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Compatibility Assessment of Native Non-Rhizospheric *Trichoderma* Isolates with Various Fungicides

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Authors' contributions

This work was carried out in collaboration among all authors. Author PNS did conception of experiment, supervised the study and critically revised the manuscript. Author ACR conducted the experiment, did data analysis and drafted the manuscript. Authors SS and MS designed the experiment, supervised the study and critically revised the manuscript. Authors UKN and MJ supervised the study. All authors read and approved the final manuscript..

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ABSTRACT

The native non-rhizosphere isolates of *Trichoderma* were tested against different systemic, contact and combi-product fungicides to test their compatibility. Total five isolates were tested against 16 different fungicides and compared with commercial *Trichoderma* isolate available in market. The native isolates showed good compatibility compared to commercial isolate. All the isolates showed high compatibility with Dimethomorph 50 % WP among systemic fungicides where least of 9.44 per cent mycelial inhibition was recorded in the isolate PSV. The systemic fungicides, Hexaconazole 4 % EC, Carbendazim 50 % WP and Thiophanate methyl 70 % WP were highly incompatible with all the *Trichoderma* isolates at all tested concentrations (100 % inhibition). All the native isolates recorded least of 22.74 per cent to highest of 35.63 per cent in case of contact fungicide, Copper Oxy Chloride 50 % WP (COC) and least of 26.98 to highest 38.66 per cent mycelial inhibition in the isolates SDKD and PSV, respectively in case of Mancozeb 75 % WP with 42.61 and 40.44 per cent inhibition in commercial isolate, respectively. The native isolates showed high incompatibility with Chlorothalonil 75 % WP (100 % inhibition at 1500 ppm). The native isolates showed good compatibility with Metalaxyl 4 %+ Mancozeb 64 % WP among combi-product fungicides with least of 50.12 per cent mycelial inhibition in case of PSV, while highest mycelial inhibition was recorded in commercial isolate 60.45 per cent. However, the native isolates showed cent per cent mycelial inhibition in combi-product fungicides Carbendazim 12 % + mancozeb 63 % and Carbendazim 25 % + Mancozeb 64 % WP. The native non-rhizosphere isolates were most superior than commercial isolates especially *Trichoderma harzianum* (PSV and GMV) which intended to study further.

Keywords: Trichoderma; fungicides; compatibility; mycelial inhibition; per cent; native.

1. INTRODUCTION

Plants play an essential role in the life of mankind by providing food, timber, furniture and raw materials for all kinds of paper products. However, the productivity of plants generally is reduced when they become diseased [1]. These diseases are caused by different classes of fungi, bacteria, viruses, nematodes, *etc*. So, various approaches are being followed to combat plant diseases which includes cultural practices, use of resistant varieties, use of chemicals, biological control methods, *etc*. Among all these practices chemical method is the most widely used [2]. It has been reported that incessant use of chemical fungicides may develop resistance in plant pathogenic fungi [3], and also harmful to various flora and fauna. The indiscriminate use of pesticides has resulted in accumulation of toxic compounds potentially hazardous to humans and environment [4]. Therefore, alternative methods must be followed for an effective disease management.

One of such potential nonchemical alternative is the use of microorganisms as biological control agents for eco-friendly and sustainable management of plant diseases [5]. Biological control offers an eco-friendly approach when applied either alone or in combination with other management practices without the demerits of chemical control [6].

Trichoderma, a fungal BCA is a free-living and diverse microbial community, highly interactive in root, soil and foliar environments [8], known worldwide for their utility as bio-control agents in management of fungal diseases of crop plants [1]. These occur worldwide and are commonly associated with root, soil and plant debris [8]. Recent advances demonstrate that the effects of *Trichoderma* on plants, including induced systemic or localized resistance, are very important [7]. The genus *Trichoderma* was identified long back during the early 17th century but its bio-control ability was revealed only in thirties of nineteenth century by Weindling [9,10]. The *Trichoderma* spp. are investigated as an efficient antagonist over 70 years and it occupies almost 50 % of fungal BCAs market.

In the scenario of intensive agriculture mainly in India, due to huge agrochemicals industries everyday lot of new chemicals and combi products with novel mode of action were released into the market. Compatibility of BCAs with modern inputs in plant protection like fungicides, insecticides, herbicides *etc*. is a pre-requisite for disease management and increasing plant growth which is needed for sustainable agriculture [11,6].

Thus, to develop an effective disease management programme, knowledge about the

compatibility of potential bio agents with commonly used agrochemicals is essential. Integration of compatible bio agents with fungicides may enhance the effectiveness of disease control and provide better management of soil borne diseases [12]. Combining antagonists with synthetic chemicals eliminates the chance of resistance development and reduces the fungicide application [13].

