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Management Strategies using SAR Activators and Fungicides against Cercospora Leaf Spot of Green Gram Caused by *Cercospora canescens*

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A B S T R A C T

Green gram (*Vigna radiata* (L.) Wilczek) is an important pulse crop valued for its short duration, adaptability, nitrogen-fixing ability and high nutritional content. The productivity of green gram is significantly constrained by fungal diseases, particularly Cercospora leaf spot caused by *Cercospora canescens*. Seven fungicides were evaluated *in vitro* at 50, 100 and 200 ppm using the poisoned food technique. Under field conditions, a single spray of SAR activators (at respective concentrations) was applied at 25 DAS in artificially inoculated plots, while fungicides were sprayed at the onset of disease symptoms. All seven SAR activators reduced Cercospora leaf spot severity, with salicylic acid (200 ppm) most effective (25.20% intensity and 48.78% reduction), followed by isonicotinic acid. *In vitro* conditions metiram + pyraclostrobin showed maximum inhibition of *Cercospora canescens* (up to 100%), while copper hydroxide was the least effective. Field application of metiram + pyraclostrobin (0.10%) resulted in the lowest disease intensity (8.10%), confirming the superiority of combination fungicides. The findings of the present study will support the development of an integrated and sustainable management strategy for Cercospora leaf spot of green gram using SAR activators and fungicides.

Introduction

Pulses provide an affordable source of dietary protein for the general population, especially vegetarians, while also serving as a nutritious and flavorful option enjoyed by the upper class (Bhat, 2019). Among the various pulses, green gram [*Vigna radiata* (L.) Wilczek] referred to as mung bean, moong bean or golden gram. It is highly valued for its rich nutritional content and versatility. Green gram is an important legume crop in India, valued for its nitrogen-fixing ability and short growth duration (Balol *et al.,* 2025). It belongs to the family Leguminosae

(Fabaceae) and is considered to have originated in the Indian subcontinent. It is a prominent pulse crop extensively cultivated throughout South and Southeast Asia due to adaptability to diverse agro-climatic conditions (Patel *et al.,* 2024). Green gram is the third most important pulse crop in India, accounting for about 8 percent of the country's total area under pulse cultivation (Bhat, 2019). In India, the crop is cultivated across three distinct growing seasons *viz*., *Kharif* (July–October), *Rabi* (September–December), and *Zaid* or summer (March–June) (Prasad *et al.,* 2024).

The seeds are nutritionally rich, comprising approximately 24.20 per cent protein, 1.30 per cent fat, and 60.40 per cent starch. In addition, they contain about 118 mg of calcium and 340 mg of phosphorus per 100 g of edible portion (Basavarajappa *et al.,* 2023). Biotic stresses impose unfavorable conditions that adversely affect plant growth and can result in substantial yield losses in green gram. The crop is highly susceptible to a diverse group of pathogens, including Cercospora leaf spot (*Cercospora canescens*), anthracnose (*Colletotrichum capsici*), powdery mildew (*Erysiphe polygoni*), web blight (*Rhizoctonia solani*), charcoal rot (*Macrophomina phaseoli*), Alternaria leaf spot (*Alternaria alternata*), and Ascochyta blight (*Ascochyta phaseolorum*).

Furthermore, it is affected by complex root diseases caused by *Fusarium spp*., *Pythium spp*., and *Rhizoctonia solani*, in addition to nematode infestations, including reniform nematode (*Rotylenchulus reniformis*) and root-knot nematodes (*Meloidogyne spp*.). It is also affected by viral pathogens such as yellow mosaic virus (Prasad *et al.,* 2024). Cercospora leaf spot, a major foliar disease of green gram, is primarily caused by the fungal pathogen *Cercospora canescens* (Semangun 2004). The fungus is ubiquitously present throughout the major green gram cultivation regions. Yield losses in green gram caused by Cercospora leaf spot disease were reported up to 61% (Sumartini, 2017). Under favorable environmental conditions, this disease can cause heavy defoliation in green gram, especially when temperatures range from 25–30 °C and relative humidity is between 90–100%, significantly affecting plant health and productivity (Ingole *et al.,* 2021). The symptoms of the disease are highly variable, initially manifesting as broad, subcircular to irregular brown lesions measuring 2.5–5 mm in diameter and later, at maturity, developing into a grayish and dirty-white mycelial mass (Basavarajappa *et al.,* 2023).

