetum glaucum L.)* lines, popular variety, and susceptible check 7042-S were obtained from the National Agriculture Research Project, Aurangabad, for various pot culture and field experiments. The pure cultures of biocontrol agents (*Pseudomonas fluorescens*-VNMKVB1, *Trichoderma harzianum*-VNMKVF13, and *Aspergillus niger*-VNMKVF19) were obtained from the Spawn Production-Cum-Biocontrol Laboratory, VNMKV, Parbhani. A total six fungicides *viz.,* Provalicarb 5.5%+Propineb 61.25% WP (Melody dew, Bayer Crop Sci. Ltd, India), Azoxystrobin 23% SC (Amistar, Syngenta India Ltd., Pune), Pyraclostrobin 5%+Metiram 55% (Cabriotop, BASF, India), Trifloxystrobin 50% WG (Flint, Bayer Crop Science, India), mectoctradin+ Dimethomorph 20.27% SC (Zempro, BASF, India) Kresoxim methyl 50% WG (Ergon, Tata rallies, India) were purchased from Aurangabad market. Plant extracts (Datura metelleaf extract (LE), Azardirachta indica leaf extract (LE), and Allium sativum bulb extract (BE)) were collected from the Research farms of the National Agriculture Research Project, Aurangabad, and adjoining fields, and their aqueous and solvent (Acetone) extracts were used in the present studies. Organic amendments (Neem seed cake and Vermicompost tea) were purchased from the market, prepared, and brought cow urine from cows at the National Agriculural Research Project (NARP) farm section, Aurangabad. Inducers/chemicals like chitosan (ORACLE) salicylic acid

(Selezol) were purchased from market. The field experiment was conducted on the Research Farm of National Agriculture Research Project, Aurangabad during *Kharif* season of 2019-20 and 2020-21, respectively to evaluate the efficacy of following six fungicides, three bio control agents, two inducers and three organic amendments and four plant extracts to manage downy mildew of pearl millet under natural field condition.

Experimental design

To create plots infected with downy mildew, plant debris from locally susceptible and 7042-S pearl millet plants affected by downy mildew, including infected leaves, proliferated ears, and malformed shoots, was gathered during the harvest of the summer pearl millet (5 m × 5 m) and then sun-dried. This plant debris was cut into small pieces, ground into a powder in a mixer, and stored in an airtight container. Before the first rain, the powder was examined under a microscope. The inoculum (1×10^5 sporangia/ml) was evenly distributed over the experimental field during field preparation.

The 7042-S Pearl millet "local susceptible," known for its vulnerability to downy mildew, was planted on May 26, 2019, and June 21, 2020, as infector rows to ensure maximum disease pressure. These rows were established three weeks ahead of the test rows (Safeeulla (1976). Infector rows were systematically placed every ninth row throughout the experimental field. The test materials for each trial were sown approximately three weeks following the planting of the infector rows to gauge the level of disease pressure, indicator rows, including the local susceptible and 7042 S, were planted concurrently with the test rows.

The field experiment was laid out in a randomised complete block design (RBD) to evaluate 19 treatments of the local pearl millet variety across two Kharif seasons. Sowing was done on 27 June 2019 and 21 July 2020. Each treatment was replicated three times, with individual plots measuring 5 m × 5 m and crop spacing of 50 × 10 cm. Standard agronomic practices were uniformly followed across all plots, and observations on disease incidence, severity, and yield parameters were recorded at scheduled intervals to assess treatment effects.

Treatment details are:T_1= *Pseudomonas fluorescens* 1 x10^8 CFU/ml seed treatment(ST) 8g/kg, T_2= *Trichoderma harzianum* 1 x10^8 CFU/ml seed treatement(ST) 8g/kg, T_3= *Aspergillus niger* 1 x 10^8 CFU/ml seed treatment (ST) 8g/kg, T_4= Provalicarb 5.5% + Propineb 61.25% w/w WP foliar application (FA) 1gm/L, T_5= Azoxystrobin 23 % SC foliar application (FA)) 2ml/L, T_6= Pyraclostrobin 5% + Metiram 55% foliar application(FA) 2g/L, T_7= Kresoxim-methyl 50% WG w/w foliar application (FA) 2ml/L, T_8= Trifloxystrobin 50 WG foliar application(FA)) 1ml/L, T_9=

