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Evaluation of Different Fungicides and Bioagents for the Management of Chickpea Wilt (*Fusarium oxysporum* f. sp. *ciceri*)

Seethiya Mahajan[1*], Deepak Kumar[1], Santosh Kumar Singh[1], Deepak Mahajan[2], Devendra Kumar[1] and Shazia Paswal[1]

[1]Division of Plant Pathology, Faculty of Agriculture, Shere-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Chatha 180009, Jammu and Kashmir, India.
[2]Division of livestock Products Technology, Faculty of Veterinary Sciences, Khalsa College of Veterinary and Animal Sciences, Amritsar 143002, Punjab, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The incidence of the chickpea wilt disease caused by *Fusarium oxysporum* f. sp. *ciceri* ranged between 8.11 - 21.67 and 10.98 - 23.99 per cent with an overall mean disease incidence of 15.64 and 16.86 per cent respectively during *Rabi* seasons of 2016-17 and 2017-18 in surveys conducted fortnightly in the different chickpea growing areas of Jammu sub-tropics. The maximum growth inhibition of pathogen i.e., 78.44 per cent was observed by local isolate *T. harzianum* (Th-III) and *P. fluorescens* (Pf-III) was least effective in controlling the growth of pathogen i.e., 53.00 per cent in *In vitro* studies. Among chemicals, carbendazim at 100 ppm was significantly effective in inhibiting the growth of pathogen (98.67%), while copper oxychloride and mancozeb showed inhibition of 83.11 and 82.22 per cent, respectively. Both the antagonists were highly sensitive to propiconazole (Tilt), carbendazim (Bavistin), difenoconazole (Score), iprodione + carbendazim (Quintal) and metalaxyl (Ridomil), giving no growth of *T. viride* (TV-III) and *T. harzianum* (TH-III). TMTD (Thiram) recorded least inhibition of both the bioagents. Under field conditions, bioagents recorded maximum seed germination of 90.21 and 90.07 per cent, whereas least germination was recorded in mancozeb

**Corresponding author: E-mail: seethiyamahajan@gmail.com;*

(84.17 and 83.10%). Carbendazim recorded lowest disease incidence (14.92 and 14.97%) over untreated control (44.42 and 45.77%). However, maximum grain yield was recorded in azoxystrobin + *T. harzianum*-III (14.30 and 14.57 q/ha) and azoxystrobin + *T. viride*-III (14.15 and 14.38 q/ha) and the least grain yield was recorded in mancozeb (10.58 and 10.64 q/ha) during *Rabi* 2016-17 and 2017-18. Maximum increase in grain yield was recorded in azoxystrobin + *T. harzianum*-III (62.31 and 62.43%) followed by azoxystrobin + *T. viride*-III (62.61 and 60.87%) during *Rabi* 2016-17 and 2017-18.

Keywords: Chickpea wilt; Fusarium oxysporum f. sp. Ciceri; survey; bioagent; fungicide; disease management.

1. INTRODUCTION

Chickpea (*Cicer arietinum* L.) a self-pollinating crop is the world third most important legume. India is the principle chickpea producing country followed by Pakistan and Turkey [1]. It is a vital source of plant derived edible protein and contains high contents of essential amino acids like cysteine, methionine and tryptophan in addition to minerals, vitamins and carbohydrates [2]. Indian sub continent accounts for 90 per cent of the total world chickpea production [3]. The pathogen of chickpea wilt disease is seed - borne [4] as well as soil borne [5]. It can survive in soil for more than 6 months in the absence of its host and can cause severe damage to crop yield [6]. The disease can appear at any stage of plant growth. Early wilting causes more loss than late wilting, but seeds from late wilted plants are lighter, rougher and dull in colour than those from healthy plants [7]. The fungus attacked the root system, made its way through the epidermis, cortex and finally into xylem vessel of the tap root from where it spread. As a result, the lateral roots might wither off [8,9]. In general, the disease causes substantial yield losses which may reach even 100 per cent under favourable weather conditions [10].

During *Rabi* season of 2016-17, the overall range of disease incidence in Jammu division remained between 8.11-21.67 per cent. The average disease incidence in Jammu district ranged from 12.98 to 21.67 per cent, in Samba district ranged from 20.76 per cent to 11.46 per cent and in Kathua district, the average disease incidence ranged from 8.11 to 15.44 per cent. The same trend was observed in the year 2017-18 also. Many workers have reported chickpea wilt throughout the crop season with maximum incidence and damage in the chickpea crop at seedling stage than at maturity and the disease was prevalent in all the chickpea growing areas surveyed [11,12,13,14,15] who have reported its occurrence in almost all the chickpea growing areas of India including Karnataka, Madhya Pradesh and Himanchal Pradesh. Keeping this in view the present experiment was conducted in the division of Plant Pathology, SKUAST-Jammu.

