The Pharma Innovation Journal 2022; 11(6): 2322-2325

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(6): 2322-2325

www.thepharmajournal.com
Received: 20-04-2022
Accepted: 28-05-2022

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Efficacy of different fungicides for the management of castor wilt (*Fusarium oxysporum* f. sp. *ricini*)

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Abstract
Castor (*Ricinus communis* L.) belonging to the family Euphorbiaceae is the most important non edible oilseed crop of arid and semiarid regions of India. Though castor is seriously affected by many diseases, wilt caused by *F. oxysporum* f. sp. *ricini* is an important destructive disease of Saurashtra region of Gujarat. Experiment was conducted to find out effective fungicides for the management of castor wilt. Different fungicides were tested against *Fusarium oxysporum* f. sp. *ricini viz.,* systemic, non-systemic and ready-mixed fungicide. In laboratory screening of different fungicides, thiram 75% WP (87.24%) was found to be quite effective in inhibiting the radial growth of test pathogen among non-systemic group of fungicides, while in systemic group of fungicides, carbendazim 50% WP (100%) and in case of ready-mixed fungicides carbendazim 12% + mancozeb 63% WP (88.33%) were significantly inhibited the growth of *F. oxysporum* f. sp. *ricini* under *in vitro.*

Keywords: Fungicides, management, castor, *Fusarium oxysporum* f. sp. *ricini*

1. Introduction
Castor (*Ricinus communis* L.) is one of the most important non-edible oilseed crop in the world. It is generally distributed in the tropical, sub-tropical and warm temperate zones (Weiss, 2000) [16]. It is a species of flowering plant in the spurge family, Euphorbiaceae. It belong to a monotypic genus, *Ricinus* and subtribe, Ricininae. Castor is believed to have originated in Egypt and Ethiopian region of tropical East Africa and India. Subsequently, it spread to China, Brazil, Thailand, Argentina, U.S.A. etc. (Anjani, 2012) [1]. Low yield of castor is attributed to several diseases and insect. Despite of different diseases, castor wilt (*Fusarium oxysporum* f. sp. *ricini)* is the most important disease of castor at present in India. Wilt and root rot are the two serious diseases causing economic yield losses in Gujarat. Due to the monocropping of castor in some places, as well as the long survival ability of the pathogen, the wilt disease is becoming a continuous threat to the cultivation of the crop. The disease appears in a severe form causing very high plant mortality in many farmers' fields of Saurashtra region of Gujarat under rainfed and irrigated conditions. The symptoms of the malady square measure a lot of distinguished at flowering and spike formation stage as gradual yellowing, inter-venial necrosis, droop down of leaves and darkening and mortification of roots (Nanda and Prasad, 1974) [10]. Wilt colonizing the vascular tissue vessels and interference them utterly inflicting serious yield loss up to 85 per cent, betting on plant matter and condition (Dange, 2003) [4]. Present study was carried out to evaluate the fungicides against *Fusarium* wilt of castor under laboratory condition.

2. Materials and Methods
2.1 Isolation and purification of pathogen
The plants showing typical symptoms of wilt, caused by *Fusarium oxysporum* f. sp. *ricini*, were collected from castor fields of the Main Oilseed Research Station, Junagadh Agricultural University, and Junagadh. The freshly collected wilted plants of castor, showing blackening and necrosis of roots were thoroughly washed and then immediately examined under a compound microscope for preliminary identification of the pathogen. Isolation of the fungus was made by tissue isolation technique on potato dextrose agar (PDA) and incubated at 28±2 ^{0}C. The resulting fungal culture was purified by hyphal tip method. The fungus was isolated, purified and sub cultured in aseptic condition. The isolates of the pathogen were identified based on colony characters and spores morphology (Booth, 1975) [3].

