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Original article

Sustainable Strategies for Managing Leaf Blight of Sunflower: Evaluation of Fungicides, Bio-control agents and Plant-Based Extracts *In-Vitro*

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Abstract

Leaf blight of sunflower incited by Alternaria helianthi (Hansf.) Tubaki and Nishihara is a potentially destructive disease in most sunflower growing countries causing leaf spots, defoliation ultimately substantial yield loss. Considering the importance of crop and disease, different fungicides, bio-agents and plant extracts were evaluated using poisoned food technique and paper towel method at different dosages. Among seed dressing fungicides, Captan 70% + Hexaconazole 5% WP recorded cent per cent inhibition at 0.2 and 0.3 per cent (94.73 per cent average inhibition) as well as highest seedling vigour index of 4325 at 0.2 per cent dose, followed by Penflufen 13.28% + Trifloxystrobin 13.28% FS which showed 79.14 per cent average mycelial inhibition while least of 11.72 per cent mycelial inhibition was recorded by Tebuconazole 5.36% FS. Least seedling vigour index of 3922 was recorded at 0.3 per cent by Carbendazim 25 + mancozeb 50% WP. Among contact fungicides, Mancozeb and Hexaconazole were the superior contact and systemic fungicides with an average of 83.52 and 84.54 per cent mycelial inhibition (100% @ 0.2% and 0.05% dose onwards), respectively. Chlorothalonil 75% WP (9.3%) and Validamycin 3% L (10.67%) were the least effective contact and systemic fungicides, respectively. With respect to combi product fungicides, Captan 70% + Hexaconazole 5% WP and Fenamidone 10% + Mancozeb 50% WG was found highest and lowest effective with 93.15 average and 31.03 per cent (@0.3%) mycelial inhibition, respectively. The bio-agents, T. harzianum and B. subtilis were best and least effective with 78.52 and 42.15% mycelial inhibition, respectively in dual culture technique. Neem leaf extract and lantana leaf extract showed highest and lowest average of 52.68 and 32.76 per cent inhibition, respectively.

Keywords: Sunflower, leaf blight, *Alternaria helianthi, in-vitro*, per cent, inhibition

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INTRODUCTION

Sunflower (*Helianthus annuus* L.), native to Southern USA and Mexico, is a major oilseed crop in the Asteraceae family, ranked third after groundnut and soybean. A short-duration crop (100-110 days), it thrives across India, including temperate hilly regions, due to its drought resistance and low water needs. It can be grown as a rabi or kharif crop, with rabi yielding better. In the south, it can be grown 2-3 times annually (Akash *et al*., 2020). Sunflower oil (40-52%) is rich in polyunsaturated fatty acids, reducing heart disease risk (Joksimovic *et al*., 2006) and has industrial uses.

Sunflower can yield 20-25 q/ha under optimal conditions, but India's national average is just 736 kg/ha. Despite increased cultivation, productivity has declined due to abiotic and biotic stresses, leaving the crop's potential largely untapped (Prathibha, 2005). Sunflower is susceptible to various fungal, viral, and nematodal diseases during cropping and storage. Leaf blight, caused by *Alternaria helianthi*, is particularly destructive, leading to leaf spots, defoliation, and yield losses of 20-30% (Dastur and Asana, 1960; Allen *et al*., 1983; Morris *et al*., 1983; Lipps and Herr, 1986; Anonymous, 2004; Shankergoud *et al*., 2006). Alternaria leaf blight causes dark, oval spots with pale margins, leading to blight, defoliation, and plant death (Cho and Yu, 2000). In favorable conditions, it can result in 80% yield loss and a 34% reduction in oil content (Hiremath *et al*., 1990; Berglund, 2009). The disease is most severe in tropical and subtropical regions with high temperature and humidity (Sujatha *et al*., 1997; Dudienas *et al*., 1998).

Given the rising demand for sunflower seeds, oil, and industrial uses, along with decreased production due to Alternaria leaf blight, there is a need for research to develop an integrated management strategy for the disease. This study was conducted to address this issue.

MATERIALS AND METHOD

In vitro evaluation of fungicides, biocontrol agents and plant extracts against *Alternaria*

Various non-systemic, systemic and combi-product fungicides, biocontrol agents and plant extracts were evaluated under *in-vitro* condition against *Alternaria.*

In-vitro evaluation of seed dressing fungicides

Seed dressing fungicides' antifungal activity was assessed using the paper towel method. The best fungicide, based on pathogen control and B:C ratio, was chosen for field trials.

Paper towel method

1. Seed germination:

Sunflower seed germination with fungicides was studied using the paper towel method (Anonymous, 1999) in a CRD with three replications. Fifty seeds, treated with different fungicide concentrations, were placed on paper towels, rolled, and incubated at 20-30ºC with 85% humidity.

Untreated seeds served as control. After 7 days, normal seedlings were counted, and the germination percentage recorded.

2. Seedling vigour:

Root and shoot lengths of randomly selected seedlings were measured using a scale, and the seedling vigor index was calculated using the formula by Abdulbaki and Anderson (1973).

SVI = (mean root length (cm) + mean shoot length (cm) × seed germination (%)

Study on *in-vitro* efficacy of fungicides against *Alternaria helianthi*

Fungicides (non-systemic, systemic, and combi-products) were tested against *Alternaria helianthi* using the poisoned food technique (Nene and Thapliyal, 1982). Systemic fungicides were evaluated at 0.025-0.1%, contact fungicides at 0.1-0.25%, and combi-products at 0.1-0.3%.

Poisoned food technique

The poisoned food technique (Nene and Thapliyal, 1982) was used to assess fungicides' efficacy against *A. helianthi*. PDA medium was prepared, and fungicide suspension was added to achieve desired concentrations. About 20 ml of poisoned medium was poured into sterilized Petri dishes, with a control plate lacking fungicide. An 8 mm mycelial disc was placed at the center of each plate and incubated at 28±1°C. Three replications were done for each treatment. The colony diameter was measured once it reached maximum growth in the control. Percent growth inhibition was calculated using Vincent's formula (1947).

$$I=(C-T/C) * 100$$

Where,

I= Per cent inhibition of mycelial growth

C= Growth of mycelium in control

T= Growth of mycelium in treatment

Study on *in-vitro* efficacy of biocontrol agents against *Alternaria*

Biocontrol agents (*Trichoderma harzianum*, *Pseudomonas fluorescens*, *Bacillus subtilis)* and *Trichoderma viride (commercial-private*) from UAS, Dharwad, were tested against *A. helianthi* using the dual culture technique (Dennis and Webster, 1971). Sterilized PDA medium (20 ml) was poured into Petri plates. Fungal antagonists were tested by placing the pathogen on one side and antagonists on the other, leaving a 3-4 cm gap. Bacterial antagonists were streaked, followed by placing a fungal disc. Each treatment was replicated five times with a control (on ly pathogen). After 12 days, pathogen growth was measured, and percent inhibition was calculated using Vincent's formula (1947).