2. MATERIALS AND METHODS

The field experiments on wilt of chickpea were conducted in the Division of Plant Pathology and at Research Farm of Sher-e-Kashmir University of Agricultural Sciences and Technology, Chatha, Jammu during *Rabi* seasons of the year 2016-17 and 2017-18.

2.1 *In vitro* Evaluation of Bio-agents against Pathogen (*F. oxysporum* f. sp. *ciceri*)

Three local isolates, isolated from three different areas of Jammu District, of all the three bio-agents were screened for their antagonistic potential against the wilt pathogen (*F. oxysporum* f. sp. *ciceri*) using dual culture technique. Twenty ml of PDA was poured in each Petri plate and allowed to solidify. Five mm discs of Pathogen and bio agents taken from 7 day old culture was placed in inverted position at equidistance with periphery of the plate in case of fungal bioagents. In case of bacterial antagonist pathogen was placed at one end of Petri plate and the bacterial culture was streaked at the other half of the Petri plate. Each treatment was replicated thrice and incubated for 7 days at 27±1°C. The activity of antagonistic organism was recorded after 72 hours by measuring the colony diameter of *F. oxysporum* f. sp. *ciceri* in each treatment and compared with control. Per cent growth inhibition of the test pathogen over control was calculated.

2.2 *In vitro* Evaluation of Fungicides against Pathogen

Five systemic fungicides namely propiconazole (Tilt 25EC), Azoxystrobin (Amistar 250EC), carbendazim (Bavistin 50WP), difenconazole (Score 25EC) and metalaxyl (Ridomil); two combination fungicides Iprodione 25% + Carbendazim 25% (Quintal), Mancozeb 64% + Metalaxyl 14% (Ridomil Gold) and three non-systemic fungicides mancozeb (Dithane-M-45), copper oxychloride (Blitox-50) and TMTD (Thiram) were assayed for their efficacy against pathogen under lab condition. The systemic fungicides were tested at 10, 25, 50 and 100 ppm concentration, whereas combinations and non-systemic fungicides were tested at 50, 100, 250 and 500 ppm using poisoned food technique given by Nene and Thapliyal, [16]. The desired concentrations were obtained by adding appropriate amount of stock solution of fungicides to PDA medium in each Petri plate. PDA without fungicide served as control. Each plate was inoculated with a 5 mm mycelial disc of the pathogen taken from 7 day old culture grown on PDA. The inoculated plates were incubated at 27± 1°C till the fungus covered the whole plate in control treatment. The radial growth of colony was recorded and per cent inhibition of each treatment was calculated by using formula given by Vincent [17].

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

Where

I = Per cent inhibition
C= Growth of pathogen (cm) in control
T= Growth of pathogen (cm) in treatment

2.3 Sensitivity of Systemic and Non-Systemic Fungicides Fungal against Bioagents

The effective isolate of bioagents *i.e., Trichoderma viride* (Tv III) and *T. harzianum* (Th III), which gave maximum inhibition of mycelial growth under *in vitro* conditions, were evaluated for tolerance against systemic and non-systemic fungicides. Five systemic fungicides namely propiconazole (Tilt), Azoxystrobin (Amitsar), carbendazim (Bavistin), difenconazole (Score), metalaxyl and three non-systemic fungicides, namely Mancozeb (Dithane M-45), Copper oxychloride (Blitox 50WP) and TMTD (Thiram 75WP), and two combinations of fungicides, namely Iprodione 25% + Carbendazim 25% (Quintal), Mancozeb 64% + Metalaxyl 14% (Ridomil Gold) were screened at different concentrations *viz.,* 10, 25 and 50 µg/ml. Four Petri plates for each concentration of fungicides were poured with 20 ml PDA added with desired concentration of fungicides in each Petri plate. All the plates were inoculated with uniform culture bit (5 mm) in inverted position at the centre from actively growing culture of bioagents.

Control plates without fungicides were also simultaneously inoculated for comparison. The inoculated plates were kept at 25±1°C untill the fungus covered the whole PDA plate in control. The diametric growth of fungus was recorded and per cent inhibition of each treatment was calculated by formulae given by Vincent [17]. Most efficient chemical(s) and bioagents were used singly or in combination, if possible, against chickpea wilt in pot studies. The results of compatibility test were kept in the formulation of combination of bio agents with fungicides.

