Plant Archives Vol. 25, No. 2, 2025 pp. 1389-1401 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.2.201

EFFICACY OF FUNGICIDES AGAINST *ALTERNARIA SOLANI* CAUSING EARLY BLIGHT OF TOMATO UNDER *IN-VITRO* AND *IN-VIVO* CONDITIONS

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(Date of Receiving-27-06-2025; Date of Acceptance-06-09-2025)

ABSTRACT

The results on evaluation of fungicides under *in-vitro* condition reveled that, most of the fungicides exhibited strong inhibitory effects on mycelial growth of *Alternaria solani* at different concentrations. However, the complete inhibition was observed from fungicides i.e. Propiconazole 25% EC, Azoxystrobin 18.2% + Difenoconazole 11.4% SC, Hexaconazole 5% SC, Azoxystrobin 11% + Tebuconazole 18.3% SC, and Hexaconazole 4% + Zineb 68% WP even at low concentration (50 ppm). Fungicides i.e. Azoxystrobin 18.2% + Difenoconazole 11.4% SC (17.33%), Propiconazole 25% EC (18.67 %), Hexaconazole 5% SC (21.33%), Hexaconazole 4% + Zineb 68% WP (22.67%) and Azoxystrobin 11% + Tebuconazole 18.3% SC (22.67%) were found highly effective in controlling the early blight of tomato under field condition. Significantly less disease severity (PDI-17.33) with maximum fruit yield (456.95 q/ha) as well as higher benefit cost ratio (2.18) were recorded from the plots treated with Azoxystrobin 18.2% + Difenoconazole 11.4% SC followed by Propiconazole 25% EC (PDI- 18.67, B:C - 2.08), Metiram 55% + Pyraclostribin 5% WG (PDI – 22.67, B:C- 2.00) and Hexaconazole 4% + Zineb 68% WP (PDI - 22.67, B:C – 1.94).

Key words : Fungicides, *Alternaria solani*, Early blight, Tomato.

Introduction

Tomato (*Solanum lycopersicum* L.) belongs to family solanaceae, is one of the most widely grown vegetable in the world (Prabakaran *et al.*, 2019). It is one of the most important fruit and vegetable crops consumed worldwide and is the fourth most cultivated crop, with over 130 million metric tons produced globally on 5.2 million hectares (FAO, 2020). Among the processing crops, tomato is 1st rank in the world (Okaiyeto *et al.*, 2023).

Early blight, caused by *Alternaria solani*, is one of the most destructive disease of tomato worldwide, capable of causing yield losses of up to 79%. It affects crop productivity by inducing premature leaf drop, which significantly reduces both the quality and quantity of the fruit (Adhikari *et al.*, 2017). The common disease symptoms of early blight include dark necrotic lesions with concentric rings (Mamgain *et al.*, 2013). The affected leaves typically show circular to angular dark brown lesions, usually 3-4 mm in diameter. The disease commonly affects stressed or aging plants, with symptoms appearing first on the oldest foliage (Agrios, 2005). The effective management of the disease could be through cultural practices, chemical, biological control and use of resistant variety however, this disease is controlled mainly by the application of agrochemicals (Nirmalkar *et al.*, 2018; Adhikari *et al.*, 2017).

Alternaria is a cosmopolitan in nature and can affect all above-ground parts of the tomato plant such as the stem, leaves, and fruits at any stage of growth (Blancard, 2012). The pathogen initially infects the leaves and gradually spreads to the stems and fruits, ultimately affecting every parts of the plant (Johnson *et al.*, 2018). The pathogen can be transmitted by seeds and spread through water, wind, insects, farm workers and agricultural tools. Spores are capable of infecting leaves, stems, or fruits (Yonghao, 2013). *Alternaria solani* can persist for extended periods in soil on infected plant debris even without the presence of its primary host. Rotem (1998) also observed that the pathogen may survive for over ten years in soil on plant debris and seed optimal temperature conditions.

Initially, the fungus produces a cottony growth that appears dark in color, ranging from grey to black with shades of brown or olive. The colonies are expansive, hairy, and vary from grey-brown to black, with an overall texture resembling that of cotton (Rahmatzai *et al.*, 2016). The mycelium of *Alternaria solani* is initially hyaline, septate and branched, but later turns dark in color. Conidiophores were produced singly or in groups, and appeared straight or flexuous, ranging in color from brown to olivaceous brown. The conidia were solitary, straight, muriform, or ellipsoidal, tapering into a beak. They were pale to olivaceous brown in color, measuring 150–300 µm in length and 15–20 µm in width at the broadest part, with 8–10 transverse and 0–4 longitudinal septa. The beaks were pale, flexuous and sometimes branched (Roopa *et al.*, 2016). The optimal temperature for *Alternaria solani* growth ranges between 25°C and 30°C, while the ideal pH lies between 6.0 and 7.0 (Mahalakshmi *et al*., 2021 and Parvin *et al*., 2021).

Regarding the management of early blight of tomato, many researchers have conducted extensive studies on the chemical control methods for managing early blight of tomato.

Materials and Methods

Isolation of pathogen from naturally infected plant

The infected disease samples of tomato plants were collected from tomato field. These were washed for five minutes under running tap water to remove dirt and dust and completely dried using paper towel method. The leaves were cut into pieces that ranges from 2-5 mm, then surface disinfected in 0.1% sodium hypochloride solution for one minute and washed thrice in sterilized distilled water to remove chemical traces. The sample were again dried completely to avoid surface contamination. Five pieces were placed in petri plates having potato dextrose agar medium. The entire process was carried out carefully under aseptic conditions. The petri dishes were incubated at 25±2°C to allow for mycelial growth and sporulation of the test pathogen. The pure culture was developed through subculture technique (Sahu *et al*., 2025 Sowmya *et al*., 2021).