In this context, five native non-rhizosphere isolates of *Trichoderma spp*. which were identified as effective in dual culture studies against pathogens [14] were tested for their compatibility with different fungicides using poisoned food technique. In the pesticide market every day new chemicals were released for commercial use but they may not be compatible with BCAs and most of workers were tested compatibility of *Trichoderma* with common agro-chemicals. But in our study new agro-chemicals which were not commonly studied by other workers were tested for their compatibility.

2. MATERIALS AND METHODS

2.1 *Trichoderma* Culture

Totally 21 different isolates of *Trichoderma* spp. were isolated from different sources and crop rhizosphere and among them few were identified as effective in dual culture studies against plant pathogenic fungi [14]. All the isolates were preserved in PDA slants and for the present study five effective native non-rhizosphere isolates *viz.,* SMV (*T. viride*), SDKd (*T. longibrachiatum*), GMV (*T. harzianum*), PSV (*T. harzianum*) and CPV (*T. asperellum*) isolated from sheep manure, saw dust, goat manure, paddy straw and coir pith, respectively were sub-cultured on PDA plates and used to study their compatibility with different fungicides.

2.2 Compatibility Studies

Poisoned food technique was used to study the compatibility of native non-rhizosphere isolates of *Trichoderma* spp. with different fungicides. PDA was used as standard medium and adequate quantities of different fungicides were mixed with molten, cool PDA medium to obtain 50, 100, 200, 400, 600, 1000 and 1500 ppm. All fungicides quantities were calculated as per active ingredient (a. i.).

Under sterile condition, 20ml of poisoned PDA medium (molten and cooled) was poured into each Petri plate and 5 mm mycelial disc from actively growing region of 5 days old culture of *Trichoderma* isolates were placed at the centre of each plate and incubated at 28 ± 2 ºC for 4-5 days. Three plates were maintained for each concentrations and the plate without any fungicide was used as control plate. Same experiment was set up for all five native *Trichoderma* isolates and one commercial isolate (*T. viride*) obtained from local pesticide shop was used as standard check.

Observations were taken on radial mycelial growth at two positions each at right angles every day and percent mycelial inhibition was calculated when mycelium of *Trichoderma* in control plate covered entire plate area of 90mm using the following formula given by Vincent [15],

$$I = (C-T/C) \times 100$$

Where,

I = Per cent radial mycelial growth inhibition
C = Radial mycelial growth of *Trichoderma* isolate in control
T = Radial mycelial growth of *Trichoderma* isolate in treatments

2.3 Statistical Analysis

Web Agri. Statistical Package (WASP), developed by CCARI (Central Coastal Agriculture Research Institute), ICAR research complex, Goa, was used for the statistical analysis of data obtained from the experiment. Critical difference and standard error of mean was analysed to compare and interpret the results.

3. RESULTS AND DISCUSSION

3.1 Compatibility with Fungicides

Seven systemic fungicides, four contact fungicides and five combination fungicides were tested for compatibility with different native *Trichoderma* isolates at seven different concentrations. The fungicides showed least mycelial inhibition at 50 ppm and as the concentration increased, per cent mycelial growth inhibition has also increased.

The data indicates that, among systemic fungicides Dimethomorph 50 % WP was the highly compatible fungicide at all seven tested concentrations. Up to 400 ppm no mycelial

inhibition was observed in any of the native isolates whereas, at concentrations above 400 ppm slight radial mycelial growth inhibition (up to 10 % in all native isolates) was observed with same fungicide. At 1500 ppm, least mycelial inhibition was observed in the isolate PSV (9.44 %) followed by GMV (10.65 %), whereas the commercial isolate recorded highest of 39.84 per cent mycelial inhibition. The other isolates *viz.,* SMV, SDKD and CPV recorded 15.35, 17.48 and 18.89 per cent mycelial inhibition by Dimethomorph 50 % WP at 1500 ppm, respectively.

Apart from dimethomorph 50 % WP, Tebuconazole 25 % EC and Difenconazole 25 % EC showed least mycelial inhibition among systemic fungicides, which showed compatibility up to 400 ppm (less than 50 % inhibition). The fungicide Tebuconazole 25 % EC showed least mycelial inhibition in the isolate PSV (16.96 - 63.33 % inhibition at concentrations of 50 -1500 ppm) whereas the highest mycelial inhibition was recorded in the isolate SMV (28.63 - 83.65 % at different concentrations of 50 -1500 ppm). At highest concentration of 1500 ppm, tebuconazole 25 % EC recorded moderate incompatibility with all the isolates with highest of 89.53 % inhibition in commercial isolate.