2.4 Integrated Disease Management of Chickpea Wilt under Field Conditions

Integrated disease management of chickpea wilt was conducted under field condition during *Rabi* 2016-17 and 2017-18 at Divisional Research Farm, Chatha. The field experiment was laid out in Randomized Block Design to test the efficacy of fungicides, bioagents, possible combinations of fungicides and bio control agents along with untreated control as per the details mentioned in the table (Table 1). The susceptible chickpea cultivar (C-235) was used for the field experiment having Plot size of 2×2 m and spacing 20×30 cm in three replications. All the standard agronomical practices were followed according to the package practices of *Rabi* crops, SKUAST-J. Seed germination (%) was assessed after 18 days of seed sowing, whereas chickpea grain yield (q/ha) was also recorded in all treatments. Disease incidence was assessed after 60, 75, 90 days after artificial inoculation [18].

The per cent disease control (%) was calculated by following formulae.

$$\text{Per cent disease control (PDC)} = \frac{C - T}{C} \times 100$$

Where,

PDC = Per cent disease control
C = Disease incidence in control
T = Disease incidence in treatment

Whereas, yield (q/ha) of individual plots was calculated as per formula:

$$\text{Per cent increase in yield} = \frac{T - C}{T} \text{x } 100$$

T = Yield in treated plot
C = Yield in control plot

Table 1. Name, dose and application method of chemicals

Tr. No.	Chemical	Dose and application method
Fungicides alone		
T_1	Azoxystrobin	1 g / kg of seed
T_2	Copper oxychloride	2 g / kg of seed
T_3	Mancozeb	2 g / kg seed
T_4	Carbendazim	2 g / kg seed
Bio control agents alone		
T_5	*T. harzianum*-III	8 g / kg seed
T_6	*T. viride*-III	8 g / kg seed
Integration of fungicides and bio control agents		
T_7	Azoxystrobin + *T. harzianum* -III	1 g / kg seed + 8 g / kg seed
T_8	Azoxystrobin + *T. viride* -III	1 g / kg seed + 8 g / kg seed
T_9	Copper oxychloride + *T. harzianum* - III	2 g / kg seed + 8 g / kg seed
T_{10}	Copper oxychloride + *T. viride* - III	2 g / kg seed + 8 g / kg seed
T_{11}	Mancozeb + *T. viride* - III	2 g / kg seed + 8 g / kg seed
T_{12}	Mancozeb + *T. viride* - III	2 g / kg seed + 8 g / kg seed
T_{13}	Untreated Control	

2.5 Analysis of Data

The data of various experiments were subjected to statistical analysis and critical difference (CD) at level p=0.05 was calculated with the help of computer software SPSS. The data was subjected to appropriate transformations, wherever needed as suggested by Gomez and Gomez [19] before analysis.

3. RESULTS AND DISSCUSSION

3.1 *In vitro* Evaluation of Bio-Agents against *F. oxysporum* f. sp. *ciceri*

All the treatments were significantly effective over control with inhibited growth of the chickpea wilt pathogen, *F. oxysporum* f. sp. *ciceri* in comparison to untreated control. The Minimum Colony growth of 19.4 mm was observed in case of *T. harzianum* Isolate III (Th-III) with the maximum growth inhibition of 78.44 per cent which was followed by *T. harzianum* isolate II (Th-II) with the colony diameter of 21.3 mm and 76.33 per cent growth inhibition over control (Table 2). Among *T. viride* isolate III (Tv-III) showed minimum colony diameter of 21.7 mm with the inhibition of 75.89 per cent, *T. harzianum* isolate II (Th-II) and *T. viride* isolate III were statistically at par with each other. Among bacterial bio agent *Pseudomonas fluorescens* all the isolates showed near about 50 per cent inhibition.

The findings of the experiments are in conformity with those of Choudhary and Mohanka [20], who studied *in vitro* antagonism of indigenous *Trichoderma* isolates against *F. oxysporum* f. sp. *lentis* causing wilt of lentil. Rajput et al. [21] also evaluated different bioagents against chickpea wilt complex (*F. oxysporum* f. sp. *ciceri, Rhizoctonia bataticola* and *Sclerotium rolfsii*) and found all bio-control agents *viz., T. harzianum*, *T. viride, P. fluorescens* and *Bacillus subtilis* exhibited antagonistic effect against *F. oxysporum* f. sp. *ciceri* under dual culture.