Efficacy of fungicides against the mycelial growth of *Alternaria solani* under *in-vitro* condition

For testing the efficacy of 16 fungicides (Metiram 70% WG, Tricyclazole 75% WP, Propiconazole 25% EC, Azoxystrobin 18.2% + Difenoconazole 11.4% SC, Validamycin 3% L, Hexaconazole 5% SC, Iprobenfos 48% EC, Azoxystrobin 11% +Tebuconazole 18.3% SC, Thifluzamide 24% SC, Mancozeb 75% WP, Propineb 70% WP, Tebuconazole 50% + Trifloxystrobin 25% WG, Kasugamycin 3% SL, Tebuconazole 38.39% w/w SC, Hexaconazole 4% + Zineb 68% WP and Metiram 55% + Pyraclostribin 5% WG) against *Alternaria solani*, the PDA medium was prepared and melted. Under the experiment, different concentrations *i.e.* 25 ppm, 50 ppm, 100 ppm, 500 ppm, 1000 ppm and 1500 ppm of each fungicide were under taken along with three replications. Each sterilized petri plate was poured with 25-30 ml of the fungicide containing medium. To prevent bacterial contamination, 500 ppm of streptocycline was added to the medium while pouring it into the petri plates. A mycelial disc with a diameter of 5 mm was taken from the fresh culture of test plant pathogen, *Alternaria solani* and placed at the center of each petri plate. Three replications were maintained for each treatment. The inoculated plates were then incubated at 25 ± 2°C for 10-12 days. Radial mycelial growth (mm) of test pathogen was recorded from each treatment at different intervals *i.e.* 4 days, 8 days and 12 days after inoculation (Goswami and Mishra, 2022).

The percentage of inhibition of mycelial growth was calculated using the formula developed by Vincent (1927)

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

Where, C = growth in control

T = growth in treatment

Efficacy of fungicides as foliar application for the control of early blight of tomato caused by *Alternaria solani* under *in-vivo* condition

The field experiment was conducted at Research Farm, BTC, CARS Bilaspur (C.G.) during *Rabi* season of 2024-25 under randomized block design (RBD) with three replications. After the appearance of the first symptoms, fungicides were sprayed on the host plants covering all plant parts above ground level. The disease severity of early blight of tomato was recorded 12 days after each spray using the 0-5 grade scale (Pandey *et al*., 2002) under natural epiphytotic condition. Pre-treatment observations were taken from different plots prior to fungicide application.

Treatment details

	Treatments	Doses ml or g/l
T_1	Metiram 70% WG	3g/l
T_2	Tricyclazole 75% WP	0.7g/l
T_3	Propiconazole 25% EC	2ml/l

T_4	Azoxystrobin 18.2% + Difenoconazole 11.4% SC	1ml/l
T_5	Validamycin 3% L	2.5ml/l
T_6	Hexaconazole 5% SC	2ml/l
T_7	Iprobenfos 48% EC	2ml/l
T_8	Azoxystrobin 11% +Tebuconazole 18.3% SC	1.5ml/l
T_9	Thifluzamide 24% SC	0.7ml/l
T_{10}	Mancozeb 75% WP	2.5g/l
T_{11}	Propineb 70% WP	2g/l
T_{12}	Tebuconazole 50% + Trifloxystrobin 25% WG	0.5g/l
T_{13}	Kasugamycin 3% SL	2.5ml/l
T_{14}	Tebuconazole 38.39% w/w SC	2.5g/l
T_{15}	Hexaconazole 4% + Zineb 68% WP	2g/l
T_{16}	Metiram 55% + Pyraclostribin 5% WG	1.5g/l
T_{17}	Control	-

Disease rating scale for early blight of tomato given by Pandey *et al.* (2002)

Disease score	Disease Intensity
0	Leave free from infection.
1	< 10% surface area covering leaf, stem, and fruit
2	11-25 % foliage of plant covered with few isolated spots
3	Many spots coalesced on the leaves, covering 25-50% surface area of plant
4	51-75 % area of the plants infected, fruits also infected at peduncle end, defoliation and blightening started. Sunken lesions with prominent concentric rings on stems, petioles and fruits
5	>75 % area of plant part blighted, sever lesions on stem and fruit rotting on peduncle end.

Per cent disease index (PDI) was calculated by using following formula as proposed by Pandey *et al.* (2002); Sahu *et al*. (2025)

$$\text{Percent Disease Index (PDI)} = \frac{\text{Sum of numerical ratings observed}}{\text{No of leaves per plants observed} \times \text{Maximum disease scale}} \times 100$$

$$\text{Per Disease Control (PDC)} = \frac{\text{PDI in Control plot – PDI in Treatment plot}}{\text{PDI in Control plot}} \times 100$$

Statistical analysis

To compare different numerical observation, data was statistically analysed using appropriate design *i.e.*, factorial CRD and RBD with desired transformation as applicable

Results and Discussion

Efficacy of fungicides against the mycelial growth of *Alternaria solani* under *in-vitro* condition

Mycelial growth of *Alternaria solani* 4 days (96 hour) after incubation

Data presented in Table 1 revealed that all tested fungicides at different concentrations (25 ppm, 50 ppm, 100 ppm, 500 ppm, 1000 ppm and 1500 ppm) significantly reduced the mycelial growth of *Alternaria solani* over control (34.50 mm). At the 25ppm concentration, fungicides i.e. Hexaconazole 5% SC (9.00 mm), Hexaconazole 4% + Zineb 68% WP (9.83 mm), Propiconazole 25% EC (10.00 mm), Azoxystrobin 11% + Tebuconazole 18.3% SC (10.00 mm), Iprobenfos 48% EC (11.00 mm), and Azoxystrobin 18.2% + Difenoconazole 11.4% SC (11.33 mm) were found to be significantly more effective in suppressing fungal growth compared to the other fungicides including control. Complete inhibition of mycelial growth was observed at the 50ppm concentration with fungicides i.e. Propiconazole 25% EC, Azoxystrobin 18.2% + Difenoconazole 11.4% SC, Hexaconazole 5% SC, Azoxystrobin 11% + Tebuconazole 18.3% SC, Tebuconazole 50% + Trifloxystrobin 25% WG, and Hexaconazole 4% + Zineb 68% WP, indicating their high potential against *A. solani*, followed by Iprobenfos 48% EC and Tebuconazole 38.39% w/w SC which were found completely inhibited at 100 ppm concentration. Whereas other fungicides i.e. Tricyclazole 75% WP, Mancozeb 75% WP, Propineb 70% W and Metiram 55% + Pyraclostrobin 5% WG were completely inhibited at 500 ppm and Metiram 70% WG, Kasugamycin 3% SL at 1000 ppm showing comparatively less effectiveness. In contrast, Validamycin 3% L and Thifluzamide 24% SC were found to be the least effective, as they failed to completely inhibit mycelial growth at any of the concentrations tested.

