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IN VITRO AND *IN VIVO* EFFICACY OF FUNGITOXICANTS AGAINST CHARCOAL ROT OF SESAME INCITED BY *Macrophomina phaseolina* (Tassi) Goid

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ABSTRACT

Different systemic, combination, and contact fungicides at different concentrations were evaluated against the charcoal rot of sesame pathogen, *Macrophomina phaseolina* under *in vitro and in vivo* conditions. Poison food technique was used to evaluate fungitoxicants under *in vitro* conditions in which complete inhibition (100%) was observed in combination with fungicides tebuconazole 50% + trifloxystrobin 25% at the lower concentration of 20 ppm and systemic fungicide tebuconazole 25EC at a concentration of 50 ppm. Two contact fungicides mancozeb (85.64 %) and chlorothalonil (57.35 %) give inhibition at 100 ppm concentration. The same set of fungicides was used under *in vivo* conditions as a foliar spray application, in which two combination fungicides tebuconazole 50% + trifloxystrobin 25%, azoxystrobin 18.2% + difenoconazole 11.4% and one systemic fungicide tebuconazole 25 EC showed lower disease severity on sesame (%).

Keywords: Charcoal rot, Fungicides, *Macrophomina phaseolina*, Sesame

Sesame (*Sesamum indicum* L.), commonly known as *Til*, is a member of the Pedaliaceae family in the genus *Sesamum* and is primarily grown for its edible seeds and oil. In India in the year 2023, the production was 8.02 lakh tonnes from 15.23 lakh hectares with average productivity of 526.7 kg/ha. Globally, sesame is cultivated across 75 nations spanning 13.04 million hectares with a production of 6.79 million tonnes (FAOSTAT, 2023). After rapeseed-mustard and sunflower, sesamum is Punjab's third most important oilseed crop, accounting for almost 11% of the state's land area and 4% of overall oilseed production (Anonymous, 2021a). Sesame (*Til*) was grown on 2.6 thousand hectares in Punjab in 2019-20, with a production of 1.0 thousand tonnes. The average yield was 3.82 quintals/ha (1.55 quintals/acre) (Anonymous, 2021b).

This crop suffers from various biotic stresses with a wide range of viral, bacterial, and fungal pathogens with *Macrophomina phaseolina* (Tassi) Goid imposing a 5-100 percent yield loss and is known to cause charcoal rot over 500 plant species such as *Sorghum bicolor, Zea mays* and *Avena sativa*, legumes such as *Cicer arietinum, Arachis hypogaea, Vigna unguiculata, Vigna mungo, Medicago sativa, Glycine max, Phaseolus* spp. and many other species of woody plants (Gupta *et al.,* 2018). This pathogen mostly damages the collar region of the stems. The diseased area rots and turns a distinctive black color. On the surface of the afflicted tissue, many dot-like black formations represent the fungus's pycnidial stage form. Numerous sclerotia develop inside the afflicted area. On the pods and seeds, infected capsules and tiny sclerotia can be found (Lakhran *et al.*, 2018).

Management of charcoal rot is difficult due to the soil-borne nature of the fungus. Till now no proper fungicide is found to be effective against this fungus under Punjab conditions. At present, information about effective fungitoxicant against charcoal rot disease is very meager and needs to be worked out to identify the novel fungitoxicants for the management of charcoal rot disease. Therefore, the present study was conducted to evaluate the combinations of fungitoxicants under *in vitro* and *in vivo* conditions against *Macrophomina phaseolina* in sesame crop.

MATERIALS AND METHODS

Isolation and pathogenicity of the pathogen

Infected roots of sesame plants with typical symptoms of charcoal rot were used to isolate the associated fungus *M. phaseolina.* The infected root was cut into small parts having both healthy as well as infected parts of the root. The small pieces of root were then surface sterilized with 0.1% mercuric chloride solution for 30-35 seconds followed by three washings in autoclaved distilled water. The

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sterilized root portion was further transferred on sterile Petri plates containing 20ml potato dextrose agar media in a laminar airflow system. Inoculated Petri plates were incubated in a B.O.D. incubator at 28±2°C temperature. Purification of fungus isolate was done by subculturing 2-3 days old fungal culture using the hyphal tip technique. The purified culture was maintained at 5°C for further lab experimentation (Dasgupta, 1988). Pathogenicity of *M. phaseolina* isolate was proved on sesame variety *Punjab Til No. 2* as per the method described by Bhaliya and Jadeja (2013).

Evaluation of fungitoxicants under *in vitro* conditions

In vitro evaluation of different fungicides viz. difenconazole 25% EC, tebuconazole 25% EC, hexaconazole 5% EC, azoxystrobin 18.2% + difenconazole 11.4% SC, tebuconazole 50% + trifloxystrobin 25% WG, chlorothalonil 75% WP, mancozeb 75% WP at different concentrations of 1, 5, 10, 20, 25, 50, 100 ppm was done using poison food technique given by Grover and Moore (1962). Stock solutions of double concentrations for each fungicide were prepared by adding the required amount of sterile double distilled water. Fifty millilitre of each concentration was added to 50 ml of liquid PDA medium of double strength (double concentration becomes the required one) and after that poured in Petri-plates and allowed to solidify. Each plate was then aseptically inoculated with a 5 mm mycelial disc of *M. phaseolina* from the periphery of a 4-5 day old colony grown on PDA and incubated in a B.O.D. incubator at 28±2^{0}C temperature. Three replications for each concentration along with control (without any fungicide) were maintained for data recording. The colony diameter was measured after every 24 hours till the control plate was fully grown. The radial growth of fungus in each treatment (percent growth inhibition) was calculated by using the formula given by Vincent (1947).