However, the fungicide Difenconazole 25 % EC showed least mycelial inhibition in the isolate PSV up to 600 ppm (19.23 - 53.26 % at 50 to 600ppm) and at 1500ppm 73.69 per cent lowest mycelial inhibition was observed in PSV, while the commercial isolate recorded highest mycelial inhibition at all tested concentrations with 86.94 % mycelial inhibition at 1500 ppm.

Table 1. Effect of different fungicides on mycelial growth of native isolates of *Trichoderma* spp. at different concentrations

Sl. No.	Fungicides	Concentrations (ppm)	Per cent mycelial inhibition					
			Trichoderma isolates					
			SMV	SDKD	GMV	PSV	CPV	Commercial
1	Carbendazim 50 % WP	50	76.72	79.41	100.00	100.00	100.00	100.00
		100	80.20	83.67	100.00	100.00	100.00	100.00
		200	88.18	85.52	100.00	100.00	100.00	100.00
		400	100.00	90.35	100.00	100.00	100.00	100.00
		600	100.00	99.88	100.00	100.00	100.00	100.00
		1000	100.00	100.00	100.00	100.00	100.00	100.00
		1500	100.00	100.00	100.00	100.00	100.00	100.00
2	Thiophanate methyl 70 % WP	50	37.77	59.22	76.01	87.96	100.00	100.00
		100	51.00	71.12	78.14	100.00	100.00	100.00
		200	63.28	76.66	90.18	100.00	100.00	100.00
		400	70.97	87.27	100.00	100.00	100.00	100.00
		600	80.96	93.67	100.00	100.00	100.00	100.00
		1000	91.26	98.53	100.00	100.00	100.00	100.00
		1500	100.00	100.00	100.00	100.00	100.00	100.00
3	Dimethomorph 50 % WP	50	0.00	0.00	0.00	0.00	0.00	2.22
		100	0.00	0.00	0.00	0.00	0.00	5.55
		200	0.00	0.00	0.00	0.00	0.00	9.81
		400	0.00	0.00	0.00	0.00	0.71	18.52
		600	3.21	3.96	0.00	0.00	4.07	30.25
		1000	7.25	8.34	4.12	3.69	10.23	36.32
		1500	15.35	17.48	10.65	9.44	18.89	39.84
4	Azoxystrobin 23 % SC	50	11.83	15.53	21.48	22.22	27.40	26.98
		100	36.98	42.21	28.14	31.11	34.81	38.88
		200	100.00	100.00	32.59	35.18	43.34	52.22
		400	100.00	100.00	45.33	47.22	55.70	67.26
		600	100.00	100.00	63.70	58.80	69.45	78.58
		1000	100.00	100.00	71.35	68.43	79.52	86.34
		1500	100.00	100.00	82.63	78.32	87.96	92.64
5	Hexaconazole 4 % EC	50	100.00	100.00	100.00	100.00	100.00	100.00
		100	100.00	100.00	100.00	100.00	100.00	100.00
		200	100.00	100.00	100.00	100.00	100.00	100.00
		400	100.00	100.00	100.00	100.00	100.00	100.00
		600	100.00	100.00	100.00	100.00	100.00	100.00
		1000	100.00	100.00	100.00	100.00	100.00	100.00
		1500	100.00	100.00	100.00	100.00	100.00	100.00