Mycelial growth of *Alternaria solani* 8 days (192 hour) after incubation

Data presented in Table 2 revealed that all tested fungicides at different concentrations (25 ppm, 50 ppm, 100 ppm, 500 ppm, 1000 ppm and 1500 ppm) significantly reduced the mycelial growth of *Alternaria solani* over control (59.67 mm). At the 25 ppm, concentration, fungicides i.e. Propiconazole 25% EC (10.83 mm), Azoxystrobin 11% + Tebuconazole 18.3% SC (11.67

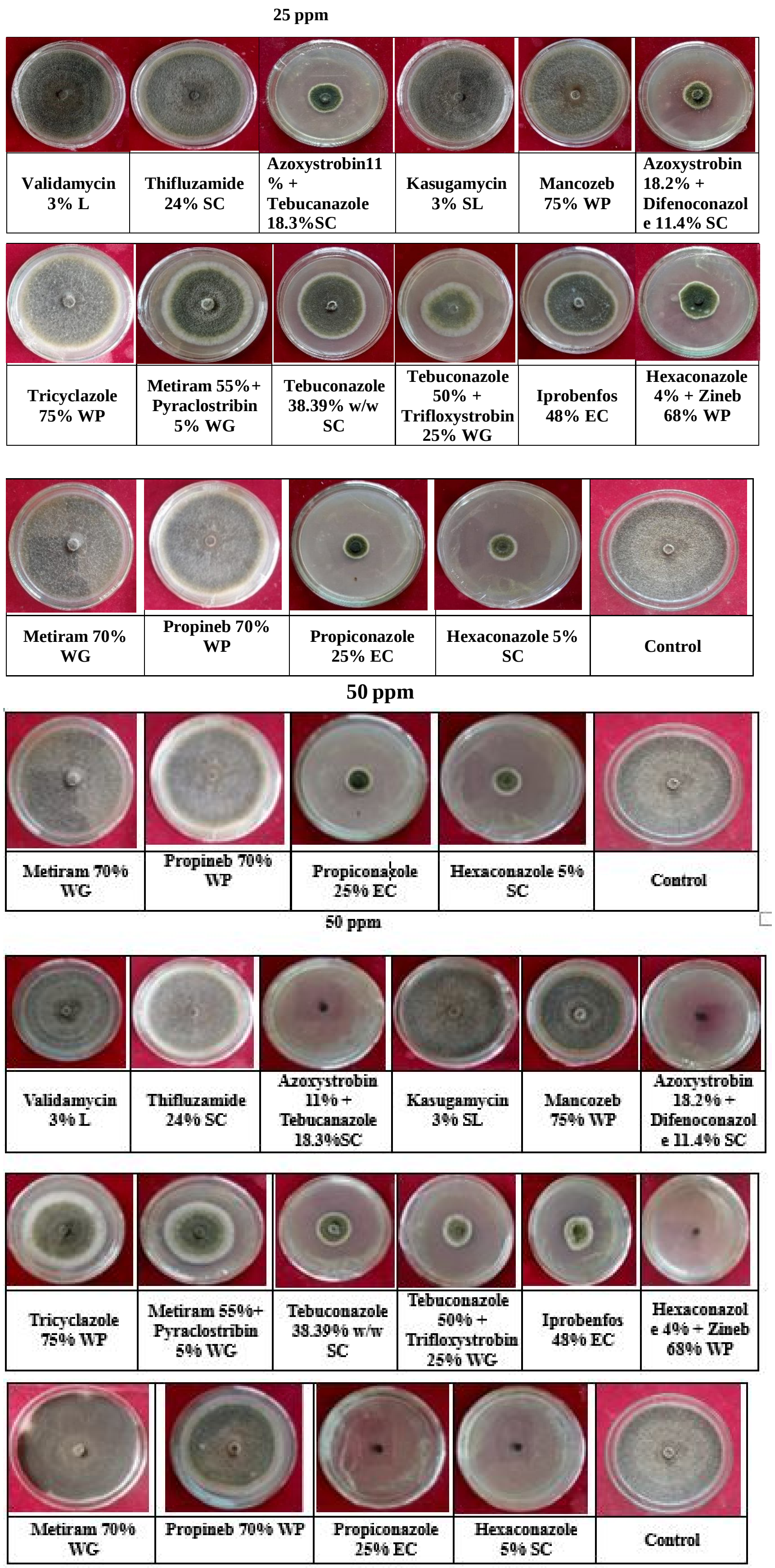


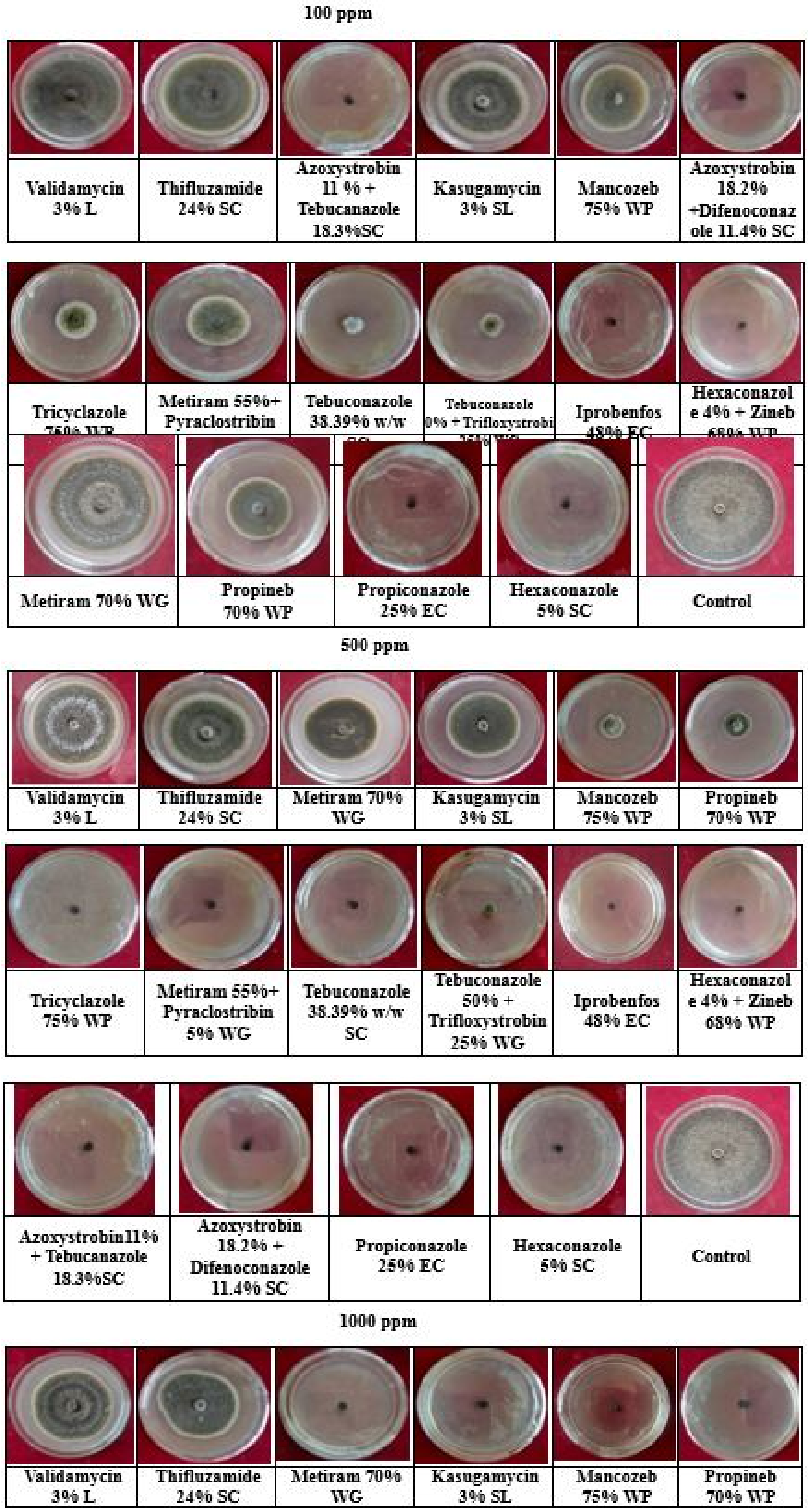
Plate 1 : *In-vitro*, evaluation of fungicides on mycelial growth of *Alternaria solani*. ***Plate 1 continued...***