Amectoctradin 27% + Dimethomorph 20.27% SC seed tratement (ST) 0.2ml/L, T_{10}= Cow urine@ 45 ml soil application (SA)) 45 ml, T_{11}= Butter milk soil application (SA) 10%, T_{12}= Neem seed cake extract soil application (SA 10%, T_{13}= Vermicompost tea soil application (SA) 10%, T_{14}= Datura metel leaf extract soil application(SA) 10%, T_{15}= Neem leaf extract soil application (SA) 10%, T_{16}= Onion bulb extract soil application (SA 10 %,T_{17}= Salicyclic acid seed treatment (ST) 15 mM, T_{18}= Chitosan seed treatment (ST) 2.5 g/ kg, T_{19}= Control (untreated)

Disease incidence (DI)

The occurrence of downy mildew in the test lines was assessed by tallying the total and infected seedlings in each plot, with the results expressed as a percentage of infected seedlings. Disease incidence (DI) was evaluated twice: initially at 30 days post-emergence (prebooting/flowering stage) and again at 60 days post-emergence (soft-dough stage).

The % DI was calculated as per following formula:

DI % = No. of infected plants / Total no. of plants observed × 100   (Eq. 1)

At crop maturity, Disease severity (DS) scores were assessed for each plant individually on a 1-5 scale, as described by Thakur *et al*. (2011). On this scale, a score of 1 indicates no infection, 2 signifies that 20% of productive tillers are infected, 3 means 50 % of productive tillers are infected, 4 represents 80% of productive tillers are infected, and 5 indicates that all tillers are affected. Disease scoring was carried out at 30 and 60 DAS. The % DS observation was calculated as described below (Anonymous, 2016).

DS (%) = (1-1). n1+ (2-1). n2 +(3-1). n3+(4-1). n4+(5-1). n5 / (5-1). N × 100   (Eq. 2)

Where n1, n2, n3, n4 and n5 are total number of plants in each of 1 to 5 rating class and N is the total number of plants in a plot and grain yield q/ha.

Statistical analysis

The data were analysed statistically in accordance with Panse and Sukhatme (1978). Percentages were transformed to arc-sin prior to analysis. Standard error (S.E.) and Critical Difference (C.D.) for each treatment were computed using P = .05 probability levels, and interpretation followed using OPSTAT software.

RESULTS AND DISCUSSION

Seed germination

Seed germination of pearl millet varied significantly among treatments, ranging from 77.00 to 91.33%, compared to 76.00–77.33% in the untreated control (Table 1 and 2). The highest germination was recorded with Trifloxystrobin 50% WG (FA) @ 1 ml L⁻¹ (91.33%), fol-

lowed by Azoxystrobin 23% SC (FA) @ 2 ml L⁻¹ (89.33 –91.33%). Among biocontrol agents, *T. harzianum* (ST) @ 8 g/kg seed (88.00%) and P. fluorescens (ST) @ 8 g/kg seed (81.00–85.66%) showed significantly higher germination than the control. Other treatments resulted in moderate germination (78.00–82.66%).

Overall, both fungicidal and biocontrol treatments significantly enhanced seed germination, with strobilurin-based fungicides exhibiting the most pronounced effect. These results corroborate earlier findings by Raj *et al*. (2011), Sangwan and Kushal Raj (2016), Sasode *et al*. (2018), and Meena *et al*. (2024), who also reported improved seed germination following seed treatment with strobilurins and beneficial microbial agents.

Downy mildew incidence and severity

At 30 DAS, all treatments significantly reduced downy mildew incidence and severity compared to the untreated control (7.66% incidence and 4.68% severity). Disease incidence ranged from 1.33% to 7.33%, and severity ranged from 0.78% to 3.64%. The lowest incidence (1.33–2.00%) and severity (0.00–0.78%) were recorded with Trifloxystrobin 50% WG (FA) @ 1 ml / L, which was statistically at par with Azoxystrobin 23% SC (FA) @ 2 ml / L. Kresoxim-methyl 50% WG (FA) @ 2 ml / L ranked next, followed by seed treatment with *Pseudomonas fluorescens* and *Trichoderma harzianum*, which also maintained significantly lower disease levels. Certain botanicals and elicitors, such as Datura metel leaf extract (10%) and chitosan, showed moderate but consistent disease suppression.