3.2 *In vitro* Evaluation of Different Fungicides against *F. oxysporum* f. sp. *ciceri*

Under *in vitro* conditions, all the chemical treatments were significantly effective over control in minimizing the radial growth of chickpea wilt pathogen, *F. oxysporum* f. sp. *ciceri*. All the treatments were highly effective at maximum concentration of 100 ppm followed by 50 and 25 ppm and the least at 10 ppm. Carbendazim showed growth inhibition of the wilt pathogen significantly at all concentrations (10, 25, 50 and 100 ppm), the maximum growth inhibition (98.67%) was, however recorded at 100 ppm followed by 50, 25 and 10 ppm recording 91.33, 80.44 and 46.88 per cent growth inhibition, respectively (Table 3), which was followed by azoxystrobin, propiconazole, difenoconazole and metalaxyl, recording 96.22, 95.33, 94.56 and 90.89 per cent growth inhibition, respectively whereas lower concentrations recorded successively lower growth inhibitions in all the treatments. Iprodione + carbendazim, mancozeb + metalaxyl, thiram, copper oxychloride and mancozeb were, however, least effective and were statistically at par with each other, recording 86.11, 84.22, 83.67, 83.11 and 82.22 per cent growth inhibition at 500 ppm, respectively and successively followed by lower concentrations. A positive correlation was observed between concentrations of the tested fungicides and inhibition of *F. oxysporum*. Higher doses of fungicides were found to be more effective than lower ones. Singh and Jha [22] evaluated seven fungicides i.e. Thiram, Bavistin (carbendazim), Blitox (copper oxychloride), Captaf (captan), Indofil M-45 (Mancozeb), Ridomil MZ (mancozeb + metalaxyl) and kitazin (Iprobenfos), against chickpea wilt under *in vitro* (each at 0.1%) and found Thiram and Bavistin as the most suitable fungicides in inhibiting the mycelial growth of *F. oxysporum* f. sp. *ciceris* under *in vitro* followed by Ridomil and Mancozeb.

Mailto et al. [23] also studied the comparative efficacy of different fungicides against *F. oxysporum* f. sp. *ciceris*, evaluating 14 fungicides against pathogen *in vitro* with five different concentrations ranging from 1-10000 ppm. Among these, only carbendazim was found most effective at all concentrations, but higher concentrations of fungicides completely inhibited Foc pathogen.

3.3 Sensitivity of Fungal Bioagents to Fungicides

In vitro studies was undertaken to evaluate the sensitivity of fungal bioagents *viz*., *Trichoderma viride* (Tv-III) and *T. harzianum* (Th-III) at 10, 25 and 50 ppm concentrations against fungicides revealed that both the antagonists were highly sensitive and their growths on PDA were affected in combined cultures with propiconazole (Tilt), carbendazim (Bavistin), difenoconazole (Score), iprodione + carbendazim (Quintal) as well as metalaxyl recorded no growth of the bioagent, thereby exhibiting 100 per cent inhibition of both biocontrol agents at all concentration (10, 25 and 50 ppm), followed by mancozeb 64% + metalaxyl 14% (Ridomil Gold) which recorded growth inhibition of 59.00, 65.00 and 69.00 per cent in *T. viride* (Tv-III) and 58.78, 61.67 and 67.44 per cent in *T. harzianum* (Th-III) at 10, 25 and 50 ppm, respectively (Table 4). Similarly, the sensitivity to bioagents successively reduced at lower concentrations in other fungicides *viz*., azoxystrobin (Amistar), mancozeb (Dithane-M 45), copper oxychloride (Blitox-50) and the least sensitivity was observed in TMTD (Thiram) which recorded maximum growth of fungal bioagents.

Gupta et al. (2005) reported that carbendazim was incompatible with *T. viride* (TV2) isolate. Naseema Beevi et al. [24] tested *in vitro* compatibility of *T. harzianum* with mancozeb, carbendazim and copper oxychloride and found that carbendazim at 0.1 per cent completely inhibited the mycelial growth while mancozeb and copper oxychloride showed compatibility with the antagonist at 0.2 and 0.1 per cent, respectively. Khan and Gangopadhyay [25] tested the compatibility of *Pseudomonas fluorescens* with the fungicides and revealed that carboxin and carbendazim were least toxic to *P. fluorescens* strain PFBC-25.