Sl. No.	Fungicides	Concentrations (ppm)	Per cent mycelial inhibition					
			Trichoderma isolates					
			SMV	SDKD	GMV	PSV	CPV	Commercial
6	Tebuconazole 25 % EC	50	28.63	20.07	19.27	16.96	18.96	24.43
		100	36.10	27.30	26.70	22.26	26.28	34.27
		200	47.26	34.55	33.33	29.10	34.22	42.50
		400	60.28	42.82	42.13	37.08	42.63	56.03
		600	68.96	52.26	50.50	45.23	51.07	71.44
		1000	76.35	61.53	60.58	54.26	60.69	80.63
		1500	83.65	73.26	71.68	63.33	71.88	89.53
7	Difenconazole 25 % EC	50	26.18	23.68	20.53	19.23	24.26	25.73
		100	35.16	33.21	30.97	28.63	32.29	36.85
		200	44.52	43.06	43.22	34.07	44.40	46.51
		400	52.04	50.85	49.93	46.44	54.11	56.34
		600	61.17	58.10	57.48	53.26	61.85	65.00
		1000	70.69	67.85	65.45	62.99	71.68	75.44
		1500	80.66	76.52	74.22	73.69	82.33	86.94
8	Mancozeb 75 % WP	50	1.11	2.21	2.02	1.48	1.85	4.07
		100	2.95	3.80	2.95	3.70	3.70	7.77
		200	4.73	5.01	4.49	5.92	5.70	9.63
		400	11.45	9.28	9.22	11.63	8.75	16.40
		600	16.37	13.13	20.13	21.30	13.75	22.70
		1000	20.63	18.22	26.35	28.32	19.63	30.63
		1500	28.33	26.98	35.62	38.66	30.25	40.44
9	Copper oxy chloride 50 % WP	50	0.00	0.00	0.00	0.37	0.00	0.00
		100	0.00	0.00	0.00	1.49	0.00	0.00
		200	1.48	0.73	0.00	3.28	0.00	2.59
		400	3.97	2.86	2.33	9.78	5.16	10.57
		600	7.37	5.07	6.11	18.51	14.26	20.68
		1000	13.62	11.23	13.22	26.35	22.36	29.63
		1500	23.65	22.74	24.56	35.63	32.54	42.61
10	Chlorothalonil 75% WP	50	49.63	45.49	100.00	81.11	78.51	85.55
		100	67.13	54.78	100.00	86.29	94.07	100.00
		200	100.00	66.25	100.00	100.00	100.00	100.00
		400	100.00	72.92	100.00	100.00	100.00	100.00
		600	100.00	79.50	100.00	100.00	100.00	100.00
		1000	100.00	92.68	100.00	100.00	100.00	100.00
		1500	100.00	100.00	100.00	100.00	100.00	100.00
11	Captan 50% WP	50	61.08	70.74	35.18	29.25	45.55	20.74
		100	65.15	74.06	40.73	41.40	53.33	52.96
		200	77.36	76.29	50.74	61.48	74.44	66.66
		400	81.23	81.07	61.38	74.44	82.93	75.18
		600	84.63	83.70	73.27	81.29	92.13	83.59
		1000	95.63	93.52	84.33	92.36	100.00	94.66
		1500	100.00	100.00	95.66	100.00	100.00	100.00
12	Cymoxanil 8%+ mancozeb 50% WS	50	2.62	0.00	0.37	18.56	15.52	16.66
		100	10.00	1.84	18.51	27.40	19.26	21.11
		200	12.22	5.90	34.07	45.44	22.22	24.47
		400	20.99	10.84	41.75	55.89	30.33	31.05
		600	24.90	17.15	52.03	67.92	40.82	42.99
		1000	35.66	28.41	65.32	79.36	53.66	57.41
		1500	49.21	40.33	80.22	91.32	70.53	74.52
13	Carbendazim 25% + Mancozeb 64% WP	50	77.03	100.00	100.00	100.00	100.00	100.00
		100	100.00	100.00	100.00	100.00	100.00	100.00
		200	100.00	100.00	100.00	100.00	100.00	100.00
		400	100.00	100.00	100.00	100.00	100.00	100.00
		600	100.00	100.00	100.00	100.00	100.00	100.00
		1000	100.00	100.00	100.00	100.00	100.00	100.00
		1500	100.00	100.00	100.00	100.00	100.00	100.00
14	Carbendazim 12% + mancozeb	50	100.00	76.95	100.00	100.00	100.00	100.00
		100	100.00	98.07	100.00	100.00	100.00	100.00
		200	100.00	100.00	100.00	100.00	100.00	100.00

Sl. No.	Fungicides	Concentrations (ppm)	Per cent mycelial inhibition					
			Trichoderma isolates					
			SMV	SDKD	GMV	PSV	CPV	Commercial
	63%	400	100.00	100.00	100.00	100.00	100.00	100.00
		600	100.00	100.00	100.00	100.00	100.00	100.00
		1000	100.00	100.00	100.00	100.00	100.00	100.00
		1500	100.00	100.00	100.00	100.00	100.00	100.00
15	Metiram 55%+ pyraclostorbin 5% WG	50	71.11	69.25	51.85	16.29	62.96	65.92
		100	77.35	74.44	61.85	30.73	73.70	75.92
		200	94.43	81.10	66.29	39.25	77.32	100.00
		400	100.00	91.08	78.48	74.44	84.13	100.00
		600	100.00	99.70	91.32	81.29	91.41	100.00
		1000	100.00	100.00	100.00	95.66	100.00	100.00
		1500	100.00	100.00	100.00	100.00	100.00	100.00
16	Metalaxyl 4%+ mancozeb 64% WP	50	4.03	0.00	0.00	1.85	1.11	0.00
		100	9.20	18.73	11.11	7.40	6.29	3.70
		200	24.07	21.26	17.77	10.74	9.81	9.25
		400	37.22	24.61	31.49	16.72	14.35	19.61
		600	41.47	30.69	43.72	24.70	26.37	31.52
		1000	55.32	43.26	58.22	37.66	40.12	47.25
		1500	70.22	59.24	71.62	50.12	52.63	60.45
	F	**Fungicide (F)**	**	**	**	**	**	**
		Concentration(C)	**	**	**	**	**	**
		F*C	**	**	**	**	**	**
	S. E. m. ±	**Fungicide (F)**	**0.50**	**0.31**	**0.30**	**0.41**	**0.24**	**0.29**
		Concentration(C)	**0.29**	**0.18**	**0.17**	**0.23**	**0.14**	**0.17**
		F*C	**1.13**	**0.69**	**0.67**	**0.91**	**0.53**	**0.64**
	CD @ 1%	**Fungicide (F)**	**1.86**	**1.14**	**1.10**	**1.50**	**0.88**	**1.06**
		Concentration(C)	**1.07**	**0.66**	**0.63**	**0.86**	**0.51**	**0.61**
		F*C	**4.16**	**2.55**	**2.46**	**3.34**	**1.96**	**2.38**

