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In vitro efficacy of non-systemic and systemic fungicides against *Rhizoctonia solani* kühn causing root rot of coriander

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Abstract
The efficacy of different non-systemic and systemic fungicides were tested under *in vitro* conditions against *Rhizoctonia solani* Kühn causing root rot of coriander. All the fungicides tested were capable of inhibiting the mycelial growth of *R. solani* at various concentrations as compared to control. Mancozeb 75% WP among non-systemic fungicides exhibited the maximum mycelial growth inhibition of 99.98 per cent whereas, wettable sulphur 80% WP was the least effective fungicide with mean mycelial growth inhibition of 3.24 per cent. Benomyl 50% WP, carbendazim 50% WP and tebuconazole 25.9% EC among systemic fungicides gave maximum mycelial growth inhibition of 90.24, 83.83 and 81.70 per cent, respectively under laboratory conditions. Whereas, the least effective fungicide was thiophanate methyl 70% WP which was found at par with fosetyl-Al 80% WP with mean mycelial growth inhibition of 0.85 and 0.74 per cent, respectively.

Keywords: Coriander, root rot, *Rhizoctonia solani*, fungicides, mycelial growth inhibition

Introduction
Coriander (*Coriandrum sativam* L.) is one of the most important spice crops in the world belonging to the family *Apiaceae.* The crop is affected by many fungal diseases like, root rot (*Rhizoctonia solani*), wilt (*Fusarium oxysporum* f. sp. *corianderii*), powdery mildew (*Erysiphe polygoni*) and stem gall caused by *Protomyces macrosporus.* Among these, root rot of coriander caused by *Rhizoctonia solani* Kühn is appear regularly in various villages of Junagadh districts of Gujarat state in mild to moderate form and adversely affect the yield. Hence, an experiment was conducted to find out the most effective fungicides in inhibiting the mycelial growth at different concentrations in laboratory conditions.

Materials and methods
Evaluation of fungicides
In vitro evaluation of different fungicides against root rot of coriander caused by *Rhizoctonia solani* was carried out in Factorial Completely Randomized Design with three repetitions. Mycelial growth inhibition activities of different six non–systemic fungicides *viz*; Chlorothalonil 75% WP, Copper hydroxide 77% WP, Copper oxychloride 50% WP, Mancozeb 75% WP, Thiram 75% WP and Wettable sulphur 80% WP at 500 ppm, 1000 ppm, 1500 ppm and 2000 ppm concentrations and six systemic fungicides *viz*; Azoxystrobin 23% SC, Benomyl 50% WP, Carbendazim 50% WP, Fosetyl-Al 80% WP, Tebuconazole 25.9% EC and Thiophanate methyl 70% WP at 50 ppm, 100 ppm, 250 ppm and 500 ppm concentrations were tested against *R. solani* under *in vitro* condition by employing poisoned food technique of Bagchi and Das (1968) [2] using Potato Dextrose Agar (PDA) as a germinating medium. The measured quantity of each fungicides required were incorporated into autoclaved PDA medium before solidification. The poisoned medium were then poured into sterilized Petri dishes (90 mm dia.) in equal quantity (20 ml per Petri dish) to form a uniform layer.
These plates were then allowed to solidify. After solidification the plates were inoculated with an actively growing mycelial bit of 4 mm diameter of *R. solani* which was transferred under aseptic conditions over the solidified PDA medium. The mycelial disc was placed in the center of plates in an inverted position to make a direct contact with the poisoned medium. Then Petri dishes were incubated at 28± 2°C for 7 days and observations were recorded on radial growth of mycelium in treated and control plates. Inoculated Petri dishes containing PDA medium without fungicides were served as control.

The radial growth of the fungal colonies were measured from two different angles in millimeter (mm) and the average values were calculated. The per cent growth inhibition of the fungus in each treatment was calculated by using following formula (Vincent, 1947) [3].

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

Where, I = Percent inhibition of mycelial growth
C = Radial growth of fungus in control (mm)
T = Radial growth of fungus in treatment (mm)

Sclerotial formations were counted in fungal culture suspension under microscope at low power (10x). The fungal culture suspension was prepared by vigorously shaking the 4 mm mycelial disc of the fungus in 10 ml sterilized distilled water. The relative degree of sclerotial formation was recorded as below.