Plate 18: Representation of a) Seed treatment with different seed dressing fungicides, b) Placing of sunflower seeds on paper towel, c) Germinated seeds after 7days and d) Decayed germinated seed in control

Plate 2: Effect of seed dressing fungicides on seed germination and seedling vigour index of sunflower

In-vitro efficacy of plant extracts against *Alternaria*

Plant-based products are cost-effective, safe, and non-hazardous for controlling plant pathogenic fungi. This study evaluated the antifungal activity of selected plant extracts at 2.5, 5, and 10% concentrations using the poisoned food technique.

RESULTS AND DISCUSSION

In-vitro evaluation of fungicides, biocontrol agents and plant extracts against *A. helianthi*

In-vitro efficacy of fungicides against *A. helianthi*

In-vitro efficacy of seed dressing fungicides on seed germination and seedling vigour index in paper towel method

A. Seed germination (%)

The efficacy of five seed dressing fungicides—Carbendazim 25% + Mancozeb 50% WP, Captan 50% WP, Carbendazim 50% WP, Captan 70% + Hexaconazole 5% WP, and Tebuconazole 5.36% FS—was tested using the paper towel method. Seed germination, root and shoot lengths, and seedling vigor index were measured after 7 days (Table 1; Plate 1 & 2; Supplementary figure 1). Fungicide treatments were compared with two control treatments, with and without pathogen inoculation. Captan 50% WP, Carbendazim 25% + Mancozeb 50% WP, and Captan 70% + Hexaconazole 5% WP resulted in 100% germination at all concentrations. Carbendazim 50% WP and Tebuconazole 5.36% FS showed 98% germination at 0.1%, with 100% germination at 0.2% and 0.3%, while controls showed 98% germination.

B. Mean root length (cm)

The highest mean root length of 20.35 cm was recorded with Captan 70% + Hexaconazole 5% WP (0.2%), followed by 20.18 cm with Tebuconazole 5.36% FS (0.3%) and 20.05 cm with Captan 70% + Hexaconazole 5% WP (0.3%) and Carbendazim 50% WP (0.3%). The lowest root length (13.31 cm) was in the control with artificial inoculation, followed by 13.77 cm in the control without inoculation. At 0.1%, Captan 70% + Hexaconazole 5% WP showed the highest root length of 17.55 cm, followed by 16.22 cm with Carbendazim 50% WP. The lowest root length was in the control with artificial inoculation (13.31 cm), followed by 13.45 cm with Carbendazim 25% + Mancozeb 50% WP. Tebuconazole 5.36% FS and Captan 50% WP recorded 14.50 cm and 13.62 cm, respectively. At 0.2%, Captan 70% + Hexaconazole 5% WP had the highest root length (20.35 cm), followed by Carbendazim 50% WP (18.45 cm)

Table 1: *In-vitro* evaluation of seed dressing fungicides against *A. helianthi* causing leaf blight of sunflower using paper towel method

Treatments/ fungicides	**Germination percentage (%)**			**Mean root length (cm)**			**Mean shoot length (cm)**			**Seedling vigour index**		
Concentrations	**0.1**	**0.2**	**0.3**	**0.1**	**0.2**	**0.3**	**0.1**	**0.2**	**0.3**	**0.1**	**0.2**	**0.3**
Carbendazim 25 + mancozeb 50% WP (Sprint 75% WP)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	13.45	18.15	17.82	17.38	21.01	21.40	3083	3916	3922
Carbendazim 50% WP (Bavistin 50% WP)	98.00 (81.87)	100.00 (90.00)	100.00 (90.00)	16.22	18.45	20.05	20.06	20.77	21.38	3628	3922	4143
Captan 50% WP (Captaf 50% WP)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	13.62	15.40	19.15	14.12	15.99	23.00	2774	3139	4215
Tebuconazole 5.36% FS (Raxil 5.36% FS)	98.00 (81.87)	100.00 (90.00)	100.00 (90.00)	14.50	16.05	20.18	14.35	20.23	21.00	2885	3628	4118
Captan 70% + Hexaconazole 5% (Taqat 75% WP)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	17.55	20.35	20.05	17.57	22.90	20.80	3512	4325	4085
Control (with artificial inoculation)	98.00 (81.87)	98.00 (81.87)	98.00 (81.87)	13.31	13.31	13.31	11.22	11.22	11.22	2007	2007	2007
Control (No artificial inoculation)	98.00 (81.87)	98.00 (81.87)	98.00 (81.87)	13.77	13.77	13.77	14.32	14.32	14.32	2702	2702	2702
	F	**C**	**F*C**	**F**	**C**	**F*C**	**F**	**C**	**F*C**	**F**	**C**	**F*C**
S. E m. ±	1.71	1.33	2.97	0.32	0.25	0.56	0.38	0.30	0.66	70.13	54.32	121.47
CD @ 1%	5.65	4.65	10.54	1.25	0.97	2.17	1.49	1.15	2.28	272.75	211.27	472.42

Note : F-Fungicide, **C-**concentration, **F*C-** interaction, *arc sine transformed values.

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and Carbendazim 25% + Mancozeb 50% WP (18.15 cm). Tebuconazole 5.36% FS and Captan 50% WP recorded 16.05 cm and 15.40 cm, respectively. At 0.3%, Tebuconazole 5.36% FS, Captan 70% + Hexaconazole 5% WP, and Carbendazim showed similar root lengths (20.18 cm and 20.05 cm), comparable to Captan 50% WP (19.15 cm), while Carbendazim 25% + Mancozeb 50% WP (17.82 cm) and controls (13.31 cm and 13.77 cm) had lower root lengths.