***- Significant, NS- Non- significant @ 1% level, F*C- interaction.*

List 1. Different compatibility reactions

Sl. No.	Reaction	Description	Per cent mycelial inhibition
1	HC	Highly compatible	<20
2	C	Compatible	21-40
3	MC	Moderately compatible	41-60
4	MIC	Moderately incompatible	61-80
5	HIC	Highly incompatible	>81

In case of Azoxystrobin 23 % SC, at 50 and 100ppm, the fungicide was compatible with all the isolates (less than 40 % inhibition). The isolates SMV and SDKd showed complete incompatibility at 200 ppm onwards (100 % mycelial inhibition) while the other native isolates were incompatible at 1000 ppm onwards (more than 80 % inhibition). The result was on par with Soumik et al*.* (2010) where they observed that the fungicide azoxystrobin 23 % SC was most compatible at all the tested concentrations of 5-300 ppm with *T. harzianum*.

However, the remaining systemic fungicides *viz*., Hexaconazole 4 % EC, Carbendazim 50 % WP and Thiophanate methyl 70 % WP were highly incompatible with all the *Trichoderma* isolates at all tested concentrations*.* The fungicide hexaconazole 4 % EC completely inhibited all the *Trichoderma* isolates starting from 50 ppm, whereas carbendazim 50 % WP was moderately incompatible with less than 85 % mycelial inhibition up to 200 ppm with the isolates SMV and SDKd while all other isolates were completely (100 %) inhibited at all seven concentrations tested. Gunda et al*.* [16] reported that Hexaconazole 5 % EC was the highly incompatible fungicide which caused 100 % inhibition of mycelial growth at all tested concentrations of 500, 1000 and 2000 ppm. Non compatibility of *T. viride* with Hexaconazole fungicides had been reported earlier by Nene and Thapliyal [17] and Sonavane and Venkataravanappa [18]; high incompatibility of *T. harzianum* with hexaconazole was reported by Morajdhwaj et al*.,* [19].

Madhusudhan et al. [20] also reported high incompatibility of Carbendazim with *T. viride* with no mycelial growth along with Hexaconazole 5 % EC and Chlorothalonil 75 % WP which recorded

up to 75 % mycelial growth inhibition with *T. viride* at tested concentrations of 50, 200, 250, 500 and 1000 ppm. Nene and Thapliyal [17] conducted a laboratory study and concluded that *T. viride* was not compatible with fungicide Carbendazim.