mm), Azoxystrobin 18.2% + Difenoconazole 11.4% SC (11.83 mm), Hexaconazole 5% SC (12.00 mm), Hexaconazole 4% + Zineb 68% WP (16.83 mm) and Iprobenfos 48% EC (18.17 mm) were found to be more effective in reducing mycelial growth compared to the control. Complete inhibition of mycelial growth was observed at the 50 ppm, concentration with fungicides i.e. Propiconazole 25% EC, Azoxystrobin 18.2% + Difenoconazole 11.4% SC, Hexaconazole 5% SC, Azoxystrobin 11% + Tebuconazole 18.3% SC, and Hexaconazole 4% + Zineb 68% WP, indicating their high potential against *A. solani*. This was followed by Iprobenfos 48% EC, which achieved complete inhibition at the 100 ppm, concentration. Fungicides i.e. Tricyclazole 75% WP, Tebuconazole 50% + Trifloxystrobin 25% WG, Tebuconazole 38.39% w/w SC, and Metiram 55% + Pyraclostrobin 5% WG required 500 ppm for full inhibition. Meanwhile, Metiram 70% WG, Mancozeb 75% WP, Propineb 70% WP, and Kasugamycin 3% SL achieved complete inhibition at 1000 ppm showing comparatively less effectiveness. In contrast, Validamycin 3% L and Thifluzamide 24% SC were found to be the least effective, as they failed to completely inhibit mycelial growth at any of the concentrations tested.

Mycelial growth of *Alternaria solani* 12 days (288 hour) after incubation

Data presented in Table 3 revealed that all tested fungicides, at different concentrations (25 ppm, 50 ppm, 100 ppm, 500 ppm, 1000 ppm and 1500 ppm) significantly reduced the mycelial growth of *Alternaria solani* compared to the control (90.00 mm). At the 25ppm concentration, fungicides i.e. Hexaconazole 5% SC (16.00 mm), Propiconazole 25% EC (16.75 mm), Azoxystrobin 18.2% + Difenoconazole 11.4% SC (20.75 mm), Azoxystrobin 11% + Tebuconazole 18.3% SC (22.00 mm), and Hexaconazole 4% + Zineb 68% WP (24.75 mm) were found to be significantly

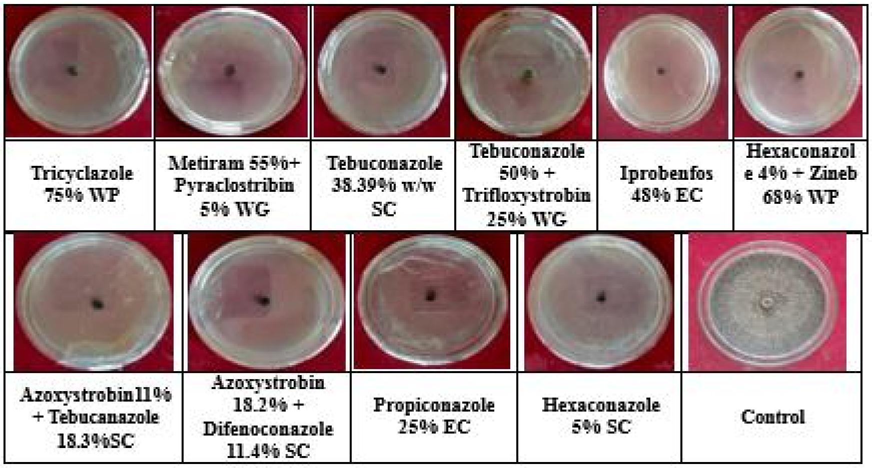
Plate 1 continued...



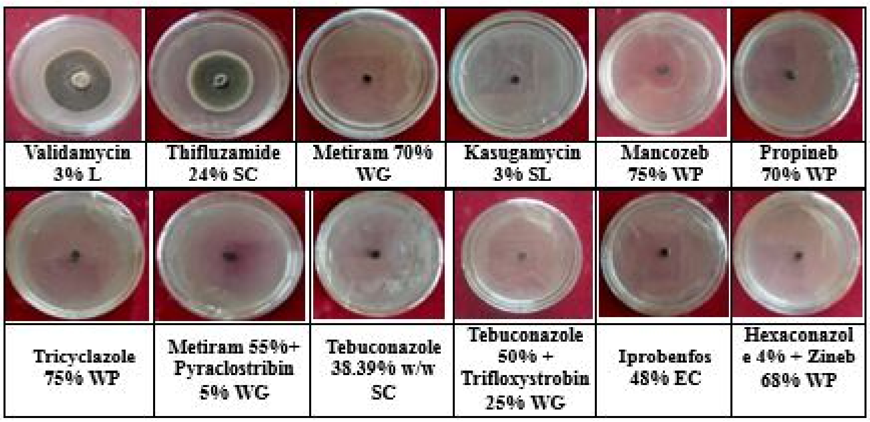
higher effective compared to the control. While these fungicides found completely inhibitory at 50 ppm concentration. This was followed by Iprobenfos 48% EC, which showed complete inhibition at 100 ppm concentration and fungicides i.e. Tricyclazole 75% WP, Tebuconazole 50% + Trifloxystrobin 25% WG, Tebuconazole 38.39% w/w SC, and Metiram 55% + Pyraclostrobin 5% WG showed complete inhibition at 500 ppm concentration. Other fungicides i.e. Metiram 70% WG, Mancozeb 75% WP, Propineb 70% WP, and Kasugamycin 3% SL were found significantly less effective and found completely inhibitory at 1000 ppm onwards. In contrast, Validamycin 3% L and Thifluzamide 24% SC were did not show significant inhibition of mycelial growth of *Alternaria solani* at higher concentration. The present study also revealed that new-generation fungicides, especially those which are having the combinations of two molecules and formulated as wettable powders (WP), emulsifiable concentrates (EC), or suspension concentrates (SC), were significantly more effective than the conventional systemic or non-systemic fungicides, currently recommended against *Alternaria solani*.