No. of sclerotia per microscopic field (10x)	Grade	Sign
0	Absent	-
1-4	Scanty	+
5-8	Moderate	++
9-15	Good	+++
>15	Abundant	++++

Results and discussion

In vitro evaluation of non-systemic fungicides against *R. solani*

The relative efficacy of six different non-systemic fungicides were tested at the concentration of 500, 1000, 1500 and 2000 ppm using poison food technique. The data of per cent inhibition of mycelial growth and sclerotial formation were presented in Table 1. Data presented in Table 1 revealed that mancozeb 75% WP was the most effective fungicide with 99.98 per cent mean mycelial growth inhibition and significantly superior over rest of the treatments. Wettable sulphur 80% WP was the least effective fungicide with mean mycelial growth inhibition of 3.24 per cent.

Among different non-systemic fungicides, mancozeb 75% WP gave 99.98 per cent mycelial growth inhibition at all concentrations (500, 1000, 1500 and 2000 ppm) which were the best treatments for inhibiting the growth of mycelium of *R. solani* under *in vitro* condition. Copper oxychloride 50% WP was found second best effective fungicide with 72.47 and 78.98 per cent inhibition at 1500 and 2000 ppm, respectively. Whereas, thiram 75% WP (23.97, 25.47, 40.07 and 62.98), chlorothalonil 75% WP (3.88, 9.62, 45.67 and 50.08); copper hydroxide 77% WP (0.40, 0.44, 0.52 and 28.76) and wettable sulphur 80% WP (0.48, 2.84, 3.89 and 5.76) exhibited per cent mycelial growth inhibition at 500, 1000, 1500 and 2000 ppm, respectively and were found least effective non-systemic fungicides.

The effect of different concentrations of non-systemic fungicides on sclerotial formation was found negatively correlated with the inhibition of growth. No sclerotial formation was found in any concentration of mancozeb. Whereas, abundant sclerotial formation were found in treatment of copper hydroxide 77% WP; wettable Sulphur 80% WP and chlorothalonil 75% WP at 500 and 1000 ppm. Good sclerotial formation was observed in the treatment of copper oxychloride 77% WP and thiram 75% WP at 1500 ppm concentration. While, scanty sclerotial formation was observed in copper oxychloride at 1500 and 2000 ppm concentration.

Similar type of findings was also reported by Anjana and Kumar (2008) [1] while working with various fungicides for control of *R. solani*. They concluded that mancozeb was superior to all others in inhibiting mycelia growth of the test fungus *R. solani* under *in vitro* condition.

Table 1: *In vitro* evaluation of non-systemic fungicides against *R. solani*

Fungicides	Per cent inhibition and sclerotial formation				Mean
	Concentration (ppm)				
	500	1000	1500	2000	
Chlorothalonil 75% WP	11.37 (3.88)	18.07 (9.62)	42.52 (45.67)	45.04 (50.08)	29.25 (27.49)
	++++	++++	+++	++	
Copper hydroxide 77% WP	1.08 (0.40)	2.91 (0.44)	3.09 (0.52)	32.43 (28.76)	9.87 (7.53)
	++++	++++	++++	++++	
Copper oxychloride 50% WP	11.03 (3.66)	39.64 (40.69)	58.36 (72.47)	62.77 (78.98)	42.95 (48.95)
	++++	+++	+	+	
Mancozeb 75% WP	89.62 (99.98)	89.62 (99.98)	89.62 (99.98)	89.62 (99.98)	89.62 (99.98)
	-	-	-	-	
Thiram 75% WP	29.32 (23.97)	30.30 (25.47)	39.27 (40.07)	52.53 (62.98)	37.85 (38.12)
	++++	++++	+++	++	
Wettable sulphur 80% WP	2.99 (0.48)	9.66 (2.84)	11.38 (3.89)	13.89 (5.76)	9.48 (3.24)
	++++	++++	++++	++++	
	Fungicides (F)	Concentration (C)	F x C		
S. Em. ±	0.45	0.37	0.91		
C. D. at 5%	1.29	1.05	2.58		
C.V. %	4.29				

Sclerotial formation

++++ = Abundant; +++ = good; ++ = moderate; + = scanty; - = no sclerotial formation.