2.2 *In vitro* evaluation of different fungicides against test pathogen

The direct and indirect effects both at genotypic and *In vitro* efficacy of different fungicides against castor wilt pathogen was evaluated by poisoned food technique (Grover and Moore, 1962) [5] as described below:

2.2.1 Poisoned food technique

Required quantity of fungicide was added in 100 ml of lukewarm PDA media and mixed thoroughly. This solution was poured into Petri plates about 20 ml in each. After solidification of media 5 mm discs of four days old culture of test pathogen were inoculated at the center of Petri plates and then incubated at 28±2 °C. Three repetitions were maintained for each fungicide. Medium without fungicide was kept as control. Per cent inhibition of the growth of the fungus over the control was calculated as per the following formula (Vincent, 1947).

$$\textbf{Per cent growth inhibition (PGI)} = \frac{C-T}{C} \times 100$$

Where,

C = Average diameter of mycelial colony in control treatment (mm)

T = Average diameter of mycelial colony in treated plate (mm)

Non systemic fungicides i.e., propineb 70% WP, mancozeb 75% WP, copper oxychloride 50% WP, thiram 75% WP, copper hydroxide 77% WP and captan 75% WP were used at 1000, 1500, 2000 and 2500 ppm concentration.

Systemic fungicides i.e., carbendazim 50% WP, tebuconazole 25.9% EC, flusilazole 40% EC, fosetyl-Al 80% WP, thiophanate methyl 70% WP, hexaconazole 5% EC, azoxystrobin 23% EC and picoxystrobin 25% EC were used under laboratory condition at 100, 250, 500 and 1000 ppm concentration.

Ready mix fungicides i.e., azoxystrobin 11% + tebuconazole 18.30% SC, carbendazim 12% + mancozeb 63% WP, carboxin 37.5% + thiram 37.5% WP, cymoxanil 8% + mancozeb 64% WP, cymoxanil 8% + mancozeb 64% WP, zineb 68% WP + hexaconazole 4% WP, mancozeb 40% + azoxystrobin 7% OS and metiram 55% WG + pyraclostrobin 5% WG were evaluated at 250, 500, 1000 and 1500 ppm concentration under laboratory condition against castor wilt pathogen following poisoned food technique as described earlier. Three repetitions were kept for each concentration of respective fungicide. Completely Randomized block Design with Factorial Concept was used for analyzing the data.

3. Results and Discussion

3.1 *In vitro* evaluation of non-systemic fungicides

Efficacy of six commonly used non-systemic fungicides *viz*., propineb, mancozeb, copper oxychloride, thiram, copper hydroxide and captan were evaluated against *Fusarium oxysporum* f. sp. *ricini* at different concentrations *viz*., 1000, 1500, 2000 and 2500 ppm using poisoned food technique as described in section 2.2.1. The data revealed that all the fungicides at all concentrations reduced mycelial growth (Table 1) of *Fusarium oxysporum* f. sp. *ricini* as compared to control.

It is inferred from the data presented in Table 1, that all the fungicides are significantly effective in inhibition of test pathogen.

The perusal of data presented in Table 1 revealed that mean per cent growth inhibition of *Fusarium oxysporum* f. sp. *ricini* was maximum in thiram 75% WP (87.24%) followed by captan 75% WP (71.86%), propineb 70% WP (67.36%), mancozeb 75% WP (66.46%) and copper oxychloride 50% WP (60.22%). They were significantly differed to each other. The least effective fungicide found was copper hydroxide 77% WP with 36.12 per cent mean mycelia growth inhibition.

There was positive correlation between concentration and inhibition of growth of pathogen. It is also observed that with increasing concentration of all fungicides, inhibition of growth of pathogen also increased. The fungicides thiram 75% WP, captan 75% WP, propineb 70% WP, mancozeb 75% WP, copper oxychloride 50% WP and copper hydroxide 77% WP showed higher 92.03, 80.16, 71.63, 76.34, 62.33 and 55.42 per cent inhibition of mycelia growth at 2500 ppm, respectively as compared to their lower concentration of 1000, 1500 and 2000 ppm. In case of concentration mean, maximum growth inhibition of 74.01 per cent was recorded at 2500 ppm concentration and lowest was 53.90 per cent at 1000 ppm.