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

where,

PGI = Per cent growth inhibition
C = Linear area of test fungus in control (mm)
T = Linear area of test fungus in respective treatment (mm)

Evaluation of fungitoxicants under *in vivo* conditions

A field experiment on the management of sesamum charcoal rot using different fungicides and bioagents was conducted. Total fifteen treatments including control were tested following Randomized Block Design (RBD) having plot size of 3 x 3 m^2 with sesame variety *Punjab Til No. 2* during *kharif* season 2021 at two different locations namely Punjab Agricultural University, Ludhiana and PAU Regional Research Station, Ballowal Saunkhri for evaluation of different fungitoxicants against *M. phaseolina* causing charcoal rot of sesame. Three replications of each treatment were maintained during the *in vivo* experiment.

One spray of inoculum was carried out before the first spray on the crop to set up the amount of disease on the crop. During the crop growth period two sprays of different treatments were given at an interval of 30 and 45 DAS. The observations were recorded on stem portion of crop to find out the amount of disease severity occurred on crop after given treatments. Disease severity on stem was recorded at 50 and 75 DAS. The two bioagents viz. *Trichoderma viride* and *Pseudomonas fluorescens* were applied as seed treatment and *T. viride* was as soil application. For soil application, *T. viride* @ 2.5 kg/ha was used to fortified 100 kg FYM. For seed treatment bio-agent consortium of PAU *T. viride* (0.4%) + *P. fluorescens* (0.4%) (4 g/ kg seeds of each formulation) was used. Seven different types of fungicides were used at two different doses of lower and higher amounts as foliar applications to check the effectiveness of fungicides against the pathogen (Table 1). A total of fifteen treatments including control were tested following randomized block design having plot size 3 x 3 m^2 with susceptible variety *Punjab Til. No. 2* during *kharif* season 2021. Each treatment was replicated thrice. The grain yield was also recorded after the harvest of the crop.

The observations on charcoal rot incidence were recorded periodically at weekly intervals starting from three days after first spray and per cent disease incidence and severity was calculated by using following formula:

Per cent Disease Incidence (PDI) =

$$\frac{\text{Total No.of infected plants}}{\text{Total no.of plants observed}} \times 100$$

Per cent Disease Severity (DSI) =

$$\frac{\{\text{sum (class frequency} * \text{score of rating class)}\}}{\{(\text{total number of plants}) * (\text{maximal disease index})\}} \times 100$$

Table 1. Treatments used in field experiment

Sr. No.	Treatment	Dose (%)
1	T_1:Foliar spray of hexaconazole 5%EC	0.1
2	T_2:Foliar spray of hexaconazole 5%EC	0.2
3	T_3:Foliar spray of tebuconazole 25%EC	0.05
4	T_4:Foliar spray of tebuconazole 25%EC	0.1
5	T_5:Foliar spray of difenoconazole 25%EC	0.05
6	T_6:Foliar spray of difenoconazole 25%EC	0.1
7	T_7:Foliar spray of chlorothalonil 75%WP	0.15
8	T_8:Foliar spray of chlorothalonil 75%WP	0.3
9	T_9:Foliar spray of azoxystrobin 18.2% + difenoconazole 11.4 %SC	0.05
10	T_{10}:Foliar spray of azoxystrobin 18.2% + difenoconazole 11.4%SC	0.1
11	T_{11}:Foliar spray of tebuconazole 50% + trifloxystrobin 25%WG	0.05
12	T_{12}:Foliar spray of tebuconazole 50% + trifloxystrobin 25%WG	0.1
13	T_{13}:Foliar spray of mancozeb 75%WP	0.2
14	T_{14}:Seed treatment with bioagent consortium of PAU *T. viride* + *P. fluorescens* and soil application of *T. viride* @ 2.5 kg/ha fortified with FYM	ST with *T. viride* (0.4%) + *P. fluorescens* (0.4%) + SA *T. viride* @ 2.5 kg/ha fortified with FYM
15	T_{15}:Control	

*ST= Seed treatment, *SA= Soil application

Statistical analysis

The statistical analysis of data of field and lab experiments was done according to the procedure given by Cochran and Cox (1957). All the laboratory experiments were done with completely randomized design and for field experiment randomized block design was used for analysis of data.

RESULTS AND DISCUSSION

In vitro evaluation of fungitoxicants against *Macrophomina phaseolina*

In vitro evaluation of fungicides was performed using poison food technique against the pathogen. Seven fungicides viz. difenconazole 25%EC, tebuconazole 25%EC, hexaconazole 5%EC, azoxystrobin 18.2% + difenconazole 11.4% SC, tebuconazole 50% + tifloxystrobin 25% WG, chlorothalonil 75%WP, mancozeb 75%WP were used to evaluate their efficacy against pathogen at various concentrations. A significant increasing trend in the inhibition of mycelial growth of *Macrophomina phaseolina* was observed at the increasing concentrations of fungicides from 1, 5, 10, 20, 25, 50 and 100 ppm. All the tested fungicides showed per cent inhibition at the lowest concentration of 1 ppm, i.e., 52.20, 61.61, 37.12, 23.53, 62.70, 42.35, 30.70 for azoxystrobin 18.2% + difenconazole 11.4% SC, tebuconazole 50% + trifloxystrobin 25% WG, hexaconazole 5%EC, chlorothalonil 75%WP, tebuconazole 25%EC, difenconazole 25%EC and mancozeb 75%WP, respectively (Table 1). Among the tested fungicides, complete inhibition (100%) was observed in combination fungicide tebuconazole 50% + trifloxystrobin 25% at the lower concentration of 20 ppm and systemic fungicide tebuconazole at a concentration of 50 ppm. The maximum per cent inhibition was recorded in hexaconazole 5%EC (88.16), azoxystrobin 18.2% + difenconazole 11.4%SC (86.49), mancozeb 75%WP (85.64) and difenconazole 25%EC (82) each at 100 ppm concentration. Among all fungicides tebuconazole 50% + trifloxystrobin 25%WG was effective as it gave complete retardation of growth of pathogen at 20 ppm concentration and even at a lower dose of 1, 5, and 10 ppm the growth retardation was 61.61, 75.97, and 84.48, respectively, suggesting its effectiveness under *in vitro* conditions. Tebuconazole 25EC gave good results at 20 and 25 ppm concentration with 85.06 and 85.88 percent inhibition of test fungus, respectively. The systemic fungicides hexaconazole 5%EC and difenconazole 25%EC were effective at 100 ppm concentration while the tebuconazole 25%EC was effective against the pathogen at 50 ppm. Among the contact fungicides mancozeb 75%WP was effective at 100 ppm and gave up to 85.64%