Materials and Methods

Experimental site

The laboratory experiments were systematically conducted at the Department of Plant Pathology, SKN College of Agriculture, Jobner, Jaipur, under controlled conditions to ensure accuracy and reliability of the results. The field experiment was conducted during the *Kharif* season of 2022 at the Agronomy Farm, Sri Karan Narendra Agriculture University, Jobner, Jaipur, Rajasthan. The area falls within the semi-arid eastern plains (Agro-Climatic Zone III A) of Rajasthan, India.

Efficacy of SAR Activators against Cercospora leaf spot

A field experiment was conducted using a susceptible cultivar to determine the efficacy different Systemic Acquired Resistance (SAR) activators against Cercospora leaf spot of green gram at Research Farm, SKN College of Agriculture, Jobner (Jaipur) during *Kharif*, 2022. Seeds of the susceptible cultivar (RMG 492) were sown on 15 July at a spacing of 30 × 10 cm. The experiment was laid out in a Randomized Complete Block Design (RCBD) comprising eight treatments with three replications. The treatments included salicylic acid, hydrogen peroxide, isonicotinic acid, naphthalene acetic acid, oxalic acid, and aminobutyric acid, each applied at a concentration of 200 ppm, whereas triacontanol was applied at 100 ppm, along with an untreated control. A single foliar spray of the respective SAR activators was applied at 25 days after sowing (DAS). Disease observations were recorded at 45 DAS by randomly selecting ten plants from each plot and assessing them using the 0–9 disease rating scale given by Mehta and Mondal (1978). The percent disease intensity (PDI) was calculated using the standard formula proposed by Krishna Prasad *et al.,* (1979) and Uddin *et al.,* (2013).

$$\text{Disease intensity (\%)} = \frac{\text{Sum of total rating}}{\text{Total number of observation x Highest grade in the scale}} \times 100$$

Efficacy of fungicides against Cercospora leaf spot

Seven systemic and contact fungicides (Table 1) at different concentrations were evaluated to determine their antimycotic potential against the mycelial growth of *Cercospora canescens* under *in vitro* as well as *in vivo* conditions.

In vitro evaluation of fungicides

The efficacy of selected fungicides at the concentration of 50, 100 and 200 ppm were assessed against *Cercospora canescens* under laboratory conditions by using "Poisoned Food Technique." The fungus *Cercospora canescens* was maintained on malt extract agar (MEA) medium and incubated for fifteen days to obtain actively growing cultures for experimental use. The required quantities of each fungicide were incorporated into sterilized malt extract agar to obtain the desired concentrations, calculated on the basis of the active ingredient present in the chemical. Approximately 20 ml of fungicide-amended medium was aseptically poured into each sterilized Petri plate and control plates were maintained without the addition of fungicides. A 5 mm diameter mycelial disc, taken from the actively growing margin of a fifteen-day-old culture, was aseptically transferred to the center of each treated and control plate. The inoculated plates were incubated at 25 ± 1°C for fifteen days. Three replications were maintained for each treatment and the experiment was laid out in a Completely Randomized Design (CRD). Radial mycelial growth was recorded by measuring colony diameter along two perpendicular diagonals when the control plates attained full mycelial growth. The percentage inhibition of mycelial growth over control was calculated using the formula proposed by Vincent (1947).