At 60 DAS, a similar trend was observed. Disease incidence and severity in treated plots ranged from 0.00–7.66% and 0.00–5.93%, respectively, compared to 8.66–9.00% incidence and 6.08–6.89% severity in the control. Azoxystrobin and Trifloxystrobin treatments were completely disease-free, followed by Kresoxim-methyl, *P. fluorescens,* Amectoctradin + Dimethomorph, and *T. harzianum*, all of which maintained low disease intensity. Other treatments recorded moderate disease levels.

Overall, strobilurin fungicides were the most effective in suppressing downy mildew, followed by bioagents and selected plant-based treatments. The superior performance of strobilurins may be attributed to their action on fungal mitochondrial respiration, where inhibition of electron transport at the cytochrome bc□ complex disrupts energy production, leading to pathogen mortality. These findings are in agreement with earlier reports demonstrating strong inhibition of sporulation, zoospore release, and motility of Sclerospora graminicola by azoxystrobin, trifloxystrobin, and kresoxim-methyl (Sudisha *et al*., 2005). Comparable field-level disease reduction using Amectoctradin + Dimethomorph was also reported by Sasode (2018).

Table 1. Field efficacy of various treatments integrated to manage pearl millet downy mildew incidence and severity during *Kharif,* 2019-20

Treatment	% Seed* germination	At 30 DAS		At 60 DAS		Grain yield q/ha
		DI (%)	DS (%)	DI (%)	DS (%)	
T$_1$= *Pseudomonas fluorescens*** (ST) @8g/kg	85.66 **(67.76)	3.33 (10.39)	1.58 (7.14)	4.00 (9.03)	2.90 (9.70)	23.69
T$_2$= *Trichoderma harzianum****(ST)@ 8g/kg	88.00 (69.73)	3.33 (10.33)	1.58 (7.21)	4.33 (10.17)	3.19 (10.24)	23.26
T$_3$= *Aspergillus niger*** (ST) @ 8g/kg	78.66 (62.49)	5.00 (12.74)	1.95 (8.02)	6.66 (13.30)	4.35 (12.00)	20.88
T$_4$= *Provalicarb 5.5% + Propineb 61.25%w/w WP (FA) @ 1gm/L*	81.00 (64.16)	5.33 (13.33)	1.97 (8.06)	5.66 (11.09)	3.86 (11.30)	22.11
T$_5$= *Azoxystrobin 23 % SC (FA) @ 2ml/L*	89.33 (70.94)	1.66 (6.03)	1.15 (6.41)	0.00 (0.00)	0.00 (0.00)	32.59
T$_6$= *Pyraclostrobin 5% + Metiram 55 % (FA)@ 2g/L*	80.66 (63.9)	5.00 (12.87)	2.73 (9.50)	5.33 (10.65)	3.47 (10.65)	21.85
T$_7$= *Kresoxim-methyl 50% WG w/w (FA)@ 2ml/L*	80.33 (63.6)	2.33 (8.74)	1.56 (7.14)	3.33 (8.48)	2.73 (9.39)	22.55
T$_8$= *Trifloxystrobin) 50 % WG (FA)@ 1ml/L*	91.33 (72.88)	1.33 (5.41)	0.78 (5.07)	0.00 (0.00)	0.00 (0.00)	30.83
T$_9$= *Amectoctradin 27% + Dimethomorph 20.27 % SC (ST) @0.2 ml/L*	82.66 (65.14)	4.33 (11.89)	1.92 (7.97)	4.66 (11.61)	3.01 (9.89)	22.19
T$_{10}$= *Cow urine (SA)@ 45 ml*	78.66 (62.49)	6.33 (14.56)	1.96 (8.05)	6.66 (13.28)	4.35 (11.98)	22.02
T$_{11}$= *Butter milk (SA) @10%*	78.66 (62.49)	5.00 (12.87)	1.93 (7.96)	6.33 (11.09)	4.00 (11.47)	20.88
T$_{12}$= *Neem seed cake (SA) @10%*	78.66 (62.49)	5.33 13.26)	3.20 (10.21)	7.33 (13.59)	5.40 (13.39)	19.64
T$_{13}$= *Vermicompost tea (SA) @10%*	78.00 (62.02)	4.33 (11.93)	1.95 (8.01)	6.33 (11.99)	4.00 (11.27)	21.76
T$_{14}$= *Datura metel LE (ST) @10%*	78.33 (62.26)	3.33 (10.49)	1.76 (7.55)	4.33 (10.17)	3.85 (11.24)	22.20
T$_{15}$= *Azardirachta indica LE (ST) @10%*	79.00 (62.72)	6.66 (14.89)	2.41 (8.93)	6.33 (11.99)	5.12 (13.03)	20.88
T$_{16}$= *Allium sativum BE (ST) @10%*	81.33 (64.40)	7.33 (15.65)	3.16 (10.24)	7.6 (15.16)	3.95 (11.39)	20.52
T$_{17}$= *Salicyclic acid (ST) 15Mm*	80.33 (63.67)	6.66 (14.89)	2.73 (9.50)	7.33 (13.59)	5.07 (13.01)	20.97
T$_{18}$= *Chitosan (ST) 2.5 g/Kg seed*	78.66 (62.49)	3.33 (10.33)	1.62 (7.04)	4.66 (11.61)	3.95 (12.80)	25.66
T$_{19}$= *Control (untreated)*	77.33 (61.57)	7.66 (16.01)	3.24 (10.37)	8.66 (15.16)	6.08 (14.23)	18.67
SEm (±)	0.25	1.17	0.43	0.62	0.62	1.75
CD (P=0.05)	0.83	3.39	1.25	1. 80	1.80	5.20
CV (%)		17.10	9.27	10.20	13.04	13.59