Table 1: Evaluation of non-systemic fungicides on growth inhibition of *Fusarium oxysporum* f. sp. *ricini* under *in vitro* condition

Tr. No.	Fungicides	Growth inhibition (%)*				Mean growth inhibition (%)
		1000 ppm	1500 ppm	2000 ppm	2500 ppm	
1.	Propineb 70% WP	53.37 (64.40)	53.93 (65.34)	55.51 (67.94)	57.81 (71.63)	55.16 (67.36)
2.	Mancozeb 75%WP	48.38 (55.88)	51.42 (61.11)	57.76 (71.53)	60.90 (76.34)	54.61 (66.46)
3.	Copper Oxychloride 50% WP	49.29 (57.46)	50.59 (59.69)	51.58 (61.39)	52.14 (62.33)	50.90 (60.22)
4.	Thiram 75% WP	66.53 (84.14)	66.74 (84.40)	69.42 (87.64)	73.60 (92.03)	69.07 (87.24)
5.	Copper Hydroxide 77% WP	13.46 (5.42)	39.90 (41.14)	46.30 (52.27)	48.11 (55.42)	36.94 (36.12)
6.	Captan 75% WP	52.38 (62.74)	54.42 (66.15)	61.50 (77.23)	63.55 (80.16)	57.96 (71.86)
	Concentration mean	47.24 (53.90)	52.83 (63.50)	57.01 (70.35)	59.35 (74.01)	
		Fungicide (F)	Conc.(C)		F x C	
	S.Em. ±	0.45	0.37		0.90	
	CD at 5%	1.29	1.05		2.57	
	CV %	2.89				

*Mean of three repetition

Figures in parentheses are re-transformed value of arc sine

The effectiveness of thiram against *Fusarium oxysporum* has been recorded by Pushpavathi *et al.* (1998) [12], Singh and Jha (2003) [14] and Hussein *et al.* (2016) [6]. Looking to concentration of individual fungicides, all the fungicides differed significantly in inhibition of test pathogen.

3.2 *In vitro* evaluation of systemic fungicides

Efficacy of eight commonly used systemic fungicides *viz*., carbendazim, tebuconazole, flusilazole, fosetyl-Al, thiophanate methyl, hexaconazole, azoxystrobin and picoxystrobin were evaluated against *F. oxysporum* f. sp. *ricini* at different concentrations *viz*., 100, 250, 500 and 1000 ppm using poisoned food technique as described in section 2.2.1. The data revealed that all the fungicides at all concentrations reduced mycelial growth (Table 2) of *F. oxysporum* f. sp. *ricini* as compared to control.

Table 2: Evaluation of systemic fungicides on growth inhibition of *Fusarium oxysporum* f. sp. *ricini* under *in vitro* condition

Tr. No.	Fungicides	Growth inhibition (%)*				Mean growth inhibition (%)
		100 ppm	250 ppm	500 ppm	1000 ppm	
1.	Carbendazim 50% WP	90.05 (100.00)	90.05 (100.00)	90.05 (100.00)	90.05 (100.00)	90.05 (100.00)
2.	Tebuconazole 25.9% EC	65.38 (82.65)	67.40 (85.23)	69.11 (87.29)	75.09 (93.38)	69.25 (87.44)
3.	Flusilazole 40% EC	43.11 (46.70)	52.11 (62.29)	57.81 (71.63)	65.17 (82.37)	54.55 (66.36)
4.	Fosetyl-Al 80% WP	12.66 (4.80)	37.16 (36.49)	47.89 (55.04)	55.56 (68.01)	38.32 (38.44)
5.	Thiophanate methyl 70% WP	48.76 (56.54)	53.44 (64.51)	58.78 (73.13)	67.71 (85.61)	57.17 (70.61)
6.	Hexaconazole 5% EC	53.76 (65.05)	54.09 (65.60)	57.29 (70.81)	72.51 (90.96)	59.41 (74.11)
7.	Azoxystrobin 23% EC	57.40 (70.97)	59.67 (74.49)	68.00 (85.97)	71.43 (89.85)	64.12 (80.95)
8	Picoxystrobin 25% EC	18.35 (9.91)	41.72 (44.30)	46.44 (52.50)	55.73 (68.29)	40.56 (42.28)
	Concentration mean	48.68 (56.41)	56.96 (70.27)	61.92 (77.85)	69.15 (87.34)	
		Fungicide (F)		Conc.(C)	F x C	
	S.Em. ±	0.37		0.26	0.73	
	CD at 5%	1.04		0.73	2.07	
	CV %	2.15				