Table 1. Effect of fungicides on percent growth inhibition of *Macrophomina phaseolina*

	Growth inhibition (%)						
Treatment	**1 ppm**	**5 ppm**	**10 ppm**	**20 ppm**	**25 ppm**	**50 ppm**	**100 ppm**
Azoxystrobin 18.2% + difenoconazole 11.4% SC	52.2	60.56	74.13	76.78	77.12	79.77	86.49
Tebuconazole 50% +trifloxystrobin 25% WG	61.61	75.97	84.48	100	100	100	100
Hexaconazole 5% EC	37.12	48.73	56.43	67.01	82.06	84.36	88.16
Chlorohalonil 75% WP	23.53	40.12	44.83	45.52	45.88	49.76	57.35
Tebuconazole 25% EC	62.70	68.23	81.41	85.06	85.88	100	100
Difenoconazole 25% EC	42.35	59.70	67.05	68.47	72.64	74.94	82.00
Mancozeb 75% WP	30.70	40.70	55.41	62.00	66.17	81.05	85.64
Factors	CD (*$p \le 0.05$*)	SE(m)					
Fungicide	*1.12*	0.40					
Concentration	*1.12*	0.40					
Interaction	*2.95*	1.05					

inhibition of the pathogen, while chlorothalonil 75%WP didn't give as good results (Fig. 1, Plate 1-4).

Several scientists conducted *in vitro* evaluation of fungicides against the *Macrophomina phaseolina*. Bashir (2018) reported that Nativo (tebuconazole 50% + trifloxystrobin 25%WG) was effective at 5, 10, 15, and 25 ppm with complete inhibition at 25 ppm, tebuconazole most effective at 50ppm concentration and mancozeb was effective at concentration range from 50-100 ppm against *M. phasiolina*. The present findings were in accordance with the findings of Bashir (2018) i.e., tebuconazole 50% + trifloxystrobin 25%WG gave complete inhibition at 20 ppm concentration and also tebuconazole 25%EC was effective at 100 ppm with complete retardation of pathogen growth. Mancozeb 75% WP also resulted in more than 50 percent inhibition of pathogen from concentration of 10 ppm and more than that at 100 ppm concentration. It resulted in maximum percent inhibition (85.64). Sanjay *et al.* (2020) has also reported similar finding to our results proposing mancozeb 75% WP effective against the pathogen. Parmar *et al.* (2017) has studied the effect of difenoconazole 25% EC, tebuconazole 25% EC, and hexaconazole 25%EC on the mycelial growth of *Macrophomina phaseolina* for 7 days and reported 75.47, 65.28, 56.83%, mean growth inhibition of pathogen at various concentrations These reported findings are very much similar to our findings against the pathogen at various concentration of fungicides.

In vivo evaluation of fungitoxicants against *Macrophomina phaseolina* causing charcoal rot of sesame

The data on percent disease severity (PDS) on stem recorded at 50 DAS, 75 DAS, and AUDPC values at Ludhiana and Ballowal Saunkhri are presented in Table 2. Significant differences were observed among treatments at both locations. At Ludhiana, the minimum PDS was observed in treatment T_{12} (tebuconazole 50% + trifloxystrobin 25% WG @ 0.1%), recording 6.74% and 15.64 % disease severity at 50 DAS and 75 DAS, respectively. It was followed by treatment T_{10} (azoxystrobin 18.2% + difenoconazole 11.4% SC @ 0.1%) with 6.82% and 15.66% PDS, respectively. The lowest AUDPC was also recorded in the treatment T_{12} (448.41) followed by T_{10} (451.48), indicating their superior performance in disease management. At Ballowal Saunkhri, a similar trend was observed where T_{12} (7.80% and 17.01% PDS at 50 and 75 DAS, respectively) and T_{10} (7.55% and 16.30%) proved most effective with the lowest AUDPC values (505.11 and 486.93, respectively) (Table 2 & 3).

Among the solo fungicides, tebuconazole 25% EC @ 0.1% (T_4) and difenoconazole 25% EC @ 0.1% (T_6) were the most effective, significantly reducing PDS compared to control. Mancozeb 75% WP (T_{13}) was least effective among fungicides, with PDS (20.19% and 30.43% at 50 and 75 DAS, respectively) and a high AUDPC (1137.32) which was statistically inferior to systemic fungicides. The untreated control (T_{15}) recorded the highest PDS (24.43% and 37.37%) and AUDPC (1383.16 at Ludhiana, 1497.72 at Ballowal Saunkhri). The differences among treatments were statistically significant (Table 2 & 3).