*Mean of three replications; **Figures in parentheses denote Arc sign transferred values; ***1×10^8 (CFU/ml); FA: Foliar application; SA: Soil application; LE: Leaf extract; BE: Bulb extract; ST: Seed treatment; DI: Disease incidence; DS: Disease severity

Bioagents such as *P. fluorescens* and *T. harzianum* also showed promising disease-suppressing activity, possibly through antibiosis, volatile metabolite production, and inhibition of sporulation, supporting earlier observations by Meena *et al*. (2024). Thus, integration of strobilurin fungicides with eco-friendly bioagents offers an effective strategy for sustainable management of downy mildew in pearl millet.

Grain yield
Grain yield of pearl millet differed significantly among treatments across both seasons, ranging from 18.94 to 32.59 q / ha, compared to 17.79–18.67 q / ha in the untreated control. The highest yield was consistently obtained with Azoxystrobin 23% SC (FA) @ 2 ml/L (32.59 and 29.95 q/ha), followed by Trifloxystrobin 50% WG (FA) @ 1 ml/L (30.83 and 29.07 q/ha). Chitosan (ST) ranked next, recording 25.66 and 27.53 q / ha. Among bioagents, *Pseudomonas fluorescens* and *Trichoderma harzianum* (both at 8 g/kg seed) produced higher yields than the control, while the remaining treatments showed moderate yields (19.64–22.55 q/ha).

Table 2. Field efficacy of various treatments integrated to manage pearl millet downy mildew incidence and severity, during *Kharif,* 2020-21