3.4 Integrated Management of Chickpea Wilt under Field Conditions

Fild studies on integrated management of chickpea wilt caused by *Fusarium oxysporum* f. sp. *ciceri* were conducted to evaluate the efficacy of two effective fungal bioagents *viz*., *Trichoderma viride* and *T. harzianum* and four fungicides alone as well as in possible

Table 2. *In vitro* evaluation of bio-control agents against *F. oxysporum* f. sp. *ciceri*

Treatment	Colony diameter of *F. oxysporum* f. sp. *Ciceri* (mm)	Growth inhibition* (%)
Trichoderma viride (Tv-I)	24.6	72.67
T. viride (Tv-II)	23.4	74.00
T. viride (Tv-III)	21.7	75.89
T. harzianum (Th-I)	22.0	75.56
T. harzianum (Th-II)	21.3	76.33
T. harzianum (Th-III)	19.4	78.44
Pseudomonas fluorescens (Pf-I)	37.2	58.67
P. fluorescens (Pf-II)	39.1	56.56
P. fluorescens (Pf-III)	42.3	53.00
Control	90.0	-
SE(m)±	0.26	
CD (p= 0.05)	0.79	

Table 3. *In vitro* evaluation of different fungicides against *F. oxysporum* f. sp. *ciceri*

Fungicide	Concentration (ppm)	Radial growth (cm)	Inhibition over control (%)
Propiconazole	10	5.00	44.44
	25	2.43	73.00
	50	0.95	89.44
	100	0.42	95.33[c]
Azoxystrobin	10	5.29	41.22
	25	2.79	69.00
	50	0.95	89.44
	100	0.34	96.22[b]
Carbendazim	10	4.78	46.88
	25	1.76	80.44
	50	0.78	91.33
	100	0.48	98.67[a]
Difeconazole	10	5.63	37.44
	25	2.85	68.33
	50	1.01	88.78
	100	0.49	94.56[d]
Metalaxyl	10	5.89	34.56
	25	3.24	64.00
	50	1.22	86.44
	100	0.82	90.89[e]
Iprodione 25% + Carbendazim 25%	50	6.27	33.33
	100	3.59	60.11
	250	1.54	82.89
	500	1.25	86.11[f]
Mancozeb 64% + Metalaxyl 14%	50	6.34	29.56
	100	3.74	58.44
	250	1.67	81.44
	500	1.42	84.22[g]
Mancozeb	50	6.13	31.89
	100	3.92	56.44
	250	1.74	80.67
	500	1.60	82.22[h]
Copper oxychloride	50	6.00	33.33
	100	3.96	56.00
	250	1.82	79.78
	500	1.52	83.11[h]
Thiram	50	5.81	35.44
	100	3.98	55.78
	250	1.95	78.33
	500	1.47	83.67[h]
Control	-	9.00	-
Factor	**SE(m)±**	**CD (p= 0.05)**	
Fungicide (F)	0.305	0.858	
Concentration (C)	0.192	0.543	
Fungicide × Concentration (F x C)	0.610	1.715	

combinations. The studies revealed that all treatments were significantly effective and recorded lower disease incidence, higher seed germination, higher grain yield, high disease control and high increase in yield over untreated control (Table 5). Since *Trichoderma viride* and *T. harzianum* proved most sensitive to carbendazim, propiconazole and difenoconazole recording no growth of bioagents under *in vitro* studies conducted earlier, combined treatments of these fungicides with bioagents were not taken up in this field trial.

Field evaluation studies reveal that as seed dressers, both the bioagents *viz*., *T. harzianum*-III and *T. viride*-III @ 8 g/kg seed each recorded maximum seed germination of 90.21 and 90.07 per cent in chickpea crop during *Rabi* 2016-17 and 90.12, and 90.17 during *Rabi* 2017-18, with highest pooled seed germination of 90.16 and 90.12 per cent in both the crop seasons, respectively as compared to 70.49 and 68.42 per cent in untreated control. Bioagents were followed by azoxystrobin @ 1g/kg seed + *T. harzianum*-III @ 8 g/kg and azoxystrobin @ 1 g/kg seed + *T. viride*-III @ 8 g/kg seed, both of which recorded 88.94 and 88.12 per cent and 89.87 and 88.25 per cent, and azoxystrobin recorded 87.32 and 86.25 per cent seed germination during *Rabi* 2016-17 and 2017-18, respectively. The next treatments in descending order were copper oxychloride + *T. harzianum*-III, copper oxychloride + *T. viride*-III and carbendazim recording 86.86, 86.04 and 86.65 per cent seed germination, respectively during *Rabi* 2016-17, all of which were statistically at par with one another, however, the pattern differed during *Rabi* 2017-18, wherein copper oxychloride + *T. harzianum*-III recorded 87.19 per cent seed germination followed by copper oxychloride (86.52%) and copper oxychloride + *T. viride*-III (86.07%). The next treatments in downward chain with respective seed germinations during *Rabi* 2016-17 and 2017-18 were copper oxychloride (85.59 and 86.52%), mancozeb + *T. harzianum*-III (85.47 and 85.52%), mancozeb + *T. viride*-III (84.89 and 85.02%) and the least was mancozeb (84.17 and 83.10%).