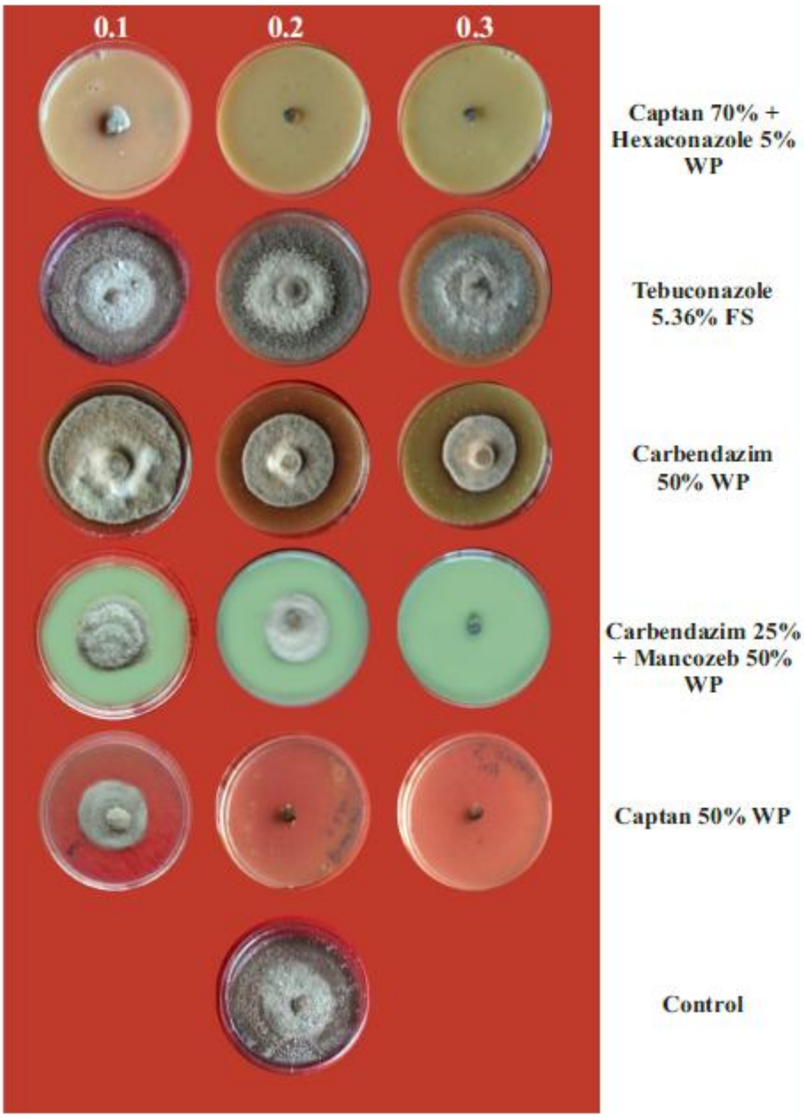

Plate 20: *In-vitro* efficacy of seed dressing fungicides in inhibiting radial mycelial growth of *A. helianthi*

Plate 3: *In-vitro* efficacy of seed dressing fungicides in inhibiting radial mycelial growth of *A. helianthi*

C. Mean shoot length (cm)

Significant differences were observed in mean shoot length with sunflower seeds treated with fungicides at three concentrations. At 0.1%, shoot length ranged from 14.12 to 20.06 cm, with Carbendazim 50% WP recording the highest (20.06 cm). At 0.2%, Captan 70%

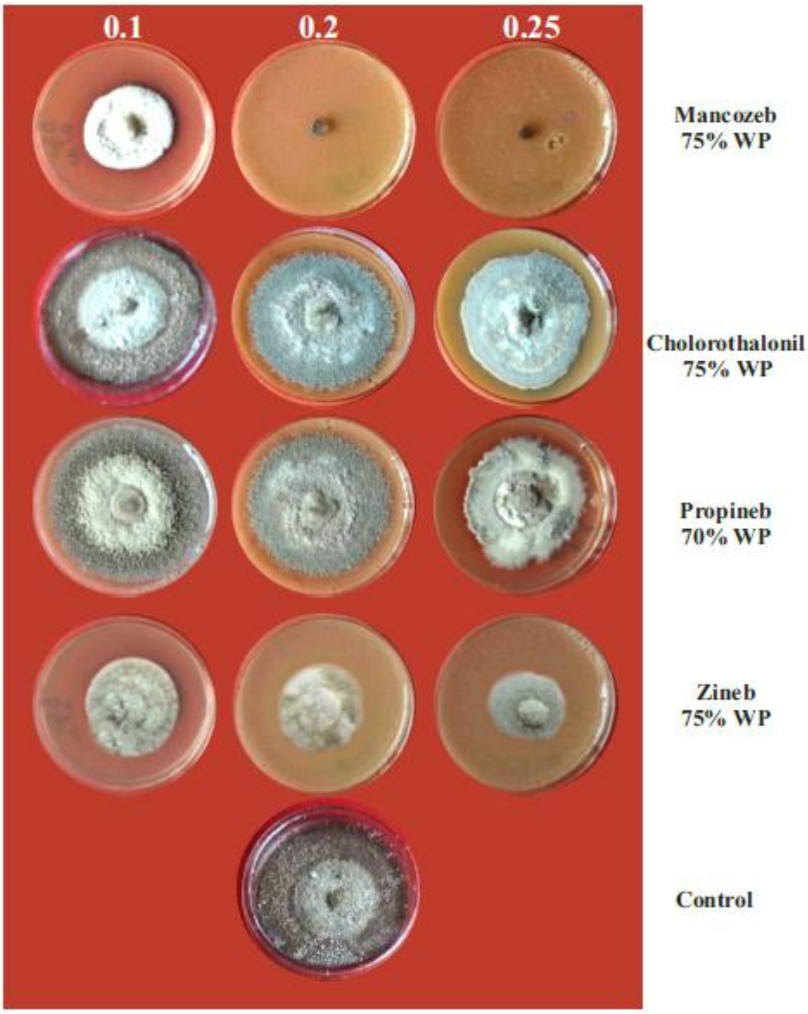

Plate 21: *In-vitro* efficacy of contact fungicides in inhibiting radial mycelial growth of *A. helianthi*

Plate 4: *In-vitro* efficacy of contact fungicides in inhibiting radial mycelial growth of *A. helianthi*

+ Hexaconazole 5% WP showed the highest shoot length of 22.90 cm. At 0.3%, Captan 50% WP had the highest shoot length of 23 cm, with other fungicides showing similar values. Control treatments recorded 11.22 cm and 14.32 cm.