Treatment	Seed* germi. (%)	At 30 DAS		At 60 DAS		Grain yield (q/ha)
		DI (%)	DS (%)	DI (%)	DS (%)	
T₁= *Pseudomonas fluorescens*** (ST) @ 8g/kg	81.00 **(64.17)	3.33 (10.49)	1.88 (7.87)	4.33 (11.7)	3.47 (10.65)	21.49
T₂= *Trichoderma harzianum****(ST)@ 8g/kg	78.66 (62.49)	3.33 (10.49)	1.92 (7.76)	4.66 (12.2)	3.95 (11.42)	21.32
T₃= *Aspergillus niger**** (ST) @ 8g/kg	80.33 (63.62)	5.66 (13.75)	2.37 (8.81)	7.33 (15.6)	4.74 (12.51)	19.47
T₄= Provalicarb 5.5% + Propineb 61.25%w/w WP (FA) @ 1gm/L	77.00 (61.62)	5.00 (12.87)	2.34 (8.65)	6.33 (14.5)	4.88 (12.71)	20.52
T₅= Azoxystrobin 23 % SC (FA) @ 2ml/L	91.33 (72.90)	2.33 (8.63)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	29.95
T₆= Pyraclostrobin 5% + Metiram 55 % (FA) @ 2g/L	80.66 (63.92)	5.00 (12.87)	2.70 (9.45)	6.00 (14.0)	4.35 (11.98)	20.79
T₇= Kresoxim-methyl 50% WG w/w (FA)@ 2ml/L	78.66 (62.49)	3.00 (9.87)	1.77 (7.63)	3.66 (11.0)	3.16 (10.19)	22.55
T₈= Trifloxystrobin) 50 % WG (FA)@ 1ml/L	81.00 (64.17)	2.00 (7.94)	0.69 (4.73)	0.00 (0.00)	0.00 (0.00)	29.07
T₉= Amectoctradin 27% + Dimethomorph 20.27 % SC (ST) @0.2 ml/L	80.60 (63.90)	4.33 (11.99)	1.97 (8.05)	4.66 (12.3)	3.56 (10.85)	21.32
T₁₀= Cow urine (SA)@ 45 ml	79.33 (62.87)	6.33 (14.56)	2.34 (8.77)	6.66 (14.8)	4.74 (12.52)	19.73
T₁₁= Butter milk (SA) @10%	80.66 (63.92)	5.33 (13.33)	2.18 (8.40)	6.66 (14.7)	4.68 (12.48)	20.26
T₁₂= Neem seed cake (SA) @10%	78.66 (62.49)	6.66 (14.92)	3.47 (8.85)	7.66 (16.1)	5.93 (14.26)	18.94
T₁₃= Vermicompost tea (SA) @10%	80.33 (63.68)	6.66 (14.92)	2.40 (8.89)	7.00 (15.2)	4.68 (12.69)	19.99
T₁₄= Datura metel LE (ST) @10%	80.33 (63.68)	3.33 (10.33)	1.92 (7.96)	5.33 (13.1)	4.29 (12.48)	21.05
T₁₅= Azardirachta indica LE (ST) @10%	78.00 (62.02)	5.33 (13.33)	2.76 (9.56)	7.33 (15.6)	5.20 (13.13)	20.26
T₁₆= Allium sativum BE (ST) @10%	77.33 (61.77)	6.66 (14.94)	2.37 (10.72)	6.66 (14.8)	4.68 (11.47)	19.64
T₁₇= Salicyclic acid (ST) 15Mm	80.33 (63.68)	6.33 (14.56)	3.64 (12.44)	7.00 (15.0)	5.46 (13.49)	19.73
T₁₈= Chitosan (ST) 2.5 g/Kg seed	78.66 (62.49)	4.33 (11.78)	1.92 (7.76)	5.33 (13.2)	4.35 (12.02)	27.53
T₁₉= Control (untreated)	76.66 (60.18)	7.66 (16.06)	4.68 (10.97)	9.00 (17.4)	6.89 (15.20)	17.79
SEm (±)	0.28	0.80	0.52	0.64	0.77	1.74
CD (P=0.05)	0.89	2.24	1.50	1.86	2.21	5.23
CV (%)		11.60	10.80	10.14	10.42	14.47

Mean of three replications; FA: Foliar application; SA: Soil application; LE: Leaf extract; BE: Bulb extract; ST: Seed treatment; DI: Disease incidence; DS: Disease severity; ***1×10⁸ (CFU/ml); **Fig. in parenthesis denote Arc sign transferred values

Overall, strobilurin fungicides were most effective in enhancing grain yield, likely due to their efficient suppression of downy mildew and their known physiological benefits, such as improved photosynthetic efficiency and delayed senescence. These findings are consistent with earlier reports showing yield enhancement with Azoxystrobin and Trifloxystrobin under downy mildew management (Raj *et al*., 2005). The yield improvement observed with chitosan and bio agents aligns with previous studies highlighting their role in induced resistance and improved plant vigor (Sangwan *et al*.,

2016; Sasode *et al*., 2018; Jaiswal *et al*., 2021). Thus, effective disease management with fungicides, supported by eco-friendly alternatives such as bioagents and elicitors, significantly increased grain yield in pearl millet.