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

That represent,
I = Per cent inhibition of mycelial growth
C = Radial growth of pathogen in control (Average of both diagonals)
T = Radial growth of pathogen in treatment (Average of both diagonals)

In vivo evaluation of fungicides

An experiment was conducted during *Kharif* 2022 to evaluate the efficacy of different fungicides for the management of Cercospora leaf spot of green gram under artificially inoculated field conditions. The seeds of susceptible variety RMG 492 were sown in 2.0 × 2.1 m² plots at 30 × 10 cm spacing. The experiment was laid out in a Randomized Block Design (RBD) with three replications. Foliar application of the fungicides at the specified concentrations (Table 1) were done at the initial appearance of disease symptoms. One untreated control was maintained. The per cent disease intensity (PDI) was recorded at 45 days after sowing (DAS) and calculated as described for the previous.

Results and Discussion

The results of the present investigation, with respect to the percentage inhibition of mycelial growth and the intensity of Cercospora leaf spot disease, are presented below:

Efficacy of SAR Activators against Cercospora leaf spot

To evaluate the efficacy of systemic acquired resistance (SAR) activators, different SAR compounds were tested for the management of Cercospora leaf spot in green gram through foliar application on standing crops. All treatments were more effective in reducing disease severity compared to the untreated control. The data are presented in Table 2 and Fig. 1 revealed that among the seven SAR Activators evaluated, salicylic acid (200 ppm) exhibited the lowest disease intensity (25.20%) and the highest reduction (48.78%) relative to the control, followed by isonicotinic acid (200 ppm), which recorded 30.48 per cent disease intensity and 38.04 per cent reduction. Hydrogen peroxide (200 ppm), naphthalene acetic acid (200 ppm), tricantanol (100 ppm), amino butyric acid (200 ppm), and oxalic acid (200 ppm) resulted in disease intensities of 31.85, 41.67, 35.72, 43.51 and 36.46 per cent, corresponding to reductions of 35.26, 15.30, 27.39, 11.56, and 25.89 per cent over the untreated control, respectively. The present findings are in close conformity with the results reported by Mamgain *et al.,* (2019), they investigated the efficacy of various chemical elicitors in inducing systemic resistance against Alternaria blight of mustard. Their study revealed that salicylic acid was the most effective treatment, resulting in the lowest disease severity (PDI 21.61%), followed by 2,6-dichloroisonicotinic acid (INA) (PDI 33.10%), as compared to the untreated control (PDI 54.75%). Rayanoothala *et al.,* (2025) reported that seeds of green gram were treated with four defence-inducing compounds, namely salicylic acid (SA), chitosan, yeast extract and jasmonic acid (JA), each applied at three different concentrations. The findings demonstrated the significant role of biochemical defence mechanisms in enhancing resistance against charcoal rot disease. Among the treatments, SA proved to be the most effective in both mung bean genotypes, functioning as a crucial signalling molecule that activates and primes plant defence responses against subsequent pathogen attack. The study by Yadav *et al.,* (2025) suggested that the SAR activator salicylic acid (200 ppm) has great potential to control powdery mildew disease in Indian jujube in an eco-friendly manner by boosting the plant defense mechanism. The highest disease control (58.75%) was recorded with salicylic acid (200 ppm) followed by isonicotinic acid (48.04%).

Evaluation of fungicides for *in vitro* mycelial growth inhibition

The efficacy of seven fungicides in controlling the mycelial growth of *Cercospora canescens* was evaluated at three concentrations (50, 100 and 200 ppm) using the poisoned food technique. All tested fungicides exhibited significantly higher inhibition of mycelial growth compared to the untreated control (Table 3 and Fig 2). Among the treatments, the combination of metiram + pyraclostrobin exhibited the highest inhibition of mycelial growth, 92.34, 100 and 100 per cent at concentrations of 50, 100 and 200 ppm, respectively. The tebuconazole + trifloxystrobin and azoxystrobin + difenoconazole showed 82.14, 100 and 100 per cent and 71.66, 82.12 and 91.12 per cent inhibition at 50, 100 and 200 ppm, respectively.