D. Seedling vigour index

Significant differences in seedling vigour index were observed across fungicides and concentrations. Control treatments had a vigour index of 2007 and 2702. At 0.1%, the lowest vigour index was recorded by Captan 50% WP (2774), and the highest by Carbendazim 50% WP (3628) and Captan 70% + Hexaconazole 5% WP (3512). At 0.2%, Captan 70% + Hexaconazole 5% WP had the highest vigour index (4325), followed by Carbendazim 50% WP (3922). At 0.3%, all fungicides showed similar results, with Captan 50% WP at 4215, Carbendazim 50% WP at 4143, and Tebuconazole 5.36% FS at 4118.

***In-vitro* efficacy of fungicides against *A. helianthi* using poisoned food technique**

Six seed dressing fungicides, four contact fungicides, six systemic fungicides, and eleven combi fungicides were evaluated against *A. helianthi* under laboratory conditions using the poisoned food technique (Table 2; Plate 3; Supplementary figure 2). All fungicides showed significant inhibition of mycelial growth compared to the control. Captan 70% + Hexaconazole 5% WP had the highest inhibition (94.73%), followed by Penflufen 13.28% + Trifloxystrobin 13.28% FS (79.14%) and Carbendazim 25% + Mancozeb 50% WP (77.90%). The inhibition increased with concentration, with 58.14% at 0.3%, 48.12% at 0.2%, and 41.27% at 0.1%. At 0.1%, Captan 70% + Hexaconazole 5% WP showed 79.46% inhibition, while Tebuconazole 5.36% FS showed the least inhibition (1.79%). At 0.3%, Captan 70% + Hexaconazole 5% WP and Carbendazim 25% + Mancozeb 50% WP caused 100% inhibition. Rao (2006) found reduced seed infection by *A. helianthi* and improved seed germination and vigour with seed dressing fungicides. As Alternaria leaf blight in sunflower is below 5%, the role of fungicides is more about enhancing seed germination and vigour. Captan 70% + Hexaconazole 5% WP likely boosts seedling vigour due to hexaconazole's phyto-tonic effects, in addition to its fungicidal properties.

In-vitro* efficacy of contact fungicides in inhibiting radial mycelial growth of *A. helianthi

Among four contact fungicides, Mancozeb 75% WP recorded the highest mean inhibition of 83.52% (Table 3; Plate 4; Supplementary figure 3)., followed by Zineb 75% WP (43.33%) and Propineb 70% WP (31.60%), with Chlorothalonil 75% WP showing the least (9.30%). At 0.25% concentration, Mancozeb achieved 100% inhibition, significantly superior to the other fungicides. These findings are consistent with Amaresh and Nargund (2002), who reported Mancozeb and Iprodione as effective against *A. helianthi*, and Deepti and Dedwania (2015), who found Mancozeb to be superior for inhibiting *A. solani*. Additionally, Waghe *et al*. (2014) observed the least efficacy of Chlorothalonil, which caused only 57.03% inhibition at 1000 ppm.

In-vitro* efficacy of systemic fungicides in inhibiting radial mycelial growth of *A. helianthi

All tested fungicides and combinations showed significant inhibition of *A. helianthi* radial growth (Table 4; Plate 5; Supplementary figure 4). Hexaconazole 5% EC recorded the highest mean inhibition of 84.54%, followed by Difenoconazole 25% EC (78.16%) and Tebuconazole 25.09% EC (57.90%). The least inhibition was observed with Validamycin 3% L (10.67%), Thiophanate methyl 70% WP (10.80%), and Propiconazole 25% EC (41.76%). At 0.1% concentration, the average inhibition was 69.20%, followed by 55.89% at 0.05% and 31.21% at 0.025%. At 0.025%, Tebuconazole 25.09% EC recorded the highest

Table 2: *In-vitro* evaluation of seed dressing fungicides against *A. helianthi* causing leaf blight of sunflower using poisoned food technique

Fungicides	**Per cent growth mycelial inhibition**			**Mean**
	Concentration (%)			
	0.1 %	**0.2 %**	**0.3 %**	
Captan 70 % + Hexaconazole 5% WP (Taqat 75% WP)	79.46 (63.05)*	100.00 (90.00)	100.00 (90.00)	**94.73 (76.73)**
Carbendazim 50 % WP (Bavistin 50% WP)	19.23 (26.01)	33.22 (35.20)	45.26 (42.28)	**32.57 (34.80)**
Tebuconazole 5.36 % FS (Raxil 5.36% FS)	1.79 (7.69)	6.21 (14.43)	11.72 (20.02)	**6.57 (14.85)**
Captan 50% WP (Captaf 50% WP)	29.66 (33.00)	33.46 (35.54)	44.30 (41.73)	**35.81 (36.76)**
Carbendazim 25 % + Mancozeb 50 % WP (Sprint 75% WP)	58.33 (49.80)	75.36 (60.24)	100.00 (90.00)	**77.90 (61.96)**
Penflufen 13.28 % + Trifloxystrobin 13.28 % FS (Evergol Extend 26.56% FS)	73.25 (58.86)	79.08 (62.78)	85.08 (67.28)	**79.14 (62.82)**
Mean	**41.27 (39.97)**	**48.12 (43.92)**	**58.14 (49.68)**	
	F	**C**	**F*C**	
S. Em. ±	0.78	0.55	1.34	
CD @ 1%	2.98	2.10	4.16	

Note: * Arc sine transformed values, **F-**Fungicide, **C-**concentration, **F*C-** interaction

Table 3: *In-vitro* evaluation of contact fungicides against *A. helianthi* causing leaf blight of sunflower using poisoned food technique