Pooled mean downy mildew incidence and severity (two years)
Pooled analysis of two years at 30 DAS showed that all treatments significantly reduced downy mildew incidence (DI) and severity (DS) compared to the untreat-

Table 3. Field efficacy of various treatments integrated to manage pearl millet downy mildew incidence and severity. (Pooled mean, *Kharif* 2019-20 and 2020-21)

Treatment	At 30 DAS		At 60 DAS		Grain yield (q/ha)
	DI (%)	DS (%)	DI (%)	DS (%)	
T$_1$= *Pseudomonas fluorescens*** (ST) @8g/kg	3.33 (10.49)	1.73 (7.53)	4.16 (11.80)	3.18 (10.36)	22.59
T$_2$= *T. harzianum***(ST)@ 8g/kg	3.33 10.49	1.75 (7.60)	4.50 (12.25)	3.37 (10.52)	22.29
T$_3$= *A. niger*** (ST) @ 8g/kg	5.33 (13.33)	2.16 (8.48)	7.00 (15.34)	4.54 (12.32)	20.17
T$_4$= *Provalicarb 5.5% + Propineb 61.25%w/w WP (FA) @ 1gm/L*	5.16 (13.14)	2.15 (8.43)	6.00 (14.18)	4.37 (12.05)	21.32
T$_5$= *Azoxystrobin 23 % SC (FA) @ 2ml/L*	1.99 (8.13)	0.57 (4.40)	0.00 (0.00)	0.00 (0.00)	31.27
T$_6$= *Pyraclostrobin 5% + Metiram 55 % (FA)@ 2g/L*	4.66 (12.40)	2.71 (9.48)	5.66 (13.74)	4.15 (11.75)	21.32
T$_7$= *Kresoxim-methyl 50% WG w/w (FA)@ 2ml/L*	2.66 (9.30)	1.66 (7.29)	3.50 (10.78)	2.94 (9.90)	22.55
T$_8$= *Trifloxystrobin) 50 % WG (FA)@ 1ml/L*	1.66 (7.29)	0.73 (4.94)	0.00 (0.00)	0.00 (0.00)	29.95
T$_9$= *Amectoctradin 27% + Dimethomorph 20.27 % SC (ST) @0.2 ml/L*	3.83 (11.27)	1.80 (7.71)	4.99 (12.90)	3.48 (10.70)	21.80
T$_{10}$= *Cow urine (SA)@ 45 ml*	6.30 (14.54)	2.15 (8.61)	6.66 (14.94)	4.54 (12.32)	20.88
T$_{11}$= *Butter milk (SA) @10%*	5.16 (13.14)	2.05 (8.23)	6.50 (14.77)	4.34 (12.03)	20.57
T$_{12}$= *Neem seed cake (SA) @10%*	6.66 (14.91)	3.33 (10.49)	7.49 (15.87)	5.66 (13.75)	19.29
T$_{13}$= *Vermicompost tea (SA) @10%*	5.49 (13.55)	2.17 (8.50)	6.66 (14.94)	4.34 (12.03)	20.88
T$_{14}$= *Datura metel LE (ST) @10%*	3.83 (11.27)	1.93 (7.95)	4.68 (12.50)	3.88 (11.34)	21.63
T$_{15}$= *Azardirachta indica LE (ST) @10%*	5.33 (13.34)	2.58 (9.25)	7.33 (15.71)	5.16 (13.14)	20.57
T$_{16}$= *Allium sativum BE (ST) @10%*	7.00 (15.34)	2.76 (9.54)	7.16 (15.50)	4.31 (11.99)	20.08
T$_{17}$= *Salicyclic acid (ST) 15Mm*	6.50 (14.77)	3.18 (10.34)	7.16 (15.50)	5.26 (13.25)	20.35
T$_{18}$= *Chitosan (ST) 2.5 g/Kg seed*	4.16 (11.80)	1.77 (7.68)	4.99 (12.90)	4.10 (11.68)	26.59
T$_{19}$= *Control (untreated)*	7.66 (16.04)	3.96 (11.45)	8.83 (17.29)	6.48 (14.75)	18.23
SEm (±)	0.35		0.18	0.36	1.16
CD (P=0.05)	0.97		0.54	1.01	3.20
CV (%)	18.26		18.18	16.65	

FA: Foliar application; SA: Soil application; LE: Leaf extract; BE: Bulb extract; ST: Seed treatment; DI: Disease incidence; DS: Disease severity; *Figures in parentheses denote Arc sign transferred values; **1×10^8 (CFU/ml)

ed control (7.66% DI and 3.96% DS; Table 3). DI and DS among treatments ranged from 1.66–7.00% and 0.57–3.33%, respectively. The lowest DI (1.66%) and DS (0.57%) were recorded with Trifloxystrobin 50% WG (FA) @ 1 ml / L, which was statistically at par with Azoxystrobin 23% SC (FA) @ 2 ml / L (1.99% DI and 0.73% DS). These were followed by Kresoxim-methyl 50% WG (FA) at 2 ml/L and the bioagents *Pseudomonas fluorescens* and *Trichoderma harzianum*, which also maintained significantly lower disease levels.