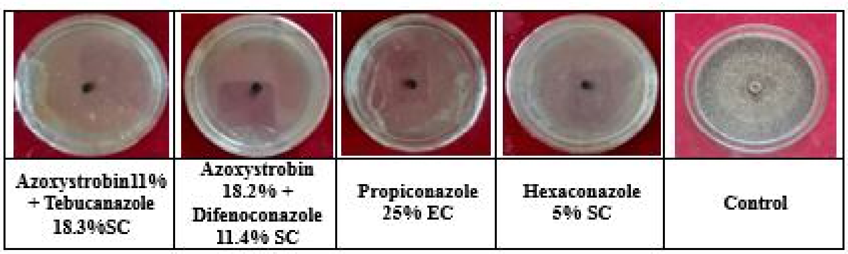
Data on percent inhibition presented in Table 4 revealed that 100% inhibition of *Alternaria solani* mycelial growth was recorded with fungicides *i.e.*; Propiconazole 25% EC, Azoxystrobin 18.2% + Difenoconazole 11.4% SC, Hexaconazole 5% SC, Azoxystrobin 11% + Tebuconazole 18.3% SC, and Hexaconazole 4% + Zineb 68% WP at 50 ppm concentrations. This was followed by Iprobenfos 48% EC, at 100 ppm concentration. Fungicides *i.e.*; Tricyclazole 75% WP, Tebuconazole 50% + Trifloxystrobin 25% WG, Tebuconazole 38.39% w/w SC, and Metiram 55% + Pyraclostrobin 5% WG required 500 ppm for complete inhibition. Whereas, Metiram 70% WG, Mancozeb 75% WP, Propineb 70% WP and Kasugamycin 3% SL there found inhibitory at 1000 ppm concentration. Some of the fungicide *i.e.*; Validamycin 3% L and Thifluzamide 24% SC were

Plate 1 continued...



1500 ppm





least effective under the present study. The higher efficacy of modern generation fungicides may be attributed to the synergistic action of the two active molecules, which enhanced their ability to inhibit the mycelial growth of *A. solani* even at low ppm concentration.

The results of the present study are in accordance with the findings of Dhaka *et al*. (2022), who reported that Propiconazole showed the highest mycelial growth inhibition against *Alternaria solani*. Similarly, Pamir *et al*. (2024) reported that Mancozeb, Difenoconazole and Azoxystrobin + Difenoconazole exhibited maximum inhibition of mycelial growth. Sudarshan *et al*. (2020) observed that Hexaconazole provided the highest inhibition, followed by Trifloxystrobin + Tebuconazole.

Efficacy of fungicides as foliar application for the control of early blight of tomato caused by *Alternaria solani* under *in-vivo* condition

Data presented in Table 5 revealed that all fungicides were significantly effective in reducing the early blight severity over control (PDI-65.33). The lowest per cent disease index (PDI) was observed in Azoxystrobin 18.2% + Difenoconazole 11.4% SC (PDI-17.33%) which was found most effective and at par with Propiconazole 25% EC (PDI-18.67), Hexaconazole 5% SC (PDI-21.33), Hexaconazole 4% + Zineb 68% WP (PDI-22.67) and Azoxystrobin 11% + Tebuconazole 18.3% SC (PDI-22.67). Other fungicides i.e. Tebuconazole 50% + Trifloxystrobin 25% WG (PDI-25.33), Tebuconazole 38.39% w/w SC (PDI-25.33), Metiram 55% + Pyraclostribin 5% WG (PDI-25.33), Tricyclazole 75% WP (PDI-26.67), Iprobenfos 48% EC (PDI-26.67), Propineb 70% WP (26.67), Mancozeb 75% WP (PDI-28.00), Kasugamycin 3% SL (PDI- 28.00), Metiram 70% WG (PDI-30.67) were also found effective and significantly suppressed the disease severity over control. Though Thifluzamide 24% SC (PDI-40.00) and Validamycin 3% L (PDI-52.00) were comparatively less effective in disease suppression, they still performed significantly better than the untreated control.

The results of present study are in accordance with the findings of Iqbal *et al.* (2020), who reported that three foliar applications of Difenoconazole at 15-day intervals were the most effective and reducing disease incidence from 61.23% to 23.48%. Similarly, Nagesh *et al.* (2019) evaluated the efficacy of different fungicide and found Difenoconazole to be the most effective, achieving a 65.44% reduction in disease incidence over the control, followed by Tebuconazole and Tebuconazole + Trifloxystrobin. The highest fruit yield of 30.07 t/ha was recorded in plots treated with Difenoconazole, followed by Tebuconazole (27.34 t/ha). Furthermore, Sharma *et*

Table 1 : *In-vitro*, evaluation of fungicides at different concentrations (ppm) against mycelial growth of *Alternaria solani*, the causal agent of early blight of tomato after 04 days (96 hrs.) of incubation.