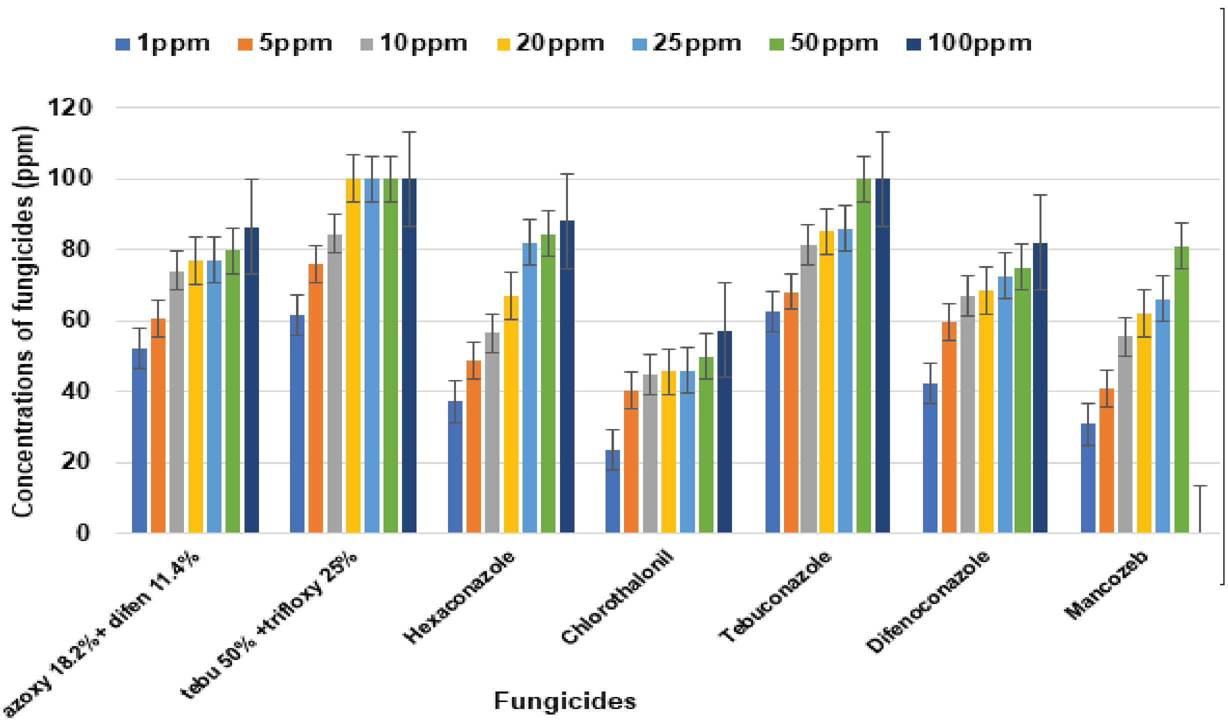

Fig. 1. Percent growth inhibition of *Macrophomina phaseolina* in poison food technique

Plate 1. Evaluation of (a) tebuconazole 25% EC, (b) azoxystrobin 18.2% + difenconazole 11.4% SC and (c) chlorothalonil 75% WP against *Macrophomina phaseolina* under *in vitro* conditions using poisoned food technique

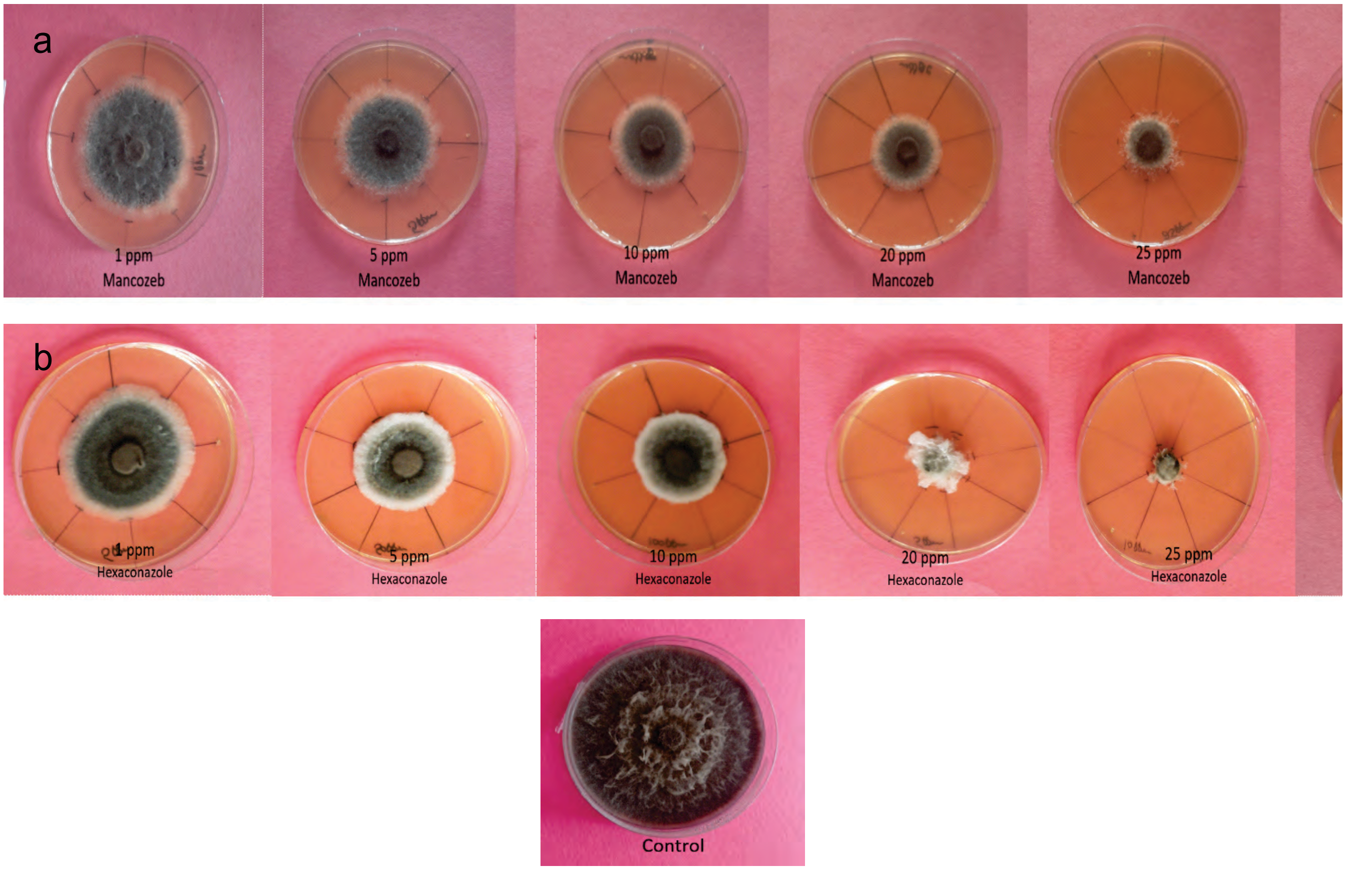

Plate 2. **Evaluation of (a) mancozeb 75% WP and (b) hexaconazole 5% EC against *Macrophomina phaseolina* under *in vitro* conditions using poisoned food technique**