At 60 DAS, a similar pattern was observed. DI and DS ranged from 0.00–7.49% and 0.00–5.66%, respective-

ly, compared to 8.83% DI and 6.48% DS in the control. Azoxystrobin and Trifloxystrobin provided complete disease control (0.00% DI and DS). This was followed by Kresoxim-methyl, *P. fluorescens*, and *T. harzianum*, which showed substantial disease suppression, whereas the remaining treatments recorded moderate disease levels.

Overall, pooled results clearly demonstrated the superior and consistent efficacy of strobilurin fungicides, particularly Azoxystrobin and Trifloxystrobin, in reducing downy mildew incidence and severity across seasons, with bioagents also contributing meaningful disease

Table 4. Economics of various treatments integration against pearl millet downy mildew (*S. graminicola)* during *Kharif,* 2019-20

Treatment	Yield(Kg/ha)	Total Gross Cost of treatment (Rs/ha)	Gross Income (Rs/ha)	Net Profit (Rs/ha)	B:C Ratio
T$_1$= *Pseudomonas fluorescens** (ST) @8g/kg	2369	21943	63967.28	42024.28	2.91
T$_2$= *T. harzianum**(ST)@ 8g/kg	2326	21943	62789.84	40846.84	2.86
T$_3$= *A. niger** (ST) @ 8g/kg	2088	21943	54280.44	32337.44	2.47
T$_4$= *Provalicarb 5.5% + Propineb 61.25%w/w WP (FA) @ 1gm/L*	2211	23590	59706.62	36116.62	2.53
T$_5$= *Azoxystrobin 23 % SC (FA) @ 2ml/L*	3259	25840	87983.22	62143.22	3.40
T$_6$= *Pyraclostrobin 5% + Metiram 55 % (FA)@ 2g/L*	2185	24040	59160.62	35120.62	2.46
T$_7$= *Kresoxim-methyl 50% WG w/w (FA)@ 2ml/L*	2255	28290	62737.02	34447.02	2.21
T$_8$= *Trifloxystrobin) 50 % WG (FA)@ 1ml/L*	3083	25340	83226.58	57886.58	3.28
T$_9$= *Amectoctradin 27% + Dimethomorph 20.27 % SC (ST) @0.2 ml/L*	2219	22340	60094.24	37754.24	2.68
T$_{10}$= *Cow urine (SA)@ 45 ml*	2202	21840	59460.18	37620.18	2.72
T$_{11}$= *Butter milk (SA) @10%*	2088	22540	55090.86	32550.86	2.44
T$_{12}$= *Neem seed cake (SA) @10%*	1964	21840	51408.62	29568.62	2.35
T$_{13}$= *Vermicompost tea (SA) @10%*	2176	22040	59002.04	36962.04	2.67
T$_{14}$= *Datura metel LE (ST) @10%*	2220	21840	61908.88	40068.88	2.83
T$_{15}$= *Azardirachta indica LE (ST) @10%*	2088	21840	56359.34	34519.34	2.58
T$_{16}$= *Allium sativum BE (ST) @10%*	2052	21840	54949.82	33109.82	2.51
T$_{17}$= *Salicyclic acid (ST) 15Mm*	2097	22534	54474.26	31940.26	2.41
T$_{18}$= *Chitosan (ST) 2.5 g/Kg seed*	2566	33090	69812.22	36722.22	2.10
T$_{19}$= *Control (untreated)*	1867	21840	45524.46	23684.46	2.08

FA: Foliar application; SA: Soil application; LE: Leaf extract; BE: Bulb extract; ST: Seed treatment; *1×10^8 (CFU/ml)

suppression under field conditions.