	Treatments	Radial mycelial growth (mm)						Mean
		25ppm	50ppm	100ppm	500ppm	1000ppm	1500ppm	
T_1	Metiram 70% WG	30.33(33.40)	29.83(33.08)	20.33(26.78)	15.67(23.30)	0.00(0.00)	0.00(0.00)	19.43
T_2	Tricyclazole 75% WP	29.00(32.56)	26.00(30.64)	11.33(19.64)	0.00(0.00)	0.00(0.00)	0.00(0.00)	13.80
T_3	Propiconazole 25% EC	10.00(18.42)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	3.07
T_4	Azoxystrobin 18.2% +Difenoconazole 11.4% SC	11.33(19.66)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	3.27
T_5	Validamycin 3% L	31.83(34.33)	31.67(34.22)	28.83(32.45)	24.67(29.76)	22.17(28.07)	17.33(24.59)	30.57
T_6	Hexaconazole 5% SC	9.00(17.44)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	2.90
T_7	Iprobenfos 48% EC	11.00(19.35)	8.33(16.77)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	6.02
T_8	Azoxystrobin11%+Tebuconazole 18.3% SC	10.00(18.42)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	3.07
T_9	Thifluzamide 24% SC	31.17(32.92)	31.00(33.81)	26.17(30.75)	20.67(27.02)	19.50(26.19)	12.83(20.97	28.78
T_{10}	Mancozeb 75% WP	29.00(32.56)	28.50(32.25)	11.67(19.95)	0.00(0.00)	0.00(0.00)	0.00(0.00)	14.12
T_{11}	Propineb 70% WP	29.83(33.08)	11.33(19.65)	8.67(17.10)	0.00(0.00)	0.00(0.00)	0.00(0.00)	11.64
T_{12}	Tebuconazole 50% +Trifloxystrobin 25% WG	16.67(24.07)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	4.01
T_{13}	Kasugamycin 3% SL	30.67(33.60)	31.00(33.81)	25.67(30.42)	14.67(22.50)	0.00(0.00)	0.00(0.00)	20.05
T_{14}	Tebuconazole 38.39%w/w SC	16.00(23.55)	8.33(16.77)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	6.72
T_{15}	Hexaconazole 4% + Zineb68% WP	9.83(18.26)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	3.04
T_{16}	Metiram 55% + Pyraclostribin5% WG	23.67(29.09)	15.83(23.42)	11.17(19.51)	0.00(0.00)	0.00(0.00)	0.00(0.00)	12.00
T_{17}	Control	34.50(35.95)	34.50(35.95)	34.50(35.95)	34.50(35.95)	34.50(35.95)	34.50(35.95)	35.95
	Mean	26.92	18.25	13.68	8.15	5.30	4.79	
		Fungicide	Concentration	F x C				
	C.D.5%	0.33	0.19	0.80				
	CV%	3.89						

*Figures in the parentheses indicate arc sine transformed.

Table 2 : *In-vitro*, evaluation of fungicides at different concentrations (ppm) against mycelial growth of *Alternaria solani*, the causal agent of early blight of tomato after 08 days (196 hrs.) of incubation.

	Treatments	Radial mycelial growth (mm)						Mean
		25ppm	50ppm	100ppm	500ppm	1000ppm	1500ppm	
T_1	Metiram 70% WG	56.00(48.27)	52.00(46.12)	45.17(42.20)	25.50(30.31)	0.00(0.00)	0.00(0.00)	27.84
T_2	Tricyclazole 75% WP	54.83(47.75)	52.50(46.41)	27.67(31.70)	0.00(0.00)	0.00(0.00)	0.00(0.00)	20.97
T_3	Propiconazole 25% EC	10.83(19.20)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	3.20
T_4	Azoxystrobin 18.2%+Difenoconazole 11.4% SC	11.83(20.11)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	3.35
T_5	Validamycin 3% L	58.33(49.77)	55.50(48.13)	54.67(47.66)	40.00(39.21)	35.33(36.45)	30.17(33.30)	42.42
T_6	Hexaconazole 5% SC	12.00(20.24)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	3.37
T_7	Iprobenfos 48% EC	18.17(25.21)	14.67(22.50)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	7.95
T_8	Azoxystrobin 11%+Tebuconazole 18.3% SC	11.67(19.96)	0.00(0.00)	0.00(0.00)	0.00(0.00	0.00(0.00)	0.00(0.00)	3.32
T_9	Thifluzamide 24% SC	55.33(48.04)	54.33(47.46)	51.17(45.65)	33.33(35.25)	31.33(34.02)	23.67(29.09)	39.9
T_{10}	Mancozeb 75% WP	56.67(48.81)	51.33(45.74)	30.00(33.18)	16.50(23.95)	0.00(0.00)	0.00(0.00)	25.28
T_{11}	Propineb 70% WP	53.33(46.89)	52.67(46.51)	26.50(30.94)	14.83(22.64)	0.00(0.00)	0.00(0.00)	24.49
T_{12}	Tebuconazole 50% +Trifloxystrobin 25% WG	24.33(29.54)	18.33(25.30)	13.67(21.68)	0.00(0.00)	0.00(0.00)	0.00(0.00)	12.75
T_{13}	Kasugamycin 3% SL	58.33(49.77)	53.67(47.08)	43.00(40.95)	25.33(30.20)	0.00(0.00)	0.00(0.00)	28.00
T_{14}	Tebuconazole 38.39% w/w SC	25.83(30.53)	19.50(26.18)	12.00(20.20)	0.00(0.00)	0.00(0.00)	0.00(0.00)	12.82
T_{15}	Hexaconazole 4% + Zineb68% WP	16.83(24.20)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	4.03
T_{16}	Metiram 55% + Pyraclostribin5% WG	45.50(42.40)	27.17(31.39)	18.67(25.57)	0.00(0.00)	0.00(0.00)	0.00(0.00)	16.56
T_{17}	Control	59.67(50.55)	59.67(50.55)	59.67(50.55)	59.67(50.55)	59.67(50.55)	59.67(50.55)	50.55
	Mean	36.55	28.43	22.96	13.65	7.11	6.64	
		Fungicide	Concentration	F x C				
	C.D.5%	0.45	0.27	1.11				
	CV%	3.60						

*Figures in the parentheses indicate arc sine transformed.

Table 3 : *In-vitro*, evaluation of fungicides at different concentrations (ppm) against mycelial growth of *Alternaria solani*, the causal agent of early blight of tomato after 12 days (288 hrs.) of incubation.