*Mean of three repetition

Figures in parentheses are re-transformed value of arc sine

It is evident from the data presented in Table 2, that carbendazim 50% WP yielded no mycelial growth and gave cent per cent inhibition of pathogen, which was significantly superior to the rest of the treatments. This was followed by tebuconazole 25.9% EC (87.44%), azoxystrobin 23% EC (80.95%), hexaconazole 5% EC (74.11%), thiophanate methyl 70% WP (70.61%) and flusilazole 40% EC (66.36%). Whereas, picoxystrobin 25% EC (42.28%) and fosetyl-AL 80% WP (38.44%) found least effective fungicide in inhibiting the mean mycelia growth of *F. oxysporum* f. sp. *ricini*.

There was positive correlation between concentration and inhibition of growth of pathogen. It is also observed that with increasing concentration of all fungicides, inhibition of growth of pathogen also increased, except carbendazim (100 ppm) which give cent per cent inhibition at lower concentration. The tebuconazole 25.9% EC, azoxystrobin 23% EC, hexaconazole 5% EC, thiophanate methyl 70% WP, flusilazole 40% EC, picoxystrobin 25% EC and fosetyl-Al 80% WP showed 93.38, 89.85, 90.96, 85.61, 82.37, 68.29 and 68.01 per cent inhibition of mycelial growth at 1000 ppm, respectively which were higher than their lower concentration of 100, 250 and 500 ppm. In case of concentration mean, maximum growth inhibition of 87.34 per cent was recorded at 1000 ppm concentration and lowest was 56.41 per cent at 100 ppm.

The effectiveness of carbendazim 50% WP against *F. oxysporum* f. sp. *ricini* has been reported by Pushpavathi *et al.* (1998) [12] whereas against *F. oxysporum* has been reported by Mayur *et al*. (2001) [9]. Singh and Jha (2003) [14] and Podder *et al*. (2004) [11] reported carbendazim 50% WP effective against *F. oxysporum* f. sp. *ciceri.* The complete growth inhibition of *F. oxysporum* f. sp. *udum*, *F. oxysporum* f. sp. *cumini* and *F. solani* by carbendazim 50% WP has been reported by Raju *et al*. (2008), Gangopadhyay *et al*. (2009) and Bhaliya *et al*. (2014) [2], respectively. Chennakesavulu *et al.* (2013) recorded carbendazim 50% WP and tebuconazole 25.9% EC both effective against *Fusarium udum*.

3.3 *In vitro* evaluation of ready-mixed fungicides

Using the poisoned food technique, eight different fungicides were examined against pathogen for relative efficacy at four concentrations of 250, 500, 1000, and 1500 ppm. Table 3 showed the data on per cent mycelial growth inhibition. The results of the experiment showed that all selected fungicide combinations at all concentrations inhibited the radial growth of tested pathogen.

It is evident from the data presented in Table 3, that maximum mean per cent inhibition of *F. oxysporum* f. sp. *ricini* mycelial growth was recorded in carbendazim 12% + mancozeb 63% WP (88.33%) followed by carboxin 37.5% + thiram 37.5% WS (84.81%), tebuconazole 50% + trifloxystrobin 25% WG (83.51%), azoxystrobin 11% + tebuconazole 18.30% SC (82.28%) and mancozeb 40% + azoxystrobin 7% OS (80.34%). Whereas, cymoxanil 8% + mancozeb 64% WP (61.30%) and metiram 55% WG + pyraclostrobin 5% WG (56.81%) found moderately effective fungicide in inhibiting the mean mycelia growth of *F. oxysporum* f. sp. *ricini*. The least effective fungicide found was zineb 68% WP + hexaconazole 4% WP with mean mycelial growth inhibition of 47.39 per cent.