Pooled mean grain yield and benefit–cost ratio
Pooled data of two years indicated that pearl millet grain yield and B: C ratio differed significantly among treatments (Table 4 and 5). Grain yield ranged from 1894 to 3127 kg/ha, while the B: C ratio varied from 2.16 to 3.26, compared to 1823 kg/ha and 2.03, respectively, in the untreated control.
The highest grain yield (3127 kg/ha) and B: C ratio (3.26) was recorded with Azoxystrobin 23% SC (FA) @ 2 ml / L, which was statistically at par with Trifloxystrobin 50% WG (FA) @ 1 ml / L (2995 kg/ha and (3.15). This was followed by Chitosan (ST) (2659 kg / ha). Among bioagents, *Trichoderma harzianum* and *Pseudomonas fluorescens* (@ 8 g / kg seed) recorded

higher yields than the control, while the remaining treatments showed moderate performance (1894–2255 kg / ha) with B:C ratios ranging from 2.16 to 2.81.
Overall, the pooled results clearly demonstrated that strobilurin fungicides not only maximized grain yield but also provided the highest economic returns, followed by chitosan and biocontrol agents, indicating their potential for economically viable and sustainable pearl millet production.

Conclusion

Field evaluation of nineteen treatments over Kharif 2019–20 and 2020–21 revealed that Trifloxystrobin 50% WG @ 1 ml / L and Azoxystrobin 23% SC @ 2 ml / L were the most effective against *Sclerospora*

Table 5. Economics of various treatments integration against pearl millet downy mildew (*S. graminicola*) during *Kharif,* 2020-21

Treatment	Yield(K Kg/ha)	Total GrossCost of treatment	Gross Income(Rs/	Net Profit (Rs/ha)	B:C Ratio
T₁= *Pseudomonas fluorescens** (ST) @8g/kg	2149	21943	59301.48	37558.48	2.70
T₂= *T. harzianum**(ST)@ 8g/kg	2132	21943	58913.84	36970.84	2.68
T₃= *A. niger* (ST) @ 8g/kg*	1947	21943	50633.40	28690.40	2.30
T₄= *Provalicarb 5.5% + Propineb 61.25%w/w*	2052	23590	55548.84	31958.84	2.35
T₅= *Azoxystrobin 23 % SC (FA) @ 2ml/L*	2995	25840	80865.56	55025.56	3.12
T₆= *Pyraclostrobin 5% + metiram 55 % (FA)@ 2g/L*	2079	24040	56306.48	32266.48	2.34
T₇= *Kresoxim-methyl 50% WG w/w (FA)@*	2255	28290	62120.16	33830.16	2.19
T₈= *Trifloxystrobin) 50 % WG (FA)@ 1ml/L*	2907	25340	76778.20	51438.20	3.02
T₉= *Amectoctradin 27% + Dimethomorph 20.27*	2132	22340	57663.00	35323.00	2.58
T₁₀= *Cow urine (SA)@ 45 ml*	1973	21840	53276.14	31436.14	2.43
T₁₁= *Butter milk (SA) @10%*	2026	22540	53469.87	30929.87	2.37
T₁₂= *Neem seed cake (SA) @10%*	1894	21840	49594.02	27754.02	2.27
T₁₃= *Vermicompost tea (SA) @10%*	1999	22040	54844.20	32804.20	2.48
T₁₄= *Datura metel LE (ST) @10%*	2105	21840	57592.42	35752.42	2.63
T₁₅= *Azardirachta indica LE (ST) @10%*	2026	21840	54703.10	32863.10	2.50
T₁₆= *Allium sativum BE (ST) @10%*	1964	21840	51056.28	29216.28	2.33
T₁₇= *Salicyclic acid (ST) 15Mm*	1973	22534	52888.54	30354.54	2.34
T₁₈= *Chitosan (ST) 2.5 g/Kg seed*	2753	33090	73345.52	40255.52	2.21
T₁₉= *Control (untreated)*	1779	21840	43374.84	21534.84	1.98

FA: Foliar application; SA: Soil application; LE: Leaf extract; BE: Bulb extract; ST: Seed treatment; *1×10⁸ (CFU/ml)

graminicola in pearl millet. Both treatments recorded maximum seed germination (91.33%), minimum downy mildew incidence and severity (1.66–1.99% and 0.57–0.73% at 30 DAS, and 0.00% at 60 DAS), and significantly higher grain yield (2995–3127 kg/ha) compared to the untreated control (1823 kg /ha). Thus, Trifloxystrobin and Azoxystrobin offer reliable and effective management of downy mildew while substantially improving productivity of pearl millet.

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Conflict of interest
The authors declares that they have no conflict of interest.

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