Hexaconazole and azoxystrobin were moderately effective, with inhibition values of 60.23, 76.10 and 88.23 per cent and 53.52, 72.69 and 84.56 per cent, respectively, at the corresponding concentrations. Similarly, tebuconazole demonstrated moderate efficacy, exhibiting 50.56, 66.00 and 80.40 per cent inhibition. Copper hydroxide was the least effective, resulting in 19.33, 39.10 and 59.74 per cent inhibition at 50, 100 and 200 ppm, respectively. Abbas *et al.,* (2020) tested five different fungicides viz., copper hydroxide, cymoxanil +mancozeb, pyraclostrobin + metiram, thiophanate-methyl and difenoconazole at different concentration (10, 50, 100 and 200 ppm) against *Cercospora canescens* using poisoned food technique. They found that pyraclostrobin + metiram was the most effective in inhibiting the mycelial growth of *C. canescens* compared to the control treatment, followed by copper hydroxide. Kumar *et al.,* (2023) revealed that all the fungicides used significantly checked the vegetative growth of *C. canescens* compared to the control. Among them, trifloxystrobin 25% + tebuconazole 50% WG was found to be the most effective against the mycelial growth of *C. canescens* (76.40%, 87.34%, 94.84%, and 100.00%) at different concentrations (50, 100, 150, and 200 ppm), followed by carbendazim 12% + mancozeb 63% WP (68.28%, 80.46%, 88.28%, and 100.00%), respectively, over the control. Patel *et al.,* (2025) reported that five systemic, five non-systemic, and five ready-mixed fungicides were evaluated against *Colletotrichum lindemuthianum in vitro* using the poison food technique. Among the systemic fungicides, the highest mean inhibition of mycelial growth was observed with tebuconazole (100%), followed by carbendazim (78.33%) and difenoconazole (75.18%).

In vivo evaluation of fungicidal activity against Cercospora leaf spot

All the fungicides were found to be significantly more effective in reducing disease intensity compared to the untreated control (Table 4 and Fig. 3). Foliar spray of these fungicides done at the initial appearance of disease symptoms. Among them, metiram + pyraclostrobin (0.10%) was the most effective, reducing disease intensity to 8.10 per cent, followed by tebuconazole + trifloxystrobin (11.74 %), azoxystrobin + difenoconazole (12.46 %), hexaconazole (14.73 %), azoxystrobin (17.37 %), and tebuconazole (19.88 %). Copper hydroxide was the least effective, resulting in a disease intensity of 24.47 per cent. Dam and Sreedhar (2019) tested five fungicides propiconazole 25% EC (0.1%), azoxystrobin 23% SC (0.1%), pyraclostrobin + metiram 60% WG (0.2%), kresoxim-methyl 44.3% SC (0.1%) and carbendazim 50% WP (0.05%).

Among these, pyraclostrobin + metiram 60% WG (0.2%) and carbendazim 50% WP (0.05%) were the most effective in controlling the disease in flue-cured Virginia (FCV) tobacco. Ingole *et al.,* (2021) reported that the minimum disease intensity (5.60%) was observed with the combined product Metiram + Pyraclostrobin WG (0.3%), followed by Propiconazole (0.1%) with 8.45 per cent. In the control, disease intensity was 32.35 per cent. Balol *et al.,* (2025) reported that the application of Fluxapyroxad + Pyraclostrobin effectively reduced the incidence of Cercospora leaf spot in greengram (*Vigna radiata* L. Wilczek). The treatment at 300 ml/ha recorded the lowest mean percent disease index (PDI) of 15.84.