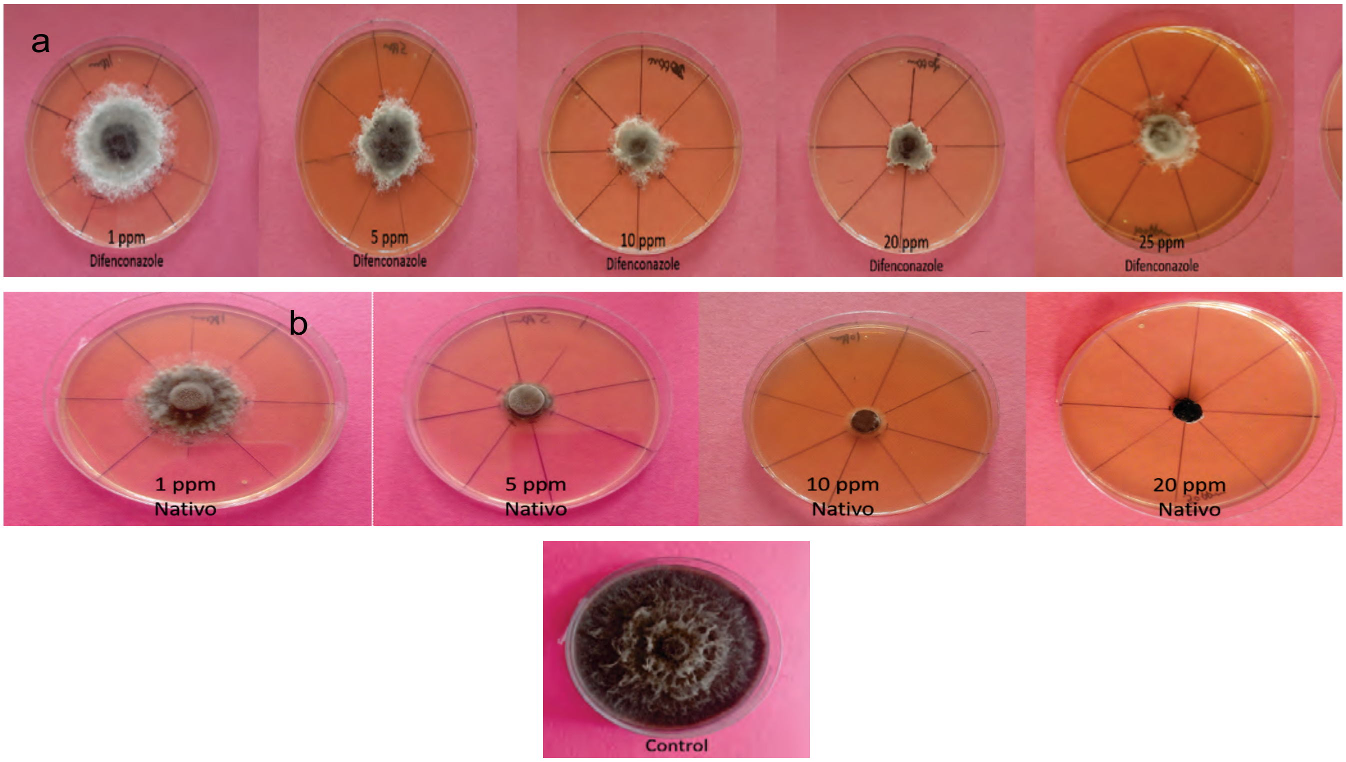

Plate 3. **Evaluation of (a) difenconazole 25% EC and (b) tebuconazole 50% + trifloxystrobin 25% WG against *Macrophomina phaseolina* under *in vitro* conditions using poisoned food technique**

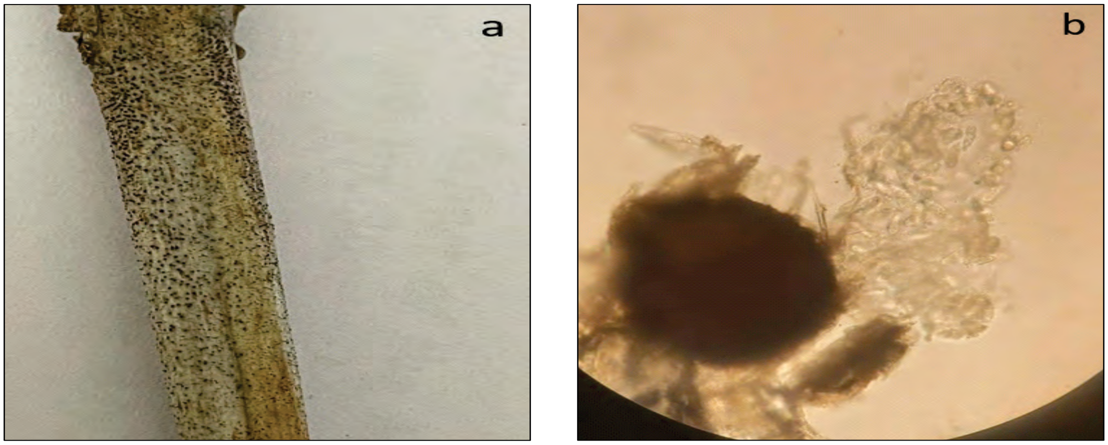

Plate 4. (a) Microsclerotia on stem (b) pycnidia under microscope at 40x

Table 2. Evaluation of fungicides against charcoal rot of sesame at PAU, Ludhiana and RRS Ballowal Saunkhri during *kharif* 2021