Fungicides	**Per cent mycelial growth inhibition**			**Mean**
	Concentration (%)			
	0.1	**0.2**	**0.25**	
Mancozeb 75% WP (Dithane M-45 75% WP)	50.56 (45.43)*	100.00 (90.00)	100.00 (90.00)	**83.52 (66.05)**
Chlorothalonil 75% WP (Kavach 75% WP)	3.98 (11.51)	5.71 (13.83)	18.19 (25.25)	**9.30 (17.76)**
Propineb 70% WP (Anthracol 70% WP)	3.16 (10.24)	43.76 (41.42)	47.87 (43.78)	**31.60 (34.20)**
Zineb 75% WP (Dithane Z-78 75% WP)	32.22 (34.58)	43.12 (41.05)	54.65 (47.67)	**43.33 (41.17)**
Mean	**22.99 (28.65)**	**48.15 (43.37)**	**55.18 (47.97)**	
	F	**C**	**F*C**	
S. Em. ±	0.34	0.29	0.59	
CD @ 1%	1.35	1.17	2.14	

Note: * Arc sine transformed values, **F-**Fungicide, **C-**concentration, **F*C-** interaction

inhibition (54.23%), followed by Hexaconazole 5% EC (53.61%). At 0.05%, Hexaconazole 5% EC showed 100% inhibition, superior to Difenoconazole 25% EC (80.25%) and Tebuconazole 25.09% EC (69.45%). Similar results were reported by Amaresh *et al*. (2004), Mesta *et al*. (2009), and Hafiz *et al*. (2020), where Hexaconazole demonstrated high efficacy. Triazoles inhibit fungal growth by blocking ergosterol biosynthesis, crucial for cell wall formation. Hexaconazole, Difenoconazole, and Tebuconazole showed 100% inhibition at 0.1%, while Propiconazole 25% EC recorded 88.97%. The lowest inhibition was recorded by Validamycin 3% L (12.69%) and Thiophanate methyl 70% WP (13.52%).

In-vitro efficacy of combi-product fungicides in inhibiting radial mycelial growth of *A. helianthi*

Among the eleven combi-product fungicides tested (Table 5; Plate 6; Supplementary figure 5)., the highest mean mycelial inhibition was observed at 0.3% concentration, with Captan 70% + **Table 4:** ***In-vitro* evaluation of systemic fungicides against *A. helianthi* causing leaf blight of sunflower using poisoned food technique**

Fungicides	**Per cent mycelial growth inhibition**			**Mean**
	Concentration (%)			
	0.025	**0.05**	**0.1**	
Tebuconazole 25.09% EC (Folicur 25.09% EC)	54.23 (47.43)*	69.45 (44.68)	100.00 (90.00)	**67.86 (55.46)**
Propiconazole 25% EC (Tilt 25% EC)	33.65 (35.46)	62.65 (40.78)	88.97 (44.41)	**61.76 (51.80)**
Hexaconazole 5% EC (Contaf 5% EC)	53.61 (47.05)	100.00 (90.00)	100.00 (90.00)	**84.54 (66.85)**
Thiophanate methyl 70% WP (Roko 70% WP)	7.17 (15.53)	11.72 (20.02)	13.52 (21.57)	**10.80 (19.19)**
Difenoconazole 25% EC (Score 25% EC)	34.12 (35.74)	80.25 (63.71)	100.00 (90.00)	**78.16 (62.14)**
Validamycin 3% L (Valida 3% L)	8.00 (16.43)	11.31 (19.65)	12.69 (20.87)	**10.67 (19.07)**
Mean	**31.21 (33.29)**	**55.89 (48.38)**	**69.20 (56.29)**	
	F	**C**	**F*C**	
S. Em. ±	0.39	0.28	0.69	
CD @ 1%	1.52	1.08	2.33	

Note: ***Arc sine transformed values, **F-Fungicide, **C-**concentration, **F*C-** interaction

Table 5: *In-vitro* evaluation of combi-product fungicides against *A. helianthi* causing leaf blight of sunflower using poisoned food technique

Fungicide/s	**Per cent mycelial growth inhibition**			**Mean**
	Concentration (%)			
	0.1	**0.2**	**0.3**	
Hexaconazole 5%+ Validamycin 2.5% SC (Valxtra 7.5% SC)	60.22 (50.90)*	72.25 (58.12)	85.42 (65.78)	**72.63 (58.46)**
Captan 70% + Hexaconazole 5% WP (Taqat 75% WP)	79.46 (63.05)	100.00 (90.00)	100.00 (90.00)	**93.15 (74.83)**
Carbendazim 12% + Mancozeb 63% WP (Kapeni 75% WP)	10.10 (18.25)	50.62 (43.60)	100.00 (90.00)	**46.87 (43.21)**
Flusilozole 12.5% + Carbendazim 25% EC (Lustre 37.5% EC)	62.36 (52.16)	69.25 (56.32)	73.22 (58.84)	**68.28 (55.72)**
Tricyclazole 18% + Mancozeb 62% WP (Merger 80% WP)	80.56 (63.84)	93.09 (71.72)	100 (90.00)	**91.22 (72.76)**
Azoxystrobin 14.4% EC + Difenconazole 11.4% EC (Godiwa Super 25.8% EC)	57.25 (49.17)	72.35 (57.15)	90.25 (54.32)	**73.28 (58.87)**
Azoxystrobin 11% EC + Tebuconazole 18.3% SC (Spectrum 29.3% EC)	59.62 (50.55)	73.52 (58.98)	91.45 (55.83)	**74.86 (59.91)**
Fenamidone 10% + Mancozeb 50% WG (Sectin 60% WG)	9.95 (18.09)	14.69 (22.00)	31.03 (28.91)	**18.65 (25.59)**

Tebuconazole 50%+ Trifloxystrobin 25% WG (Nativo 75% WG)	23.86 (27.34)	39.82 (38.26)	60.41 (51.01)	**41.36 (40.02)**
Zineb 68% + Hexaconazole 4 % WP(Avtar 72% WP)	30.33 (31.81)	58.45 (45.27)	100.00 (71.81)	**62.93 (52.49)**
Azoxystrobin 18.2% + Difenconazole 11.4% EC (Amistar top 29.6% EC)	56.22 (46.06)	76.75 (61.12)	100.00 (90.00)	**77.66 (61.79)**
Mean	**48.18 (43.96)**	**63.70 (52.95)**	**83.79 (65.49)**	
	F	**C**	**F*C**	
S. Em. ±	0.74	0.39	1.28	
CD @ 1%	2.78	1.45	4.82	

Note: * Arc sine transformed values, **F-**Fungicide, **C-**concentration, **F*C-** interaction