	Treatments	Radial mycelial growth (mm)						Mean
		25ppm	50ppm	100ppm	500ppm	1000ppm	1500ppm	
T_1	Metiram 70% WG	90.00(71.53)	90.00(71.53)	75.50(60.30)	39.00(38.62)	0.00(0,00)	0.00(0.00)	40.33
T_2	Tricyclazole 75% WP	90.00(71.53)	75.50(60.32)	33.50(35.31)	0.00(0.00)	0.00(0.00)	0.00(0.00)	27.86
T_3	Propiconazole 25% EC	16.75(24.14)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	4.02
T_4	Azoxystrobin 18.2%+Difenoconazole 11.4% SC	20.75(27.08)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	4.51
T_5	Validamycin 3% L	90.00(71.53)	90.00(71.53)	90.00(71,53)	74.00(59.32)	47.00(43.26)	40.50(39.50)	59.45
T_6	Hexaconazole 5% SC	16.00(23.56)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	3.92
T_7	Iprobenfos 48% EC	57.67(49.39)	28.50(32.24)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	13.60
T_8	Azoxystrobin 11%+Tebuconazole 18.3% SC	22.00(27.95)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	4.66
T_9	Thifluzamide 24% SC	90.00(71.53)	90.00(71.53)	79.67(63.17)	61.33(51.53)	41.50(40.09)	33.17(35.14)	55.50
T_{10}	Mancozeb 75% WP	90.00(71.53)	89.50(71.07)	51.83(46.03)	22.50(28.30)	0.00(0.00)	0.00(0.00)	36.15
T_{11}	Propineb 70% WP	90.00(71.53)	85.17(67.39)	46.00(42.68)	19.33(26.06)	0.00(0.00)	0.00(0.00)	34.61
T_{12}	Tebuconazole 50% +Trifloxystrobin 25% WG	45.75(42.54)	21.67(27.72)	18.17(25.20)	0.00(0.00)	0.00(0.00)	0.00(0.00)	15.91
T_{13}	Kasugamycin 3% SL	90.00(71.53)	90.00(71.53)	64.00(53.11)	39.33(38.82)	0.00 (0.00)	0.00(0.00)	39.16
T_{14}	Tebuconazole 38.39% w/w SC	50.33(45.17)	26.67(31.06)	13.00(21.11)	0.00(0.00)	0.00(0.00)	0.00(0.00)	16.22
T_{15}	Hexaconazole 4% + Zineb68% WP	24.75(29.82)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.00)	4.97
T_{16}	Metiram 55% + Pyraclostribin5% WG	75.00(59.98)	48.33(44.02)	34.50(35.95)	0.00(0.00)	0.00(0.00)	0.00(0.00)	23.32
T_{17}	Control	90.00(71.53)	90.00(71.53)	90.00(71.53)	90.00(71.53)	90.00(71.53)	90.00(71.53)	71.53
	Mean	53.05	40.67	30.94	18.48	9.11	8.59	
		Fungicide	Concentration	F x C				
	C.D.5%	0.41	0.24	1.00				
	CV%	2.32						

*Figures in the parentheses indicate arc sine transformed.

Table 5 : Efficacy of fungicides as foliar spray for the control of early blight of tomato caused by *Alternaria solani*.

	Treatment	Doses ml or g/l	Disease severity (PDI)				% Reduction over control	Fruit Yield q/ha
			Before Spray	12 days after 1st spray	12 days after 2nd spray	12 days after 3rd spray		
T_1	Metiram 70% WG	3g/l	33.33(35.24)	34.67(36.00)	32.00(34.35)	30.67(33.53)	52.22(46.30)	328.68
T_2	Tricyclazole 75% WP	0.7g/l	30.67(33.60)	32.00(34.40)	29.33(32.70)	26.67(30.91)	58.66(50.10)	339.23
T_3	Propiconazole 25% EC	2ml/l	33.33(35.21)	30.67(33.53)	25.33(30.19)	18.67(25.55)	71.06(57.51)	427.80
T_4	Azoxystrobin 18.2% +Difenoconazole 11.4% SC	1ml/l	30.67(33.60)	29.33(32.70)	24.00(29.27)	17.33(24.56)	73.29(58.90)	456.95
T_5	Validamycin 3% L	2ml/l	30.67(33.60)	40.00(39.16)	45.33(42.29)	52.00(46.13)	20.32(26.77)	293.75
T_6	Hexaconazole 5% SC	2ml/l	32.00(34.40)	32.00(34.40)	25.33(30.10)	21.33(27.35)	67.73(55.42)	367.08
T_7	Iprobenfos 48% EC	2ml/l	34.67(36.04)	34.67(36.04)	32.00(34.40)	26.67(31.02)	58.61(50.00)	343.30
T_8	Azoxystrobin 11% +Tebuconazole 18.3% SC	1.5ml/l	33.33(35.24)	33.33(35.19)	30.67(33.60)	22.67(28.27)	65.00(53.86)	354.35
T_9	Thifluzamide 24% SC	0.7ml/l	34.67(36.02)	37.33(37.60)	38.67(38.39)	40.00(39.20)	38.29(38.08)	305.68
T_{10}	Mancozeb 75% WP	2.5g/l	36.00(36.83)	34.67(36.04)	33.33(35.24)	28.00(31.89)	57.04(49.04)	330.31
T_{11}	Propineb 70% WP	2g/l	32.00(34.40)	32.00(34.43)	30.67(33.53)	26.67(30.97)	58.84(50.15)	351.01
T_{12}	Tebuconazole 50% +Trifloxystrobin 25% WG	0.5g/l	34.67(36.04)	32.00(34.40)	29.33(32.61)	25.33(30.19)	60.83(51.27)	382.55
T_{13}	Kasugamycin 3% SL	2ml/l	33.33(35.24)	34.67(36.00)	33.33(35.24)	28.00(31.89)	57.04(49.04)	327.55
T_{14}	Tebuconazole 38.39% w/w SC	2.5g/l	36.00(36.83)	36.00(36.83)	30.67(33.60)	25.33(30.10)	60.69(51.26)	350.70
T_{15}	Hexaconazole 4% + Zineb68% WP	2g/l	36.00(36.83)	32.00(34.40)	26.67(31.06)	22.67(28.40)	65.14(53.81)	399.16
T_{16}	Metiram 55% +Pyraclostribin 5% WG	1.5g/l	34.67(36.04)	34.67(36.00)	30.67(33.53)	25.33(30.10)	60.69(51.26)	419.18
T_{17}	Control	-	34.67(36.04)	49.33(44.60)	56.00(48.43)	65.33(53.96)	0.00(0.00)	232.05
	CD 5%		**NS**	**5.11**	**5.34**	**5.57**	**-**	**89.17**
	CV		**NS**	**8.50**	**9.23**	**10.23**	**-**	**15.09**

*Figures in the parentheses indicate arc sine transformed.

Table 6 : Fruit yield and economics of tomato cultivation as influenced by foliar application of fungicides for the management of early blight of tomato.