Treatment	Percent disease severity on stem					
	LUDHIANA			BALLOWAL SAUNKHRI		
	50 DAS	75 DAS	AUDPC	50 DAS	75 DAS	AUDPC
T_1 (hexaconazole 5%EC@ 0.1%)	15.72 (23.33)	30.24 (33.30)	967.54	19.37 (26.07)	31.18 (33.84)	1116.23
T_2 (hexaconazole 5%EC @ 0.2%)	13.23 (21.23)	22.87 (28.43)	782.01	15.09 (22.80)	25.51 (30.20)	884.82
T_3 (tebuconazole 25%EC @ 0.05%)	11.97 (20.13)	24.61 (29.47)	756.52	13.86 (21.80)	24.73 (29.73)	828.94
T_4 (tebuconazole 25%EC @ 0.1%)	7.88 (16.24)	16.95 (24.13)	507.24	10.37 (18.77)	20.72 (27.02)	648.04
T_5 (difenoconazole 25%EC @ 0.05%)	15.07 (22.18)	27.6 (31.57)	910.22	15.77 (23.84)	26.65 (30.98)	924.55
T_6 (difenoconazole 25%EC @ 0.1%)	7.38 (15.56)	19.6 (25.07)	521.81	9.50 (17.90)	19.22 (25.96)	596.61
T_7 (chlorothalonil 75%WP @ 0.15%)	14.74 (22.56)	24.77 (29.75)	862.40	16.35 (23.81)	27.70 (31.65)	959.33
T_8 (chlorothalonil 75%WP @ 0.3%)	10.80 (19.14)	22.15 (28.01)	681.78	12.21 (20.36)	21.69 (27.62)	729.06
T_9 (azoxystrobin 18.2% +difenconazole 11.4% SC @ 0.05%)	7.10 (15.35)	16.54 (23.13)	472.89	8.78 (17.21)	18.77 (25.64)	563.68
T_{10} (azoxystrobin 18.2%+ difenconazole 11.4% @ SC 0.1%)	6.82 (14.28)	15.66 (21.64)	451.48	7.55 (15.89)	16.30 (23.71)	486.93
T_{11} (tebuconazole 50% + trifloxystrobin 25% WG @ 0.05%)	10.83 (19.16)	16.67 (23.68)	614.50	13.12 (21.21)	23.05 (28.580	780.22
T_{12} (tebuconazole 50% + trifloxystrobin 25% WG @ 0.1%)	6.74 (14.88)	15.64 (22.91)	448.41	7.80 (16.14)	17.01 (24.27)	505.11
T_{13} (Mancozeb 75% WP @ 0.2%)	20.19 (26.53)	30.43 (33.44)	1137.32	22.03 (27.93)	33.16 (35.09)	1240.42
T_{14} (ST with *T. viride* (0.4%) + *P. fluorescens* (0.4%) + SA *T. viride*)	13.59 (21.34)	21.16 (26.82)	774.22	17.45 (24.58)	29.20 (32.60)	1019.53
T_{15} (Control)	24.43 (29.58)	37.37 (37.62)	1383.16	26.00 (30.55)	41.82 (40.26)	1497.72
SE(m)	2.09	2.87		1.16	1.97	
CD ($p \le 0.05$)	*6.09*	*8.36*		*3.37*	*5.75*	
CV (%)	18.02	17.8		9.14	11.47	

The present investigation clearly indicated that tebuconazole 50% + trifloxystrobin 25% WG (0.1%) and azoxystrobin 18.2% + difenoconazole 11.4% SC (0.1%) were most effective in minimizing disease severity on stem under field conditions, which may be attributed to their dual modes of action-triazoles inhibit ergosterol biosynthesis and strobilurins block mitochondrial respiration, leading to effective pathogen suppression (Bartlett *et al.*, 2002; FRAC, 2024). Similar findings were reported by Kaur *et al.* (2021), who observed significant reduction in disease severity of Alternaria blight of Brassica with strobilurin + triazole combinations under Punjab conditions. Sharma *et al.* (2020a) also emphasized that mixtures of fungicides with different modes of action not only provide better disease control but also delay the development of fungicide resistance in pathogen populations. The solo triazoles, particularly tebuconazole 25% EC @ 0.1% and difenoconazole 25 EC @ 0.1%, were also highly effective and statistically comparable to the combination fungicides, corroborating the findings of Meena *et al.* (2019) who reported that triazoles at recommended doses were superior in reducing disease severity and improving seed yield. The contact fungicide mancozeb, although widely used as a protectant, showed comparatively lower efficacy, which may be attributed to its surface action and inability to eradicate existing infections. This is consistent with the results of Singh and Gupta (2018)

Table 3. Pooled mean of per cent disease index of charcoal rot of sesame on stem at PAU Ludhiana and RRS Ballowal Saunkhri during *kharif* 2021

Treatment	Pooled mean of Ludhiana and Ballowal Saunkhri	
	50 DAS	**75 DAS**
T_1 (hexaconazole 5%EC@ 0.1%)	17.55	30.71
T_2 (hexaconazole 5%EC @ 0.2%)	14.16	24.19
T_3 (tebuconazole 25%EC @ 0.05%)	12.92	24.67
T_4 (tebuconazole 25%EC @ 0.1%)	9.12	18.84
T_5 (difenoconazole 25%EC @ 0.05%)	15.42	27.13
T_6 (difenoconazole 25%EC @ 0.1%)	8.44	19.41
T_7 (chlorothalonil 75%WP @ 0.15%)	15.55	26.24
T_8 (chlorothalonil 75%WP @ 0.3%)	11.51	21.92
T_9 (azoxystrobin 18.2% +difenconazole 11.4% SC @ 0.05%)	7.94	17.65
T_{10} (azoxystrobin 18.2%+ difenconazole 11.4% @ SC 0.1%)	7.19	15.98
T_{11} (tebuconazole 50% + trifloxystrobin 25% WG @ 0.05%)	11.97	19.87
T_{12} (tebuconazole 50% + trifloxystrobin 25% WG @ 0.1%)	7.27	16.32
T_{13} (Mancozeb 75% WP @ 0.2%)	21.11	31.79
T_{14} (ST with *T. viride* (0.4%) + *P. fluorescens* (0.4%) + SA *T. viride*)	15.52	25.18
T_{15} (Control)	25.21	39.59
CD ($p \leq 0.05$)	*5.35*	*9.20*