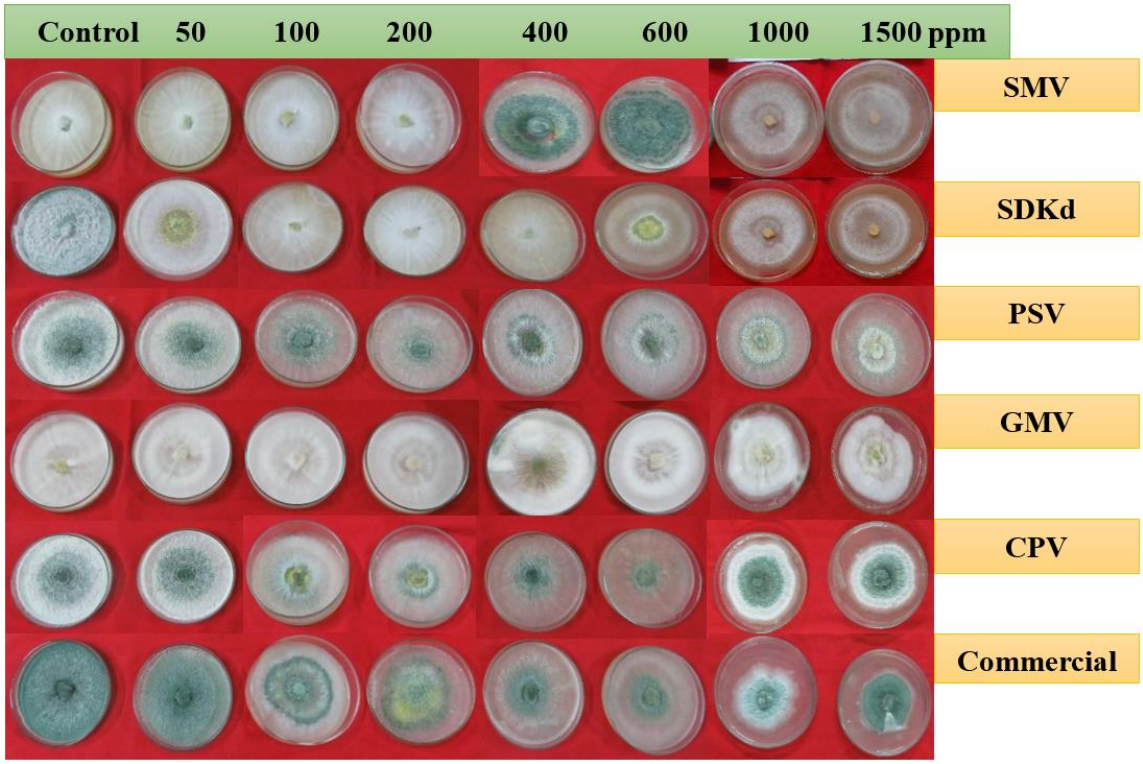

Plate 1. Effect of systemic fungicide dimethomorph 70% WP on mycelial growth of native isolates of *Trichoderma* spp. at different concentrations (ppm)

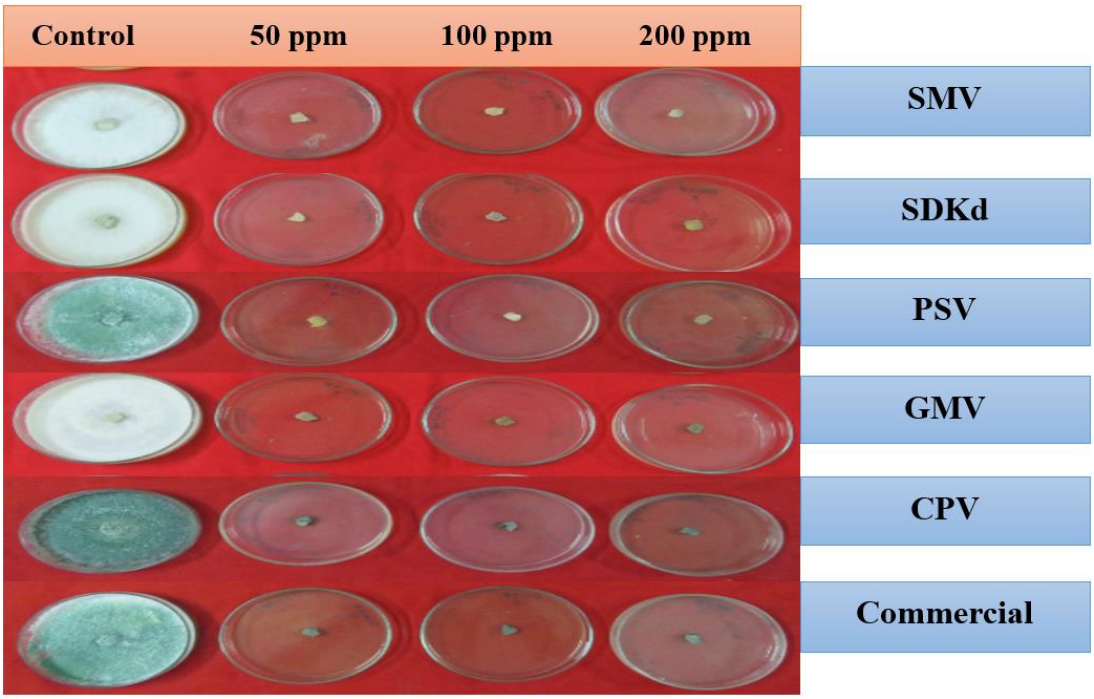

Plate 2. Effect of systemic fungicide hexaconazole 5% EC on mycelial growth of native isolates of *Trichoderma* spp. at different concentrations

Table 2. Compatibility reactions of various agrochemicals with different native *Trichoderma* isolates at 1500ppm