- Values in parentheses are re-transformed values while outside were transformed with arcsine transformation before analysis.

1.	Chlorothalonil 75% WP
2.	Copper hydroxide 77% WP
3.	Copper oxychloride 50% WP
4.	Mancozeb 75% WP
5.	Thiram 75%WP
6.	Wettable sulphur 80% WP

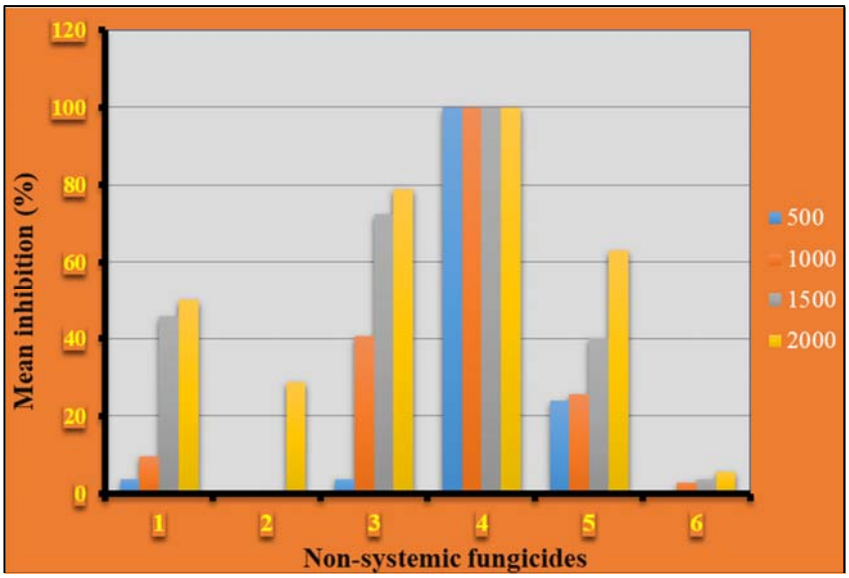

Fig 1: *In vitro* evaluation of non-systemic fungicides against *R. solani*

In vitro* evaluation of systemic fungicides against *R. solani

The relative efficacy of six different systemic fungicides was tested at the concentration of 50, 100, 250 and 500 ppm using poison food technique. The data on per cent inhibition of mycelial growth and sclerotial formation were presented in Table 2.

The data presented in Table 2 indicated that benomyl 50% WP was significantly superior over rest of the treatments with 90.24 per cent mean mycelial growth inhibition. Whereas, carbendazim 50% WP was the next best fungicide and found equally effective with tebuconazole 25.9% EC and showed 83.83 and 81.70 per cent mean mycelial growth inhibition, respectively. The least effective fungicide was thiophanate methyl 70% WP which was found at par with fosetyl-Al 80% WP with mean mycelial growth inhibition of 0.85 and 0.74 per cent, respectively.

Among different systemic fungicides tested *in vitro*, benomyl 50% WP found the best among all treatments and gave 87.31, 87.04, 87.75 and 99.88 per cent inhibition of growth of the fungus at 50, 100, 250 and 500 ppm concentrations, respectively, under *in vitro* condition. Second best effective treatment was carbendazim 50% WP (82.21, 83.24, 84.49 and 85.41) followed by tebuconazole 25.9% EC with 73.29, 81.42, 83.24 and 88.88 per cent inhibition of mycelial growth at 50, 100, 250 and 500 ppm concentrations, respectively.

Azoxystrobin 23% SC gave 97.77 per cent mycelial growth inhibition at 500 ppm. Whereas, same fungicide exhibited 1.62, 2.58 and 4.85 per cent mycelial growth inhibition at 50, 100, and 250 ppm, respectively. Thiophanate methyl 70% WP (0.35, 0.8, 0.98 and 1.30) and fosetyl-Al 80% WP (0.38, 0.8, 0.86 and 0.93) were equally effective in mycelial growth inhibition at 50, 100, 250 and 500 ppm, respectively and were least effective systemic fungicides.