Table 4. Pearson correlation of yield with AUDPC on stem, no. of pods, no. of branchs and plant height at PAU Ludhiana location

	AUDPC	**No. of total pods**	**Total no of branches**	**Plant height**	**Seed yield**
AUDPC	1.00				
No. of total pods	-0.235NS	1.00			
Total no of branches	-0.342NS	0.134NS	1.00		
Plant height	-0.150NS	-0.025NS	0.275NS	1.00	
Seed yield	-0.844**	0.067NS	0.376NS	0.081NS	1.00

**Significant at $p \leq 0.01$

Table 5. Pearson correlation of yield with AUDPC on stem, no. of pods, no. of branchs and plant height at RRS Ballowal Saunkhri location

	AUDPC	No. of total pods	Total no of branches	Plant height	Seed yield
AUDPC	1.00				
No. of total pods	-0.291NS	1.00			
Total no of branches	-0.244NS	0.296NS	1.00		
Plant height	-0.247NS	0.239NS	0.029NS	1.00	
Seed yield	-0.722**	0.327NS	0.171NS	0.409NS	1.00

**Significant at *p≤0.01*

Table 6. Seed yield in different treatments at Ludhiana and Ballowal Saunkhri during *kharif* 2021

Treatment	Yield (kg/ha)	
	Ludhiana	Ballowal Saunkhri
T_1 (hexaconazole 5%EC@ 0.1%)	667.19	655.36
T_2 (hexaconazole 5%EC @ 0.2%)	812.20	728.66
T_3 (tebuconazole 25%EC @ 0.05%)	710.71	597.97
T_4 (tebuconazole 25%EC @ 0.1%)	868.65	757.81
T_5 (difenoconazole 25%EC @ 0.05%)	703.59	724.04
T_6 (difenoconazole 25%EC @ 0.1%)	796.67	806.29
T_7 (chlorothalonil 75%WP @ 0.15%)	671.53	745.64
T_8 (chlorothalonil 75%WP @ 0.3%)	740.88	774.42
T_9 (azoxystrobin 18.2% +difenconazole 11.4% SC @ 0.05%)	743.34	788.03
T_{10} (azoxystrobin 18.2%+ difenconazole 11.4% @ SC 0.1%)	842.49	848.38
T_{11} (tebuconazole 50% + trifloxystrobin 25% WG @ 0.05%)	709.30	728.72
T_{12} (tebuconazole 50% + trifloxystrobin 25% WG @ 0.1%)	883.98	797.28
T_{13} (Mancozeb 75% WP @ 0.2%)	666.23	690.87
T_{14} (ST with *T. viride* (0.4%) + *P. fluorescens* (0.4%) + SA *T. viride*)	650.23	584.72
T_{15} (Control)	541.74	528.48
SE(m)	55.23	43.53
CD	62.20	70.38
CV (%)	13.22	11.34

who observed partial control of foliar blight with mancozeb 75% WP alone.

The Pearson correlation coefficients of seed yield with AUDPC, number of pods, number of branches, and plant height at PAU Ludhiana and RRS, Ballowal Saunkhri are presented in Tables 4 and 5. At Ludhiana, seed yield showed a strong and highly significant negative correlation with AUDPC (r = -0.844**), indicating that higher disease severity on stem was associated with a sharp decline in yield. Seed yield exhibited a positive, though non-significant, correlation with number of branches (r = 0.376NS) and plant height (r = 0.081NS). A very weak and non-significant correlation was observed with number of pods (r = 0.067NS). At Ballowal Saunkhri, a similar pattern was observed. Seed yield was negatively and significantly correlated with AUDPC (r = -0.722)**. Correlation with number of pods (r = 0.327NS), number of branches (r = 0.171NS), and plant height (r = 0.409NS) was positive but non-significant. Overall, the results from both locations consistently indicated that AUDPC was the most important factor for reduction of the sesame yield under field conditions, while other yield components showed only weak or inconsistent associations with final seed yield (Fig. 2 & 3).

The significant negative correlation between seed yield and AUDPC observed at both locations indicates that stem blight severity has a direct and adverse impact on crop productivity. These findings corroborate earlier reports by Meena *et al.* (2019) and Kaur *et al.* (2021), who demonstrated that Alternaria blight severity is inversely related to seed yield, and higher AUDPC values are associated with substantial yield losses in rapeseed-mustard.

The weak and non-significant correlation of seed yield with number of pods, branches, and plant height suggests that these traits are less reliable indicators of yield under disease pressure. This may be attributed to the fact that disease severity disrupts source-sink relationships, leading to reduced seed filling even when the number of pods or plant height