Hexaconazole 5% WP showing 93.15% inhibition, followed by Tricyclazole 18% + Mancozeb 62% WP (91.22%) and Azoxystrobin 18.2% + Difenconazole 11.4% EC (77.66%). The least inhibition was observed in Fenamidone 10% + Mancozeb 50% WG (18.65%). At 0.1%, Tricyclazole 18% + Mancozeb 62% WP exhibited the highest inhibition (80.56%), followed by Captan 70% + Hexaconazole 5% WP (79.46%) and Flusilozole 12.5% + Carbendazim 25% EC (62.36%). At 0.2%, Captan 70% + Hexaconazole 5% WP recorded 100% inhibition, followed by Tricyclazole 18% + Mancozeb 62% WP (93.09%). At 0.3%, Captan 70% + Hexaconazole 5% WP, Tricyclazole 18% + Mancozeb 62% WP, Carbendazim 12% + Mancozeb 63% WP, and Azoxystrobin 11% EC + Tebuconazole 18.3% SC recorded 100% inhibition. The least effective combination was Fenamidone 10% + Mancozeb 50% WG (31.03%). The results are in agreement with Waghunde *et al*. (2011), who reported 100% inhibition of *Alternaria* from Aonla fruit at both 1000 and 1500ppm**.**

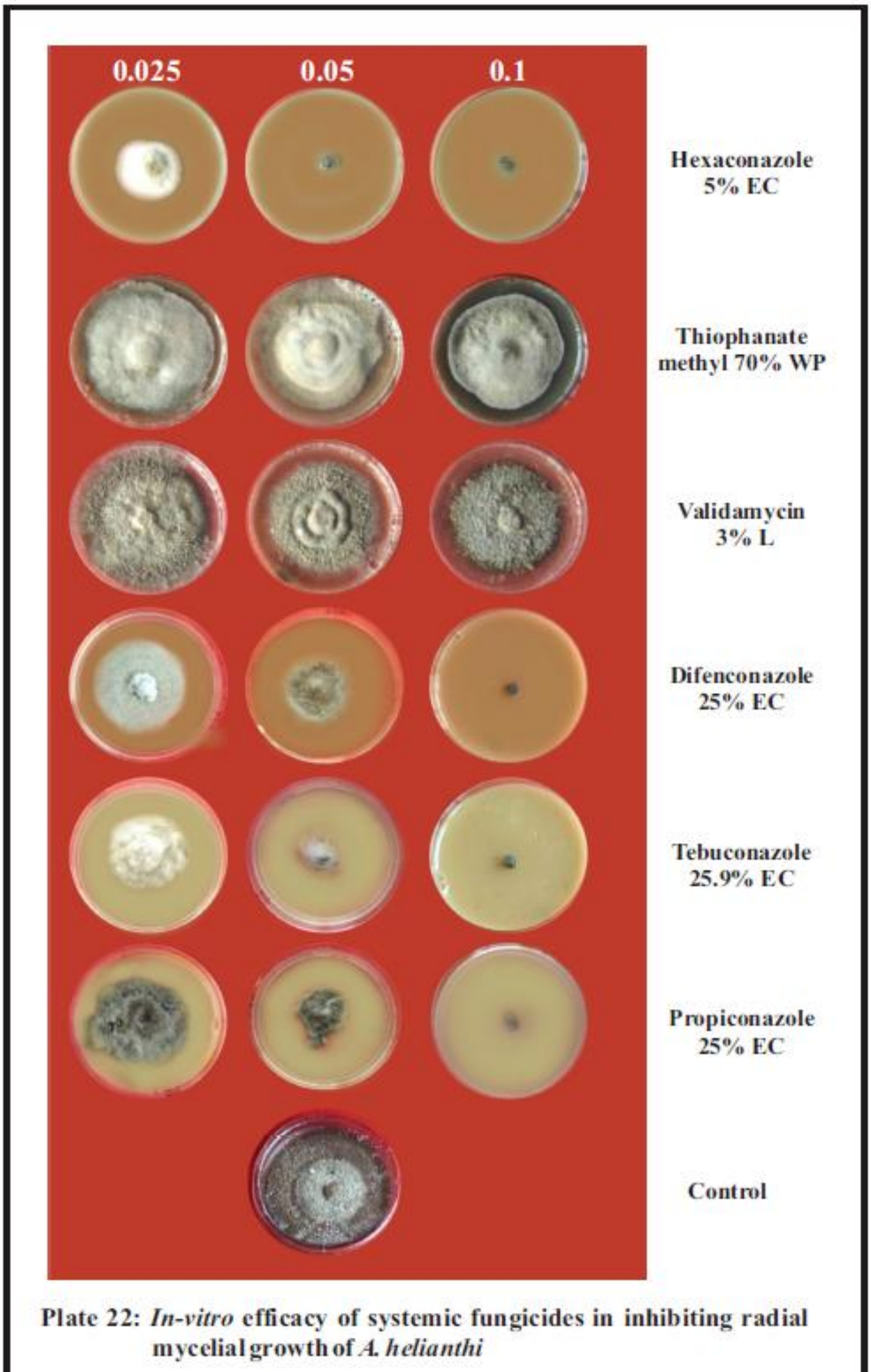

Plate 5: *In-vitro* efficacy of contact fungicides in inhibiting radial mycelial growth of *A. helianthi*