Table.1 Details of different fungicides used

S. No.	Fungicides	Concentration	
		In vitro (ppm)	*In vitro* (ppm)
T1	Hexaconazole	50,100,200	0.1%
T2	Tebuconazole	50,100,200	0.1%
T3	Trifloxystrobin + tebuconazole	50,100,200	0.08%
T4	Azoxystrobin + difenoconazole	50,100,200	0.08%
T5	Metiram + pyraclostrobin	50,100,200	0.1%
T6	Azoxystrobin	50,100,200	0.1%
T7.	Copper hydroxide	50,100,200	0.2%
T8.	Control		

Table.2 Efficacy of systemic acquired resistance (SAR) activators against Cercospora leaf spot of green gram

S. No.	SAR activators	Conc. (ppm)	Per cent disease intensity*	PDI over control
1.	Salicylic acid	200	25.20 (30.10)	48.78
2.	Iso-nicotinic acid	200	30.48 (33.49)	38.04
3.	Hydrogen peroxide	200	31.85 (34.33)	35.26
4.	Naphthalene acetic acid	200	41.67 (40.18)	15.30
5.	Tricantanol	100	35.72 (36.67)	27.39
6.	Amino butyric acid	200	43.51 (41.25)	11.56
7.	Oxalic acid	200	36.46 (37.12)	25.89
8.	Control	200	49.20 (44.52)	
	SEm±		0.93	
	CD (p=0.05)		2.85	

*Average of three replications (%); Figures given in parentheses are angular transformed values

Table.3 Efficacy of fungicides on mycelial growth inhibition of *Cercospora canescens* (*in vitro*)

Fungicides	Per cent inhibition of mycelial growth at different concentration (ppm)*			Mean
	50 ppm	100 ppm	200 ppm	
Hexaconazole	60.23 (50.90)	76.10 (60.84)	88.23 (70.57)	74.85 (60.77)
Tebuconazole	50.56 (45.30)	66.00 (54.31)	80.40 (63.74)	65.65 (54.45)
Trifloxystrobin + tebuconazole	82.14 (65.20)	100 (90.00)	100 (90.00)	94.04 (81.73)
Azoxystrobin + difenoconazole	71.66 (57.85)	82.12 (65.10)	91.12 (73.37)	81.65 (62.44)
Metiram + pyraclostrobin	92.34 (73.99)	100.00 (90.00)	100.00 (90.00)	97.44 (84.66)
Azoxystrobin	53.52 (46.99)	72.69 (58.49)	84.56 (66.91)	70.25 (57.47)
Copper hydroxide	19.33 (20.06)	39.10 (38.68)	59.74 (50.60)	39.39 (38.45)
Control	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Mean	53.72 (45.79)	67.00 (57.18)	75.51 (63.15)	-
	SEm±		**CD (p=0.05)**	
Fungicides (F)	1.02		2.91	
Concentrations (C)	0.62		1.78	
F x C	1.76		5.04	

*Average of three replications (%); Figures given in parentheses are angular transformed values

Table.4 Efficacy of fungicides against Cercospora leaf spot of Green gram (*in vivo*)

S. No.	Fungicides	Conc. (%)	Per cent disease intensity*	PDI over control
1.	Hexaconazole	0.1	14.73 (22.78)	71.38
2.	Tebuconazole	0.1	19.88 (26.74)	61.36
3.	Trifloxystrobin + tebuconazole	0.08	11.74 (20.21)	77.19
4.	Azoxystrobin + difenoconazole	0.08	12.46 (20.86)	75.78
5.	Metiram + pyraclostrobin	0.1	8.10 (16.68)	84.25
6.	Azoxystrobin	0.1	17.37 (24.86)	66.24
7.	Copper hydroxide	0.2	24.47 (29.94)	52.44
8.	Control	-	51.47 (45.82)	-
	SEm±		0.39	
	CD (p=0.05)		1.20	

*Average of three replications (%)
Figures given in parentheses are angular transformed values

Fig.1 Efficacy of systemic acquired resistance SAR activators against Cercospora leaf spot of Green gram