Table 2: *In vitro* evaluation of systemic fungicides against *R. solani*

Fungicides	Per cent inhibition and sclerotial formation				Mean
	Concentration (ppm)				
	50	100	250	500	
Azoxystrobin 23% SC	7.29 (1.62)	9.08 (2.58)	12.70 (4.85)	81.41 (97.77)	27.62 (26.70)
	++++	++++	++++	-	
Benomyl 50% WP	69.14 (87.31)	68.93 (87.04)	69.83 (87.75)	83.94 (98.88)	72.96 (90.24)
	-	-	-	-	
Carbendazim 50% WP	65.05 (82.21)	66.17 (83.24)	66.79 (84.49)	67.56 (85.41)	66.39 (83.83)
	-	-	-	-	
Fosetyl-Al 80% WP	1.08 (0.38)	4.54 (0.80)	4.71 (0.86)	4.88 (0.93)	3.80 (0.74)
	++++	++++	++++	++++	
Tebuconazole 25.9% EC	58.90 (73.29)	64.49 (81.42)	65.87 (83.24)	70.53 (88.88)	64.94 (81.70)
	+	-	-	-	
Thiophanate-methyl 70% WP	1.08 (0.35)	4.56 (0.80)	5.00 (0.98)	5.72 (1.30)	4.09 (0.85)
	++++	++++	++++	++++	
	Fungicide (F)	Concentration (C)	F x C		
S. Em. ±	0.57	0.46	1.14		
C.D. at 5%	1.62	1.32	3.23		
C. V. %	4.92				

Sclerotial formation

++++ = Abundant; +++ = good; ++ = moderate; + = scanty; - = no sclerotial formation.

- Values in parentheses are re-transformed value while outside were transformed with arcsine transformation before analysis.

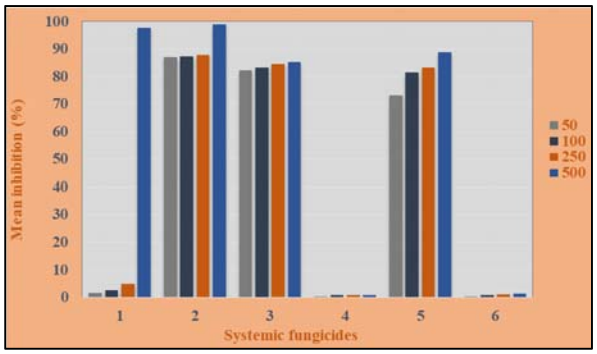

Fig 2: *In vitro* evaluation of systemic fungicides against *R. solani*

1.	Azoxystrobin 23% SC	4.	Fosetyl-Al 80% WP
2.	Benomyl 50% WP	5.	Tebuconazole 25.9% EC
3.	Carbendazim 50% WP	6.	Thiophanate methyl 70% WP

The effect of different concentrations of systemic fungicides on sclerotial formation was found negatively correlated with the inhibition of growth. No sclerotial formation was found at any concentrations of benomyl 50% WP and carbendazim 50% WP. Whereas, tebuconazole 25.9% EC at 100, 250 and 500 ppm and azoxystrobin 23% SC at 500 ppm form no any sclerotia. While, abundant sclerotial formation was found in all concentration of fosetyl-Al 80% WP and thiophanate methyl 70% WP as well as in azoxystrobin 23% SC at 50, 100, and 250 ppm. Scanty sclerotial formation was observed in tebuconazole 25.9% EC at 50 ppm concentration.

The present investigation was in close conformity with the similar type of findings reported by Wenham *et al*. (1976) [5] during their *in vitro* study. They reported benomyl as the best systemic fungicides for control of *R. solani* and were superior to all others in inhibiting mycelial growth of the test fungus *R. solani* under *in vitro*. Similarly, Wasira Akhter *et al*. (2015) [4] also reported bavistin 50% WP as the most effective fungicide with completely inhibiting the radial growth of *R. solani*, even at the lowest concentration (100 ppm).

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