Sl. No.	Fungicides/Insecticides/ Bactericide/ Herbicide	*Trichoderma* isolates					
		SMV	SDKd	GMV	PSV	CPV	Commercial
1	Dimethomorph 50% WP	HC	HC	HC	HC	HC	C
2	Mancozeb 75% WP	C	C	C	C	C	C
3	Copper oxy chloride 50% WP	C	C	C	C	C	C
4	Cymoxanil 8%+ mancozeb 50% WS	MC	C	HI	HI	MC	MC
5	Metalaxyl 4%+ mancozeb 64% WP	MI	MC	MI	MC	MC	MC
6	Tebuconazole 25% EC	HI	MI	MI	MI	MI	HI
7	Difenconazole 25% EC	HI	MI	MI	MI	HI	HI
8	Azoxystrobin 23% SC	HI	HI	HI	MI	HI	HI
9	Captan 50% WP	HI	HI	HI	HI	HI	HI
10	Thiophanate methyl 70% WP	HI	HI	HI	HI	HI	HI
11	Carbendazim 50% WP	HI	HI	HI	HI	HI	HI
12	Hexaconazole 5% EC	HI	HI	HI	HI	HI	HI
13	Chlorothalonil 75% WP	HI	MI	HI	HI	HI	HI
14	Carbendazim 25%+ mancozeb 64%	HI	HI	HI	HI	HI	HI
15	Carbendazim 12%+ mancozeb 63%	HI	HI	HI	HI	HI	HI
16	Metiram 55%+ pyraclostorbin 5% WG	HI	HI	HI	HI	HI	HI

Fungicide, Carbendazim completely inhibited mycelial growth of *Trichoderma* from 250 to 1000 ppm [18]. *T. viride* is highly incompatible with carbendazim and could not grow even 1 mm at 1 ppm carbendazim [21]. Pooja et al*.,* [22] reported the incompatibility of hexaconazole and tebuconazole with *T. viride* at 100ppm onwards. Results of the studies conducted by many other workers also confirmed high toxicity of Carbendazim and Hexaconazole towards *T. viride* [23,24,25,26,27].

With respect to Thiophanate methyl 70 % WP, the isolate GMV showed high incompatibility at 100 ppm onwards (more than 80 % inhibition), SMV (more than 80 % inhibition) and SDKd (>80 %) at 400 and 200 ppm, respectively. The isolates PSV, CPV and commercial isolate were completely inhibited (100 %) at all seven tested concentrations.

Among contact fungicides, Copper Oxy Chloride 50 % WP (COC) and mancozeb 75 % WP were the most compatible fungicides at all seven tested concentrations and with all the *Trichoderma* isolates. The fungicide COC 50 % WP was highly compatible with all the *Trichoderma* isolates with no significant mycelial inhibition up to 400 ppm (<10 % inhibition) and 22.74-35.63 % mycelial inhibition of different native *Trichoderma* isolates with least mycelial inhibition in SDKd and highest in PSV at 1500 ppm and commercial isolate recorded 42.61 % mycelial inhibition at 1500 ppm. The isolates SMV, GMV and CPV recorded 23.65, 24.56 and 32.54 per cent mycelial inhibition at 1500 ppm by COC. Mareeswaran and Asir [28] and Soumik et al*.* [29] observed that COC 50 % WP was the most compatible fungicide at 1000 ppm with less than 10 % inhibition.

Another contact fungicide mancozeb 75 % WP was also safer to all the *Trichoderma* isolates with a mycelial inhibition range of 26.98- 38.66 % in different native *Trichoderma* isolates and 40.44 % mycelial inhibition in commercial isolate at 1500 ppm. Similar results were obtained by Thoudam and Dutta [30], where combined applications of BCAs followed by small quantities of fungicides recorded less inhibition of *Trichoderma* with mancozeb at lower concentrations of 100 ppm. Maximum compatibility of *Trichoderma* isolates T45, T2, T9 and T16 with mancozeb (0.15 and 0.20 per cent) was reported by Ramanagouda and Naik [31]. Similar results were reported by many workers in *T. viride* and *T. harzianum* [23,25,18,20].

In case of captan 50 % WP, the isolates SMV and SDKd showed moderate incompatibility with more than 60 % mycelial inhibition at 50 ppm, while all other native isolates including commercial isolate showed moderate compatibility up to 100 ppm (less than 50 % mycelial inhibition) and moderate incompatibility was observed at rest of the concentrations (above 400 ppm) and complete mycelial inhibition (100 %) was observed at 1500 ppm in all the isolates. However, the another contact

fungicide chlorothalonil 75 % WP was highly incompatible with most of the *Trichoderma* isolates, where 100 % mycelial inhibition was observed at 200 ppm and above in the isolates SMV, PSV and CPV, while GMV and commercial isolates showed 100 % mycelial inhibition even at low concentration of 50 and 100 ppm onwards, respectively. Maheshwary et al. [27] observed compatibility of *T. asperellum* with copper oxy chloride and mancozeb and incompatibility with captan under *in-vitro* condition.