Studies also reveal that all the treatments were significantly effective and recorded lower incidence of chickpea wilt in both the crop seasons. Both the fungal bioagents and fungicides were significantly effective singly or in combinations in either of the crop seasons. However, carbendazim recorded lowest disease incidence (14.92 and 14.97%) over untreated control (44.72 and 45.77%) followed by azoxystrobin + *T. harzianum*-III (16.47 and 17.00%) and azoxystrobin + *T. viride*-III (17.09 and 17.52%) all of which were statistically at par with one another, followed further by azoxystrobin (18.04 and 18.26%), respectively during *Rabi* 2016-17 and 2017-18. The next treatments lower in superiority recording higher disease incidence were copper oxychloride + *T. harzianum* -III (23.23 and 23.82%), copper oxychloride + *T. viride* -III + (23.73 and 24.20%), Mancozeb + *T. harzianum*-III (23.74 and 23.82%) and Mancozeb + *T. viride*-III (23.80 and 24.10%), respectively during *Rabi* 2016-17 and 2017-18, all of which were at par with one another, followed by copper oxychloride (28.26 and 28.28%) mancozeb (28.15 and 28.79%), and *T. harzianum*-III (28.60 and 29.65%) all of which were at par with one another. However, *T. viride*-III was least effective recording the highest disease incidence (29.23 and 30.28%), respectively during *Rabi* 2016-17 and 2017-18. Investigations further reveal that all single as well as combined treatments were effective and the disease control ranged between 34.66-66.63 per cent during *Rabi* 2016-17 and 33.95-67.29 per cent during *Rabi* 2017-18. However, carbendazim was most effective recording maximum (66.63 and 67.29%) disease control, followed by azoxystrobin + *T. harzianum*-III (63.17 and 62.85%), azoxystrobin + *T. viride*-III (61.78 and 61.72%), azoxystrobin (59.66 and 60.10%), copper oxychloride + *T. harzianum* -III (48.05 and 47.95%), copper oxychloride + *T. viride* -III (46.93 and 47.12%), mancozeb + *T. harzianum* -III (46.91 and 47.95%), mancozeb + *T. viride* -III (46.71 and 47.34%), mancozeb (37.05 and 37.09%), copper oxychloride (36.80 and 38.21%), *T. harzianum*-III (36.04 and 35.21%) and the least disease control was recorded in *T. viride*-III (34.66 and 33.95%), respectively during *Rabi* 2016-17 and 2017-18 crop seasons.

Data (Table 5) reveal that all the treatments were significantly effective and recorded higher chickpea grain yield than untreated control in both the crop seasons. However, maximum grain yield was recorded in azoxystrobin + *T. harzianum*-III (14.30 and 14.57 q/ha), azoxystrobin + *T. viride*-III (14.15 and 14.38 q/ha), carbendazim (13.98 and 14.31 q/ha) and azoxystrobin (13.93 and 14.27q/ha) as compared to low grain yield in untreated control (8.81 and 8.97 q/ha), respectively during *Rabi* 2016-17 and 2017-18 and all the combined treatments were statistically at par with each other. The next treatments recording respectively lower grain yields in succession during *Rabi* 2016-17 and 2017-18 were mancozeb + *T. harzianum*-III (11.91 and 12.12 q/ha), copper oxychloride + *T. harzianum*-III (11.87 and 12.08 q/ha), mancozeb + *T. viride*-III (11.70 11.94 q/ha) and copper oxychloride + *T. viride*-III (11.65 and 11.74 q/ha) all of which statistically at par with each other. However, the least grain yield was recorded in copper oxychloride (10.42 and 10.88 q/ha), *T. viride*-III (10.56 and 10.74 q/ha), Mancozeb (10.58 and 10.64 q/ha) and *T. harzianum*-III (10.60 and 10.62 q/ha), respectively during *Rabi* 2016-17 and 2017-18 all of which were statistically at par with each other. When compared to untreated control, all the treatments recorded increase in grain yield of chickpea in both the crop seasons. However, maximum increase in grain yield with respective increase during *Rabi* 2016-17 and 2017-18 was recorded in Azoxystrobin + *T. harzianum*-III (62.31 and 62.43%) followed by Azoxystrobin + *T. viride*-III (60.61 and 60.87%), Carbendazim (58.68 and 59.53), Azoxystrobin (58.11 and 59.08%), mancozeb + *T. harzianum* -III (35.18 and 35.11%), copper oxychloride + *T. harzianum*-III (34.73 and 34.67%), Mancozeb + *T. viride*-III (32.80 and 33.11%), copper oxychloride + *T. viride*-III (32.23 and 30.88%), copper oxychloride (18.27 and 21.29%), *T. viride*-III (19.86 and 19.73%), mancozeb (20.01 and 18.61%), and the least per cent increase of grain yield was recorded in *T. harzianum*-III.