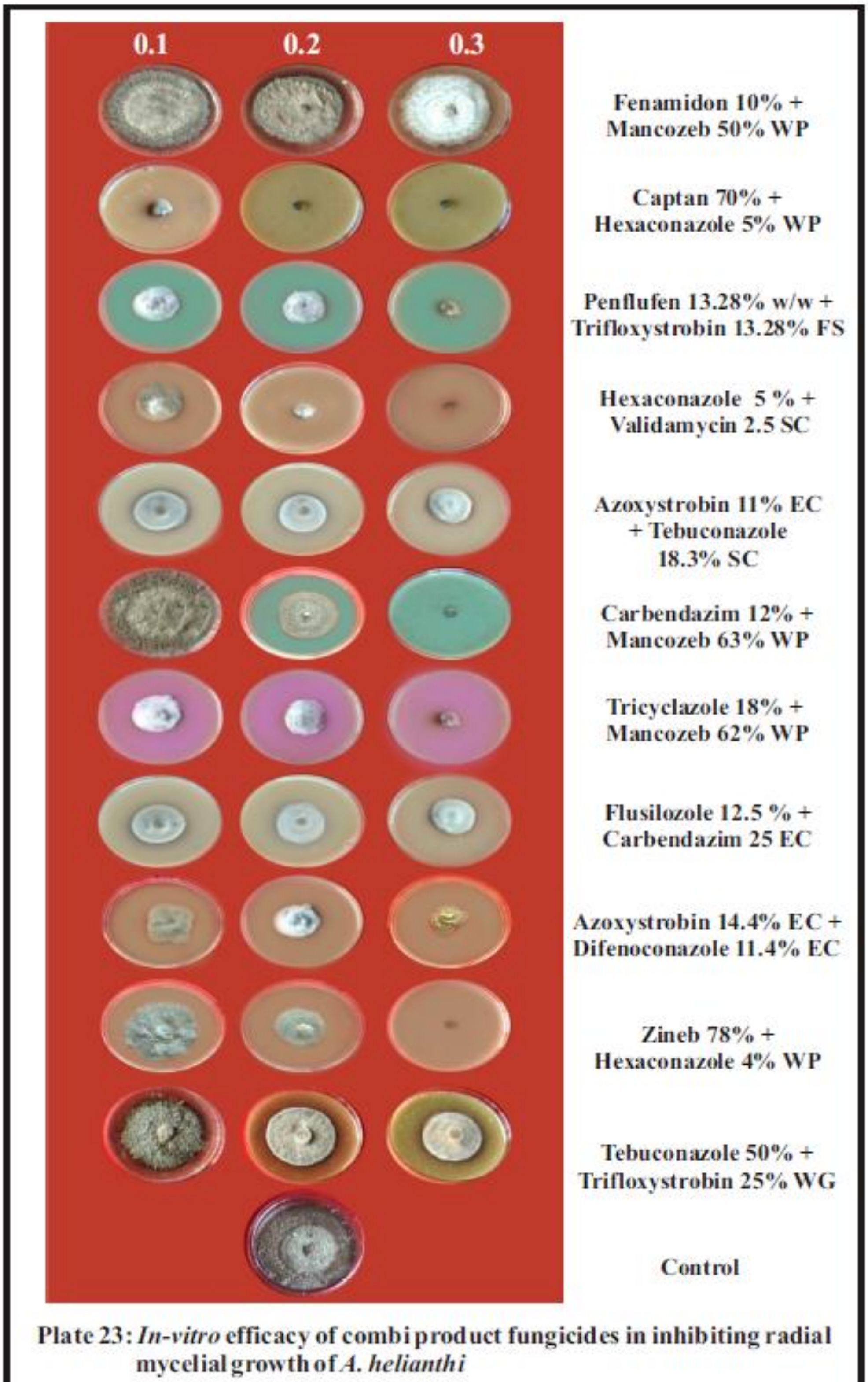

Plate 6: *In-vitro* efficacy of combi-product fungicides in inhibiting radial mycelial growth of *A. helianthi*

Table 6: *In-vitro* evaluation of bio- agents against *A. helianthi* causing leaf blight of sunflower using dual culture technique

Biocontrol agents	Per cent mycelial growth inhibition
Trichoderma harzianum	78.52 (62.39)*
Trichoderma viride	60.41 (51.01)
Pseuodomonas fluorescens	65.36 (53.95)
Bacillus subtilis	42.15 (40.48)
Mean	**61.61 (51.71)**
S. Em. ±	1.68
C.D. at 1%	5.95

Note: * Arc sine transformed values, **F-**Fungicide, **C-**concentration, **F*C-** interaction

In-vitro efficacy of biocontrol agents in inhibiting radial mycelial growth of *A. helianthi*

All biocontrol agents tested (Table 6; Plate 7; Supplementary figure 6). showed a mean of 61.61% mycelial inhibition, with *Trichoderma harzianum* being the most effective (78.52%), followed by *Pseudomonas fluorescens* (65.36%) and *Trichoderma viride* (60.41%). The lowest inhibition was by *Bacillus subtilis* (42.15%). These findings are consistent with previous studies by Amaresh (2000) and Rao (2006), who also identified *T. harzianum* and *P. fluorescens* as effective against *A. helianthi*. Patil *et al*. (2018) similarly highlighted the efficacy of *T. harzianum*, *T. virens*, and *T. koningii* against *A. alternata*. Trichoderma species produce secondary metabolites and enzymes that inhibit fungal growth, as noted by Vinale *et al*. (2008). Other studies (Kareem, 2008; Rahman *et al*., 2015; Sairam *et al*., 2020) confirmed the effectiveness of *T. harzianum*.

In-vitro efficacy of plant extracts in inhibiting radial mycelial growth of *A. helianthi*

The bio-efficacy of plant extracts (*neem* leaf, *neem* seed, *ginger* rhizomes, *garlic* bulbs, *pongamia*, and *lantana* leaves) against *A. helianthi* was evaluated (Table 7; Plate 8; Supplementary figure 7). Neem leaf extract showed the highest mean inhibition of 52.68%, followed by neem seed kernel (50.35%) and garlic extract (42.55%). Lantana leaf extract recorded the lowest inhibition (32.76%), followed by ginger (35.18%) and pongamia (39.89%). At 10%, neem leaf extract achieved 63.22% inhibition, while neem seed kernel extract showed 60.22%. At 5%, neem leaf and neem seed kernel extracts were superior (50.31% and 48.46% inhibition, respectively). At 2.5%, neem leaf and neem seed kernel extracts recorded 44.52% and 42.36%, respectively. The results align with previous studies by Meena *et al*. (2020) and Mahadevaswamy *et al.* (2018), who also found neem extracts to be effective against *Alternaria* species.