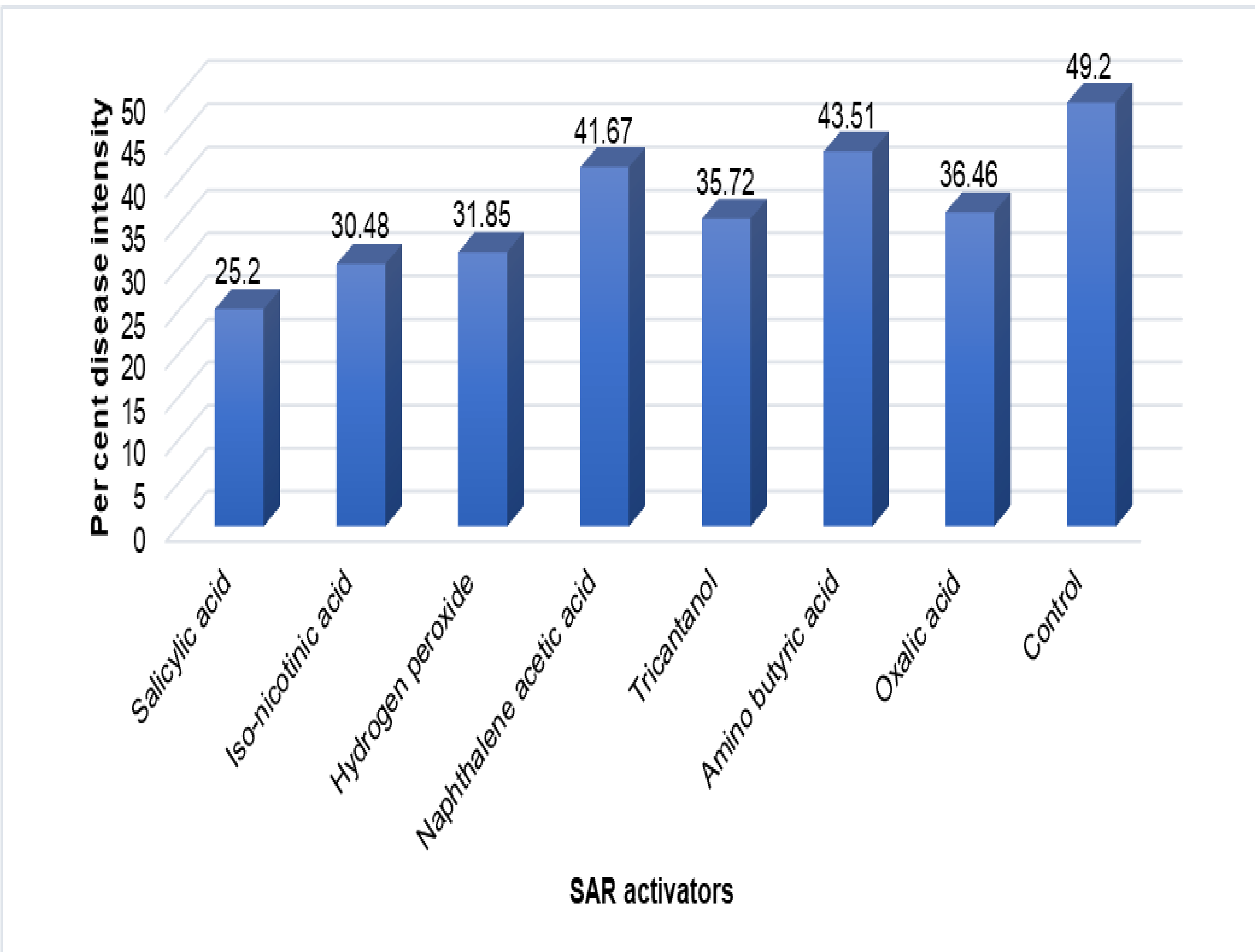


Fig.2 Efficacy of fungicides on mycelial growth inhibition of *Cercospora canescens* (*in vitro*)