Among the five combi fungicides metalaxyl 4 %+ mancozeb 64 % WP and cymoxanil 8 %+ mancozeb 50 % WS were compatible with *Trichoderma* isolates whereas other combi products caused significant mycelial inhibition. The combi fungicide metalaxyl 4 %+ mancozeb 64 % WP showed compatibility up to 1000 ppm with less than 50 % mycelial inhibition and moderately incompatible at 1500 ppm with all the *Trichoderma* isolates with a least inhibition range of 1.85 - 50.12 % in the isolate PSV at different concentrations of 50-1500 ppm.

Theertha et al*.* [32] observed similar results where metalaxyl 4 %+ mancozeb 64 % WP was the most compatible fungicides among thirteen fungicides with *T. asperellum* at all four tested concentrations of 100, 200, 400 and 800 ppm. High compatibility of metalaxyl + mancozeb was observed by Maheshwary et al*.*. [27].

In case of cymoxanil 8 %+ mancozeb 50 % WS, the isolates SMV and SDKd were compatible at all seven concentrations with high compatibility up to 600 ppm (less than 25 % inhibition), CPV and commercial isolates were highly compatible up to 100 ppm and GMV and PSV were highly compatible up to 100 and at 50 ppm, respectively. while the isolates PSV and GMV were incompatible at 1500 ppm (>80 % inhibition). The isolate SDKd showed least mycelial inhibition among all isolates with an inhibition range of 0-40.33 % at different concentrations of 50-1500 ppm. Dinkwar et al*.* [33] showed the compatibility of *Trichoderma* with cymoxanil 8% + mancozeb 64% WP.

Another combi fungicide metiram 55 %+ pyraclostrobin 20 % WG was incompatible with all the *Trichoderma* isolates with more than 80 % mycelial inhibition above 200 ppm. However, the isolate PSV showed compatibility up to 200 ppm (less than 40% inhibition) whereas all the *Trichoderma* isolates were completely inhibited at 1000 ppm (100 %) in which the isolates SMV and commercial showed 100 % mycelial inhibition at 400 and 200 ppm onwards, respectively.

Other two carbendazim containing combi fungicides *viz.,* carbendazim 12 %+ mancozeb 63 % WP and carbendazim 25 %+ mancozeb 64 % WP were highly incompatible with complete mycelial inhibition in all six isolates at all seven tested concentrations. Similar result was observed by Dinkwar et al*.* [33].

Theertha et al*.* [32] observed that the fungicides containing carbendazim (sprint, saaf, bavistin, turf and starbenz) were highly inhibitory (100 % inhibition) to mycelial growth of *Trichoderma* even at low concentration of 100 ppm [34].

4. CONCLUSION

Organic measures to combat pests are the need of the hour and highest priority has been given for this. However, bio-agents have not yet attained efficiencies matching those of currently available fungicides. Integration of pesticides with bio-control agents will be a better option for improving the efficiency of bio-control agents. Combined application of chemical and bio- agents will help in extending the period of active disease control as well as reducing the cost of crop protection. Hence it is necessary to give importance to compatibility of bio-agents and agrochemicals while making decision on integration of management options.

Five native isolates of *Trichoderma* spp. were tested for their compatibility with 25 different agro-chemicals under *in-vitro* conditions. Different chemicals showed different compatibility range. When compared among all the agrochemicals, SDKd, GMV and PSV were the isolates which showed compatibility with most number of agrochemicals at 1500 ppm. However, the commercial isolate showed compatibility with least number of agrochemicals.

The fungicide dimethomorph 50 % WP was highly compatible with all the *Trichoderma* isolates whereas the fungicides mancozeb 75 % WP, COC 50 % WP, cymoxanil 8 %+ mancozeb 50 % WS, metalaxyl 4 %+ mancozeb

64 % WP showed compatibility with *Trichoderma* isolates.

The fungicides carbendazim 50 % WP, hexaconazole 4 % EC, and carbendazim containing fungicides *viz.,* carbendazim 25 %+ mancozeb 64 % WP, carbendazim 12 %+ mancozeb 63 % WP were highly incompatible and completely inhibited the mycelial growth of *Trichoderma* spp.

So, from the present study on compatibility of native *Trichoderma* isolates with different agrochemicals, we can conclude that the native isolates were more compatible than commercial *Trichoderma* isolate. Among different isolates, SDKd, PSV and GMV were the superior isolates which showed compatibility with maximum number of agrochemicals.

Trichoderma being a fungus, it is affected by most of the fungicides. Hence at most care may be taken while applying incompatible combination of fungicides and bio-agents or a safe interval must be provided while application. In order to draw proper conclusion, the study has to be conducted at filed level to select effective and compatible *Trichoderma* isolates and safer agro-chemicals.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc have been used during writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

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CONSENT FOR PUBLICATIONS

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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