Plate 24: ***In-vitro*** **efficacy of biocontrol agents in inhibiting radial mycelial growth of** ***A. helianthi***

Plate 7: ***In-vitro*** **efficacy of biocontrol agents in inhibiting radial mycelial growth of** ***A. helianthi***

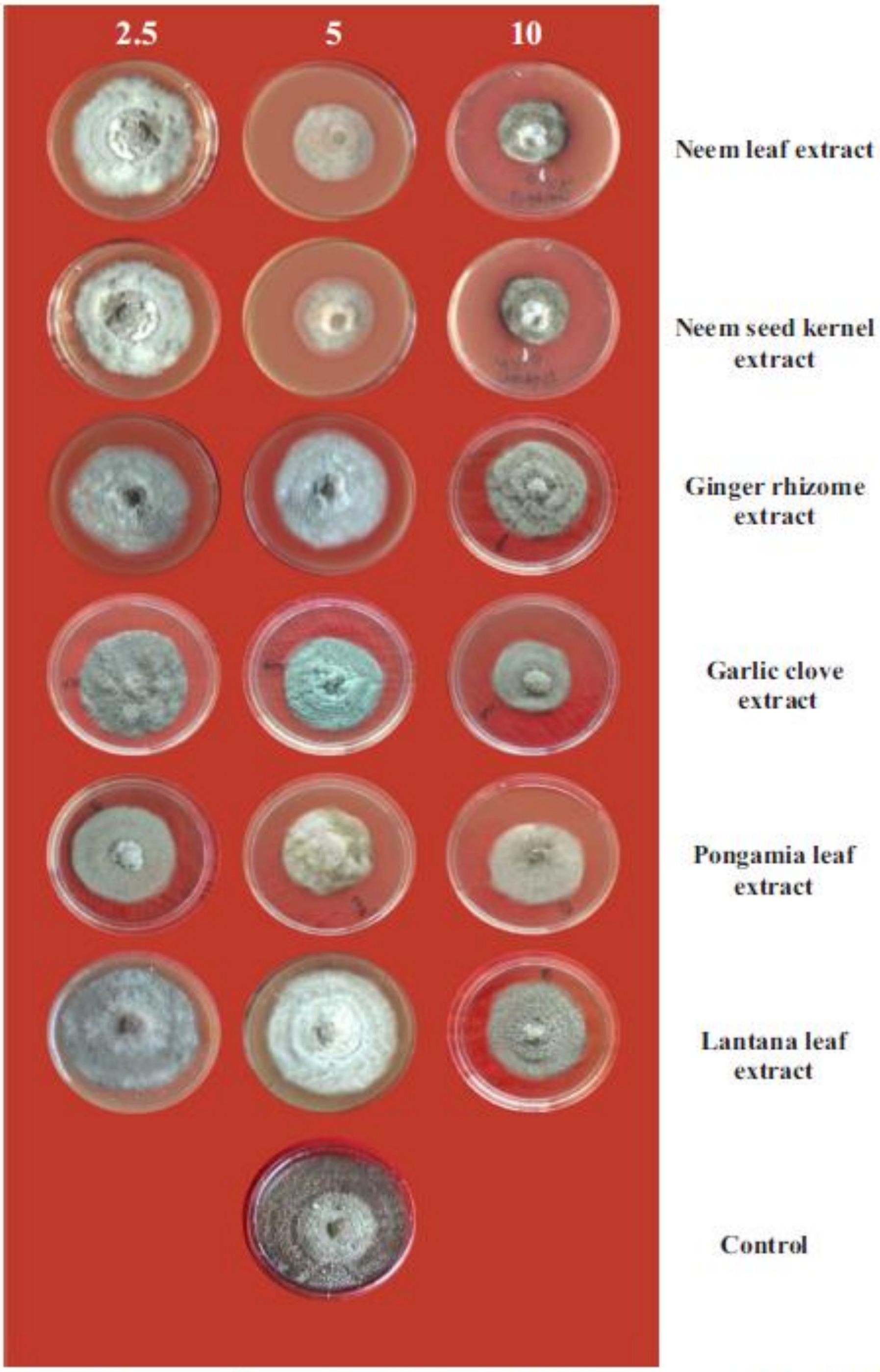

Plate 25: ***In-vitro*** **efficacy of plant extracts in inhibiting radial mycelial growth of** ***A. helianthi***

Plate 8: ***In-vitro*** **efficacy of plant extracts in inhibiting radial mycelial growth of** ***A. helianthi***

Table 7: *In-vitro* evaluation of plant extracts against *A. helianthi* causing leaf blight of sunflower using poisoned food technique

Product	Per cent mycelial growth inhibition			Mean
	Concentration (%)			
	2.5	5	10	
Neem leaf extract	44.52 (41.85)*	50.31 (45.18)	63.22 (52.67)	**52.68 (46.54)**
NSKE	42.36 (40.61)	48.46 (44.12)	60.22 (50.90)	**50.35 (45.20)**
Ginger rhizome extract	29.63 (32.98)	35.22 (36.40)	40.68 (39.63)	**35.18 (36.38)**
Garlic clove extract	34.65 (36.06)	42.33 (40.59)	50.67 (45.38)	**42.55 (40.72)**
Pongamia leaf extract	32.62 (34.83)	40.51 (39.53)	46.55 (43.02)	**39.89 (39.17)**
Lantana leaf extract	26.22 (30.80)	32.52 (34.77)	39.54 (38.96)	**32.76 (34.92)**
Mean	**35.00 (36.27)**	**41.56 (40.14)**	**50.15 (65.49)**	
	PE	**C**	**PE*C**	
S. Em. ±	1.07	1.18	1.52	
CD @ 1%	3.24	3.11	4.57	

Note: * arc sine transformed values, **PE-**plant extract, **C-**concentration, **PE*C-** interaction, **NSKE-** neem seed kernel extract.

CONCLUSIONS

In a study of seed dressing fungicides, Captan 70% + Hexaconazole 5% WP showed the highest mycelial inhibition (94.73%) and seedling vigour index (4325), achieving 100% inhibition at 0.2 and 0.3% concentrations. Penflufen 13.28% + Trifloxystrobin 13.28% FS recorded 79.14% average inhibition, with a maximum of 85.08% at 0.3%. In contrast, Tebuconazole 5.36% FS had the lowest inhibition at 6.57%. For contact fungicides, Mancozeb demonstrated 83.52% inhibition, while Chlorothalonil 75% WP recorded only 9.3%. Hexaconazole 5% EC, a systemic fungicide, showed 84.54% inhibition, with 100% at 0.05%. The bio-agent T. harzianum achieved 78.52% inhibition, while B. subtilis was less effective (42.15%). Among plant extracts, neem leaf extract proved most effective with 52.68% inhibition, peaking at 63.22% at 10%, while lantana leaf extract had the lowest at 32.76%.

Based on these results, effective treatments such as Captan 70% + Hexaconazole 5% WP, Hexaconazole 5% EC, *T. harzianum*, and neem leaf extract were selected for field trials to manage sunflower leaf blight.

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