Table 4. Sensitivity of fungal antagonists to different fungicides

Fungicide	Concentration (ppm)	***T. viride*** **(Tv-III)**		***T. harzianum*** **(Th-III)**	
		Radial growth (mm)	**Inhibition (%)**	**Radial growth (mm)**	**Inhibition (%)**
Propiconazole	10	0.00	100	0.00	100
	25	0.00	100	0.00	100
	50	0.00	100	0.00	100
Azoxystrobin	10	44.0	51.11	46.7	48.11
	25	38.7	57.00	41.4	54.00
	50	34.2	62.00	37.1	58.78
Carbendazim	10	0.00	100	0.00	100
	25	0.00	100	0.00	100
	50	0.00	100	0.00	100
Difenoconazole	10	0.00	100	0.00	100
	25	0.00	100	0.00	100
	50	0.00	100	0.00	100
Metalaxyl	10	0.00	100	0.00	100
	25	0.00	100	0.00	100
	50	0.00	100	0.00	100
Iprodione 25%+ Carbendazim 25%	10	0.00	100	0.00	100
	25	0.00	100	0.00	100
	50	0.00	100	0.00	100
Mancozeb 64%+ Metalaxyl 14%	10	36.9	59.00	37.1	58.78
	25	31.5	65.00	34.5	61.67
	50	27.9	69.00	29.3	67.44
Mancozeb	10	58.4	35.11	63.4	29.56
	25	51.3	43.00	54.5	39.44
	50	47.3	47.44	49.3	45.22
Copper oxychloride	10	73.3	18.56	69.4	22.88
	25	67.3	25.22	63.4	29.56
	50	62.4	30.67	67.3	25.22
Thiram	10	79.3	11.89	84.2	6.44
	25	74.9	16.78	78.3	13.00
	50	71.8	20.22	74.0	17.78
Control	-	90.0	-	90.0	-
SE (m)±		0.41		0.27	
CD (p= 0.05)		1.16		0.77	

Table 5. Integrated management of chickpea wilt caused by *Fusarium oxysporum* f. sp. *ciceri* under field conditions

Tr. No.	Treatment	Dose of chemicals and bio control agents / Kg of seed	Seed germination (%)			Disease incidence (%)			Disease control (%)			Grain yield (q/ha)			Increase in grain yield over control (%)		
			2016 - 17	2017 - 18	Pooled	2016 - 17	2017 - 18	Pooled	2016 - 17	2017 - 18	Pooled	2016 - 17	2017 - 18	Pooled	2016-17	2017-18	Pooled
T_1	Azoxystrobin	1 g	87.32	86.25	86.78	18.04	18.26	18.14	59.66	60.10	61.07	13.93	14.27	14.10	58.11	59.08	58.60
T_2	Copper oxychloride	2 g	85.59	86.52	86.05	28.26	28.28	28.49	36.80	38.21	37.54	10.42	10.88	10.65	18.27	21.29	19.80
T_3	Mancozeb	2 g	84.17	83.10	83.63	28.15	28.79	28.72	37.05	37.09	37.11	10.58	10.64	10.62	20.01	18.61	19.46
T_4	Carbendazim	2 g	86.65	85.58	86.11	14.92	14.97	14.94	66.63	67.29	66.95	13.98	14.31	14.15	58.68	59.53	59.17
T_5	*T. harzianum*-III	8 g	90.21	90.12	90.16	28.60	29.65	29.16	36.04	35.21	35.66	10.60	10.62	10.61	20.32	18.39	19.34
T_6	*T. viride*- III	8 g	90.07	90.17	90.12	29.23	30.28	29.77	34.66	33.95	34.33	10.56	10.74	10.65	19.86	19.73	19.79
T_7	Azoxystrobin + *T. harzianum*- III	1 g + 8 g	88.94	89.87	89.40	16.47	17.00	16.89	63.17	62.85	63.00	14.30	14.57	14.44	62.31	62.43	62.42
T_8	Azoxystrobin + *T. viride*- III	1 g + 8 g	88.12	88.25	88.18	17.09	17.52	17.47	61.78	61.72	61.60	14.15	14.38	14.27	60.61	60.87	60.51
T_9	Copper oxychloride + *T. harzianum*- III	2 g + 8 g	86.86	87.19	87.02	23.23	23.82	23.69	48.05	47.95	48.04	11.87	12.08	11.98	34.73	34.67	35.76
T_{10}	Copper oxychloride + *T. viride*- III	2 g + 8 g	86.04	86.07	86.05	23.73	24.20	23.93	46.93	47.12	46.49	11.65	11.74	11.70	32.23	30.88	31.61
T_{11}	Mancozeb + *T. harzianum*- III	2 g + 8 g	85.47	85.52	85.49	23.74	23.82	23.83	46.91	47.95	47.47	11.91	12.12	12.02	35.18	35.11	35.21
T_{12}	Mancozeb + *T. viride*- III	2 g + 8 g	84.89	85.02	84.95	23.80	24.10	24.11	46.71	47.34	47.09	11.70	11.94	11.82	32.80	33.11	32.96
T_{13}	Control (Untreated)		70.49	68.42	69.45	44.72	45.77	45.24	-	-	-	8.81	8.97	8.89	-	-	-
	SE(m)±		0.30	0.38	0.60	0.24	0.21	0.09			0.26	0.11	0.09	0.03			0.23
	CD (p= 0.05)		0.88	1.11	1.77	0.74	0.63	0.28			0.79	0.33	0.28	0.11			0.69