Table 3: Evaluation of ready-mixed fungicides on growth inhibition of *Fusarium oxysporum* f. sp. *ricini* under *in vitro* condition

Tr. No.	Fungicides	Growth inhibition (%)*				Mean growth inhibition (%)
		250 ppm	500 ppm	1000 ppm	1500 ppm	
1.	Azoxystrobin 11% + tebuconazole 18.30% SC	55.53 (67.97)	63.70 (80.37)	68.63 (86.72)	72.55 (91.00)	65.10 (82.28)
2.	Carbendazim 12% + mancozeb 63% WP	66.39 (83.96)	69.02 (87.18)	69.58 (87.83)	75.12 (93.41)	70.03 (88.33)
3.	Carboxin 37.5% + thiram 37.5% WP	66.32 (83.87)	66.95 (84.67)	67.34 (85.16)	67.64 (85.52)	67.06 (84.81)
4.	Cymoxanil 8% + mancozeb 64% WP	43.50 (47.39)	46.08 (51.89)	46.14 (51.99)	70.41 (88.76)	51.53 (61.30)
5.	Tebuconazole 50% + trifloxystobin 25% WG	61.92 (77.85)	63.39 (79.94)	65.35 (82.60)	73.51 (91.94)	66.04 (83.51)
6.	Zineb 68% WP + hexaconazole 4% WP	37.07 (36.33)	43.66 (47.67)	45.13 (50.23)	48.16 (55.51)	43.50 (47.39)
7.	Mancozeb 40% + azoxystrobin 7% OS	55.55 (68.01)	64.20 (81.06)	65.87 (83.29)	69.09 (87.26)	63.68 (80.34)
8	Metiram 55% WG + pyraclostrobin 5% WG	41.24 (43.46)	48.00 (55.23)	51.99 (62.08)	54.43 (66.16)	48.92 (56.81)
	Concentration mean	53.44 (64.52)	58.13 (72.12)	60.00 (75.01)	66.36 (83.92)	
		Fungicide (F)		Conc.(C)	F x C	
	S.Em. ±	0.34		0.24	0.67	
	CD at 5%	0.95		0.67	1.90	
	CV %	1.95				

*Mean of three repetition
Figures in parentheses are re-transformed value of arc sine

There was also found positive correlation between concentration and inhibition of growth of pathogen. It is also observed that with increasing concentration of all fungicides, inhibition of growth of pathogen also increased. carbendazim 12% + mancozeb 63% WP, carboxin 37.5% + thiram 37.5% WS, tebuconazole 50% + trifloxystrobin 25% WG, azoxystrobin 11% + tebuconazole 18.30% SC, mancozeb 40% + azoxystrobin 7% OS, cymoxanil 8% + mancozeb 64% WP, metiram 55% WG + pyraclostrobin 5% WG and zineb 68% + hexaconazole 4% WP at 1500 ppm concentration showed 93.41, 85.52, 91.94, 91.00, 87.26, 88.76, 66.16 and 55.51 per cent inhibition of mycelial growth, respectively which were higher as compared to their lower concentration of 250, 500, 1000 and 1500 ppm. In case of concentration mean, maximum growth inhibition of 83.92 per cent was recorded at 1500 ppm concentration and lowest was 64.52 per cent at 250 ppm.

Yadav (2009) [17] in *F. oxysporum* f. sp. *ciceri*, Raheja and Patel (2011) [13] in *Fusarium oxysporum* f. sp. *cumini*, Bhaliya *et al*. (2014) [2] in *Fusarium solani* and Jat and Ahir (2017) [7] in *Fusarium oxysporum* f. sp. *corianderii* recorded the combination of carbendazim 12% + mancozeb 63% WP as most effective in inhibiting mycelia growth of pathogen. Whereas Kala *et al*. (2013) [8] recorded carboxin + thiram effective against *F. oxysporum* f. sp. *ciceri*.

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