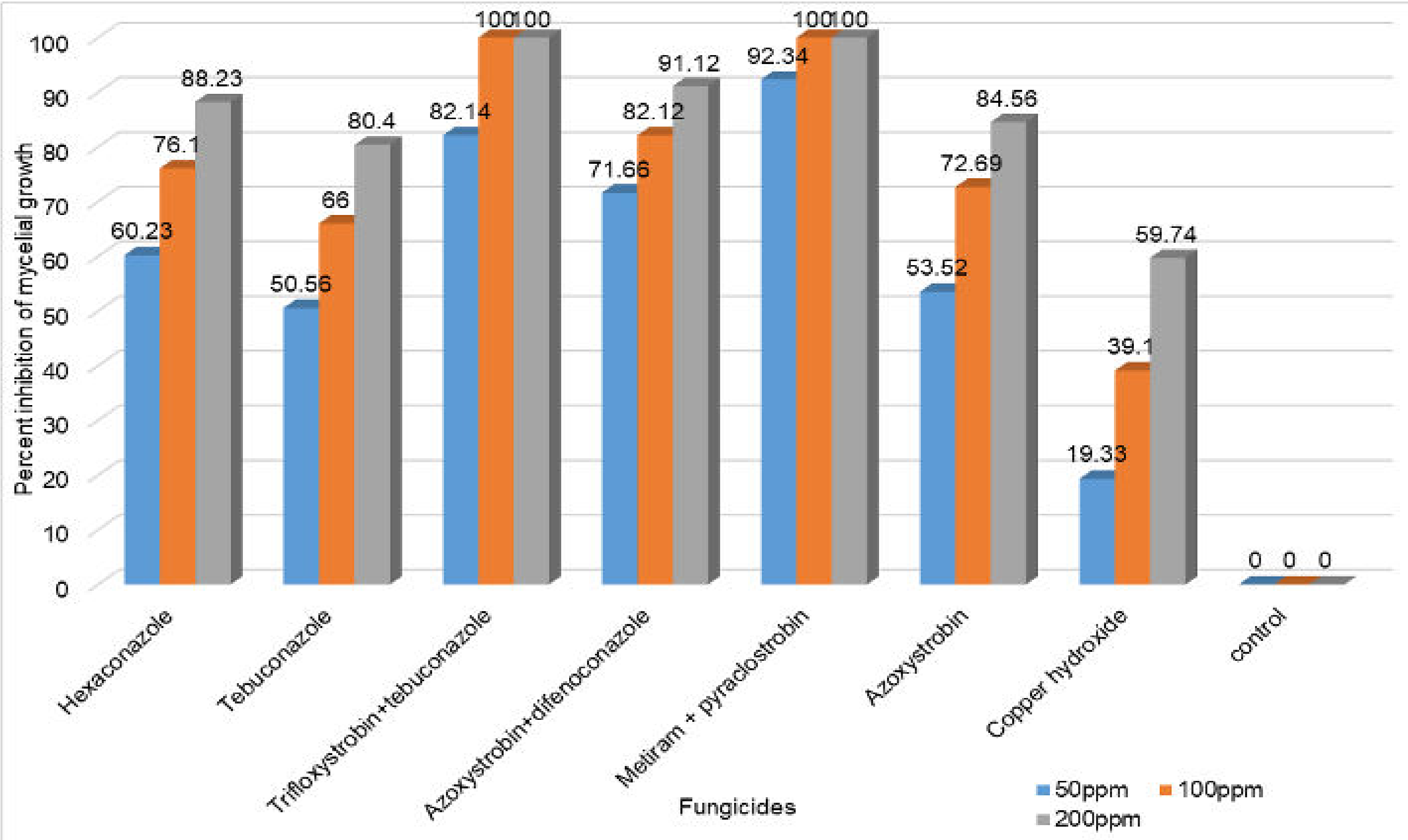
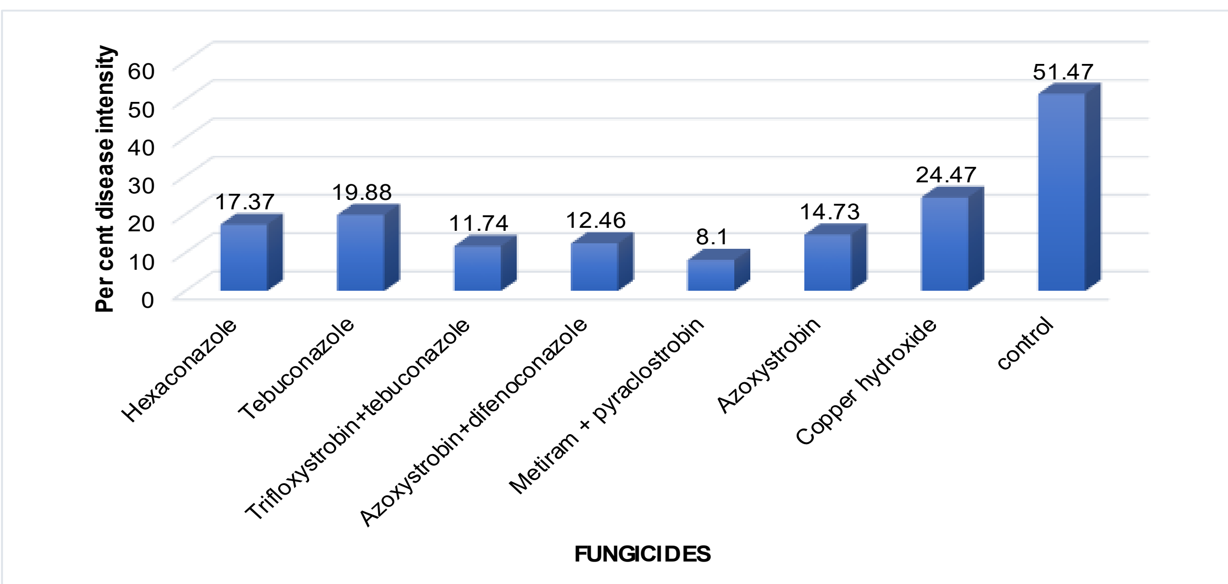