In the present studies on integrated management of chickpea wilt, it has been observed that among all the treatments under investigation, azoxystrobin alone as well as in combination with both the bioagents, besides carbendazim has been found most effective and recorded lower disease incidence, higher indices of seed germination, grain yield, disease control and increase in yield over control. The bioagents *viz*., *T. viride* and *T. harzianum* recorded maximum seed germination in both the crop seasons, but were inferior to other treatments with reference to disease incidence, disease control, grain yield and increase in grain yield over control. Our findings are in agreement with Singh and Sindhan [26] as well as Poddar et al. [27] who also observed that seed treatment of chickpea with bioagents like *T. harzianum* and *T. viride* gave excellent results against *F. oxysporum* f. sp. *ciceri*; seed treatment with *T. viride* (8 g/kg) and *P. fluorescens* (10 g/kg) observed 61.79, 56.75 and 54.62 per cent disease control against *F. oxysporum* f. sp. *ciceri* and maximum chickpea grain yield (1157 kg/ha) was obtained in the seed treatment with *T. harzianum* @ 4g/kg as compared to control (728 kg/ha). Poddar et al. [27] also reported that *T. harzianum* in combination with carbendazim (100 ppm) was effective against wilt (*F. oxysporum* f. sp. *ciceris*) in chickpea variety JG 62. Tiwari and Singh [28] evaluated the *in vitro* efficacy of different fungicides against *T. harzianum* @ 1500 ppm and found that the mycelial growth of *T. harzianum* was completely inhibited by carbendazim and hexaconazole @ 1500 ppm and the inhibition with copper oxychloride and mancozeb was 90 and 41 per cent. Chandel and Tomer [29] evaluated the efficacy of fungicides *i.e.* carbendazim, thiophanate methyl, thiram, Quintal (carbendazim 25% + iprodione 25%) and Saaf (carbendazim 12% + mancozeb 63%) as well as biopesticides i.e. Neemazal (1.0% EC) and Nimbicidine (0.03% EC) against Fusarium wilt (*F. oxysporum* f. sp. *gladioli*) of gladiolus. and found Quintal, carbendazim and Saaf as effective fungicides. Jayasekhar et al. [30] found that under field conditions soil application of *Pseudomonas fluorescens* followed by carbendazim spray (0.2%) after 30 days of *P. fluorescens* application recorded the lowest disease incidence of 3.77 per cent.

4. CONCLUSION

All the fungal bioagents were effective in minimizing the growth. *Trichoderma harzianum* III was found highly effective in minimizing the growth of *F. oxysporum* f. sp. *ciceri* by inhibition of 78.44 per cent under laboratory conditions.

The chemical evaluation under laboratory conditions Carbendazim was found highly effective treatment in minimizing the growth of pathogen. But it was observed that Thiram and Copper oxychloride allowed the growth of *Trichoderma harzianum* III. It showed that only these two chemicals were suitable for combination of bioagents with chemicals.

In the field experiment it was observed that the Carbendazim alone was found highly effective in minimizing the disease incidence (14.94 per cent) followed by the treatment of Azoxystrobin + *T. harzianum*- III **(**16.89 per cent). Azoxystrobin + *T. harzianum*- III was observed as second best treatment but it may be used to manage the disease effectively with minimizing the pesticide use which will lower down the production cost and toxicity in the produce.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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