	Treatment	Fruit Yield (q/ha)	Cost of cultivation (` ha^{-1})	Additional cost (` ha^{-1})	Total cost of cultivation (` ha^{-1})	Gross return (` ha^{-1})	Net return (` ha^{-1})	Benefit : Cost ratio
T_1	Metiram 70% WG	328.68	1,30,000	9,630	1,39,630	3,28,680	1,89,050	1.35
T_2	Tricyclazole 75% WP	339.23	1,30,000	5,208	1,35,208	3,39,230	2,04,022	1.51
T_3	Propiconazole 25% EC	427.80	1,30,000	8,850	1,38,850	4,27,800	2,88,950	2.08
T_4	Azoxystrobin 18.2% + Difenoconazole 11.4% SC	456.95	1,30,000	13,566	1,43,566	4,56,950	3,13,384	2.18
T_5	Validamycin 3% L	293.75	1,30,000	6,150	1,36,150	2,93,750	1,57,600	1.16
T_6	Hexaconazole 5% SC	367.08	1,30,000	4,062	1,34,062	3,67,080	2,33,018	1.74
T_7	Iprobenfos 48% EC	343.30	1,30,000	5,430	1,35,430	3,43,300	2,07,870	1.53
T_8	Azoxystrobin 11% + Tebuconazole 18.3% SC	354.35	1,30,000	10,575	1,40,575	3,54,350	2,13,775	1.52
T_9	Thifluzamide 24% SC	305.68	1,30,000	7,770	1,37,770	3,05,680	1,67,910	1.22
T_{10}	Mancozeb 75% WP	330.31	1,30,000	5,535	1,35,535	3,30,320	1,94,785	1.44
T_{11}	Propineb 70% WP	351.01	1,30,000	4,950	1,34,950	3,51,020	2,16,070	1.60
T_{12}	Tebuconazole 50% + Trifloxystrobin 25% WG	382.55	1,30,000	12,150	1,42,150	3,82,550	2,40,400	1.69
T_{13}	Kasugamycin 3% SL	327.55	1,30,000	5,328	1,35,328	3,27,550	1,92,222	1.42
T_{14}	Tebuconazole 38.39% w/w SC	350.70	1,30,000	12,150	1,42,150	3,50,700	2,08,550	1.47
T_{15}	Hexaconazole 4% + Zineb 68% WP	399.16	1,30,000	5,925	1,35,925	3,99,170	2,63,245	1.94
T_{16}	Metiram 55% + Pyraclostribin 5% WG	419.18	1,30,000	9,945	1,39,945	4,19,180	2,79,235	2.00
T_{17}	Control	232.05	1,30,000	-	1,30,000	2,32,050	1,02,050	0.79

al. (2024) reported that two foliar sprays of Hexaconazole (0.2%) at 15-day intervals resulted in the maximum disease reduction (79.74%), along with a significant increase in fruit yield (88.51%) over the control.

Modern systemic fungicides act in a more targeted manner by penetrating fungal cells and inhibiting specific biochemical pathways, such as mitochondrial respiration (e.g., QoI and SDHI fungicides) and sterol biosynthesis (e.g., DMI fungicides), which are essential for fungal growth and survival. In contrast, traditional fungicides, such as contact fungicides, generally exhibit multi-site activity by disrupting the fungal cell wall or interfering with various enzymatic systems, leading to cell death (Kim *et al.*, 2022).

In terms of fruit yield, all treatments had significantly higher fruit yield over the control (232.05 q/ha). The highest fruit yield (456.95 q/ha) was recorded from treated with Azoxystrobin 18.2% + Difenoconazole 11.4% SC, which was at par with Propiconazole 25% EC (427.80 q/ha), Metiram 55% + Pyraclostribin 5% WG (419.18 q/ha), Hexaconazole 4% + Zineb 68% WP (399.16 q/ha), Tebuconazole 50% + Trifloxystrobin 25% WG (382.55 q/ha) and Hexaconazole 5% SC (367.08 q/ha). Other fungicides *i.e.*; Azoxystrobin 11% + Tebuconazole 18.3% SC (354.35 q/ha), Propineb 70% WP (351.01 q/ha), Tebuconazole 38.39% w/w SC (350.70 q/ha), Iprobenfos 48% EC (343.30), Tricyclazole 75% WP (339.23 q/ha), Mancozeb 75% WP (330.31 q/ha), Metiram 70% WG (328.68 q/ha) and Kasugamycin 3% SL (327.55) were found significantly effective over control. Fungicides *i.e.*;

Thifluzamide 24% SC (305.68) and Validamycin 3% L (293.75 q/ha) were found least effective and produced fruit yield which was statistically at par with control (232.05 q/ha).

The data presented in the table 6 revealed that among all the treatments, the highest net returns of [1] 3,13,384/ha and higher benefit cost ration was obtained from from the treatments *i.e.*; Azoxystrobin 18.2% + Difenoconazole 11.4% SC with a higher benefit cost ratio 2.18 closely followed by Propiconazole 25% EC, Metiram 55% + Pyraclostrobin 5% WG and Hexaconazole 4% + Zineb 68% WP. These fungicides were not only found significantly more effective over other fungicides in suppressing disease severity and enhancing fruit yield of tomato but also found economically superior giving higher net profit (` 2,63,245/ha- 2,88,950/ha) with higher benefit cost ratio 1.94 - 2.08. Additional cost was varied from ` 4,062 (Hexaconazole 5% SC) to ` 13,566 (Azoxystrobin 18.2% + Difenoconazole 11.4% SC) in different treatments and therefore the net returns and benefit cost ratio were found to be less despite having significant effect on disease control and enhancing fruit yield. which determine the net returns (` 1,57,600/ha - ` 3,13,384/ha) and benefit cost ratio (1.16 - 2.18). Therefore, the economics of fungicides, which are going to be use for the control of early blight of tomato must be taken into the consideration while recommending the control measure against early blight of tomato.

Conclusion

Azoxystrobin 18.2% + Difenoconazole 11.4% SC was found most effective in checking the severity of early blight of tomato and producing higher fruit yield, followed by Propiconazole 25% EC. However, some of the fungicides *i.e.*; Propiconazole 25% EC, Azoxystrobin 18.2% + Difenoconazole 11.4% SC, Metiram + Pyraclostribin 5% WG were found economical in terms of obtaining higher benefit cost ratio of 2.08, 2.18, 2.00, respectively.

Acknowledgements

Authors are thankful to Section of Plant Pathology, BTC, College of Agriculture and Research Station, Bilaspur (IGKV), Chhattisgarh for support to conducting investigation. I would like to thanks to Dr. RKS Tiwari and Dr. VK Nirmalkar for their valuable support and guidance throughout the entire research work.

Declaration

As the author of this manuscript, I hereby make the following disclosure to the best of my knowledge:

I have no relevant interest (s) to divulge.

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