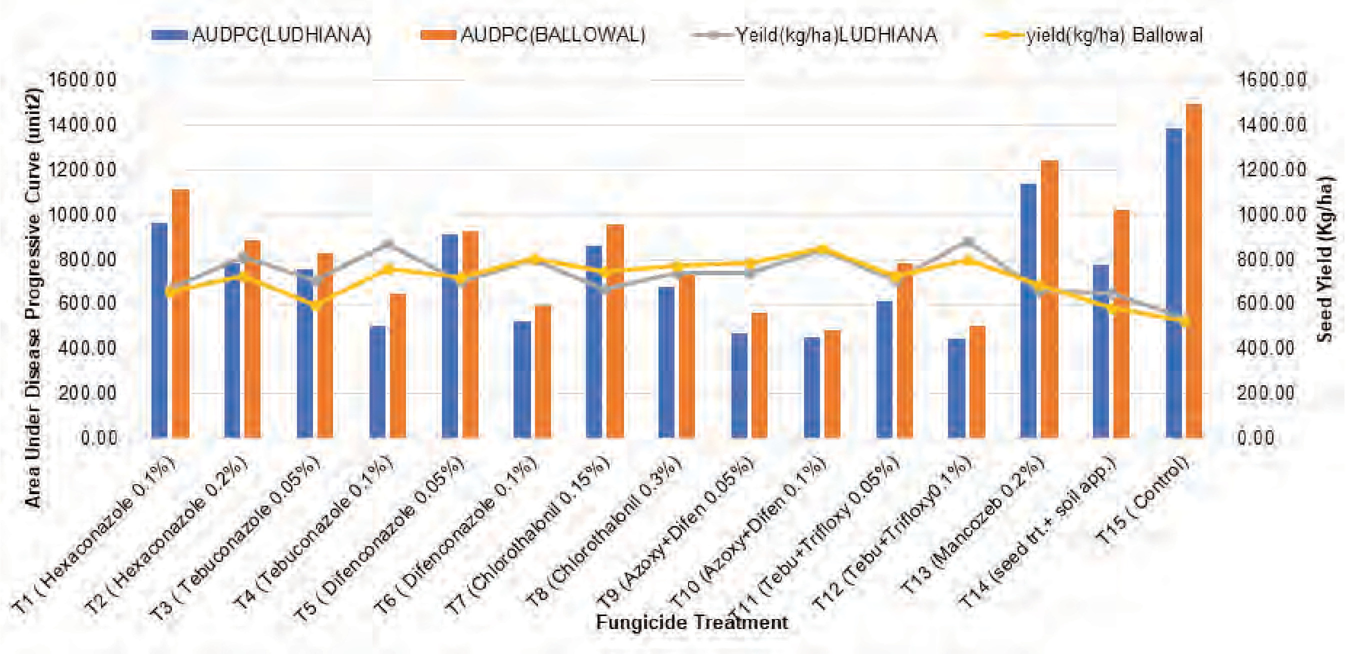

Fig. 2. **Area under disease progress curve (AUDPC) of disease severity on stem and seed yield at PAU Ludhiana and RRS Ballowal Saunkhri during *kharif* 2021**

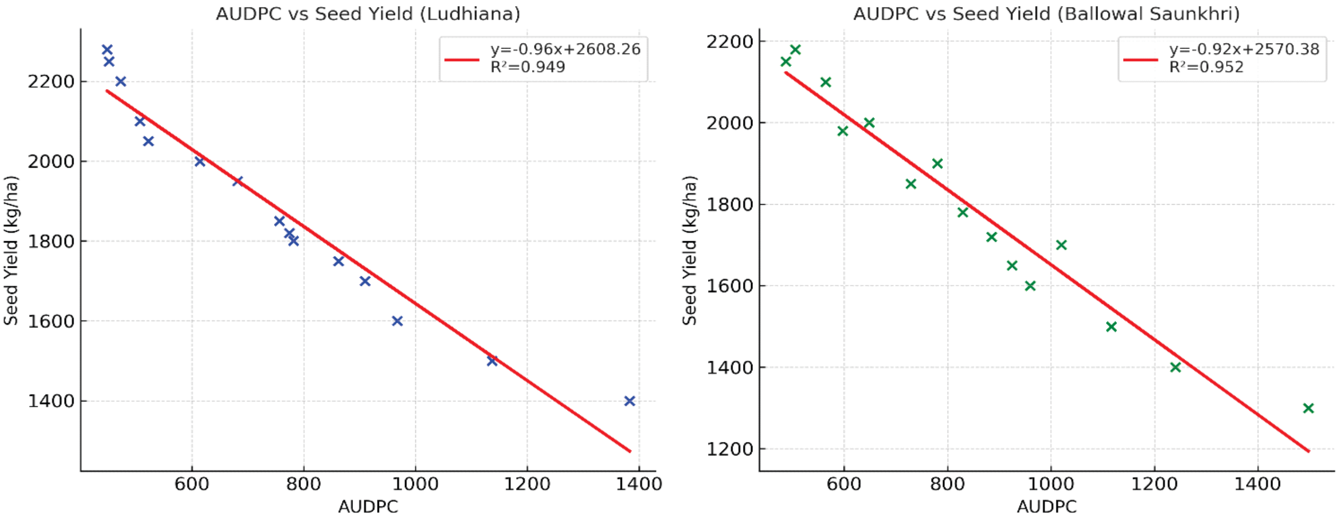

Fig. 3. **Scatter plots with regression line for correlation between sesame seed yield and AUDPC at PAU, Ludhiana and RRS Ballowal Saunkhri**

is not drastically affected (Sharma *et al.*, 2020b).

Similar results were reported by Singh and Gupta (2018), who observed that physiological traits and yield components contribute to final yield only when disease incidence is low; under heavy epiphytotic conditions, disease severity becomes the dominant factor governing yield losses. The strong association between AUDPC and yield observed in this study implies that AUDPC can serve as a reliable selection criterion in screening and breeding programs aimed at developing Alternaria blight-resistant genotypes (Chattopadhyay *et al.*, 2011).

CONCLUSION

In vitro and *in vivo* evaluation of seven fungicides was done against the charcoal rot of sesame caused by *Macrophomina phaseolina*. Under *in vitro* conditions one combination fungicide tebuconazole 50% + trifloxystrobin 25% gave complete inhibition of pathogen at 20 ppm concentration and one systemic fungicide tebuconazole 25 EC gave complete inhibition at 50 ppm concentration. The same fungicides were evaluated *in vivo* conditions and both combination fungicides tebuconazole 50% + trifloxystrobin 25%, azoxystrobin 18.2% + difenoconazole 11.4% and one systemic fungicide tebuconazole 25 EC gave lower disease severity on the plant after foliar application.

Overall, the present study suggests that systemic fungicides, particularly combination formulations, are more reliable for effective management of stem blight and could be integrated in disease management schedules for sustainable crop protection. Reducing AUDPC through timely fungicide applications could be expected to improve seed yield significantly under epidemic conditions.

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