Fig.3 Efficacy of fungicides against Cercospora leaf spot of Green gram (*in vivo*)



Application at 200 ml/ha was also highly effective and statistically comparable to the higher dose, with no phytotoxic effects observed even at elevated levels.

The superior control is attributed to the complementary action of Fluxapyroxad and Pyraclostrobin, providing both preventive and curative protection.

Fluxapyroxad + Pyraclostrobin at 200 ml/ha was identified as an effective, economically viable, and safe option for managing Cercospora leaf spot in green gram.

In conclusion, Cercospora leaf spot is a major disease affecting green gram, causing significant yield losses. Salicylic acid (200 ppm) was the most effective SAR activator in reducing Cercospora leaf spot in green gram. Among fungicides, metiram + pyraclostrobin exhibited the highest *in vitro* mycelial inhibition and field efficacy, while copper hydroxide was least effective.

Overall, combination of fungicides proved superior to single compounds in disease management. These findings demonstrate the potential of using SAR activators and combination fungicides as effective and sustainable strategies for managing Cercospora leaf spot in green gram.

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Author Contributions

Manisha Khichar: Investigation, formal analysis, writing—original draft. Shailesh Godika: Validation, methodology, writing—reviewing. Harshdeep Singh:—Formal analysis, writing—review and editing. Pinki: Investigation, writing—reviewing. Vijay Kumar Kasotiya: Resources, investigation writing—reviewing. Ravi Regar: Validation, formal analysis, writing—reviewing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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