LR-5325
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RESEARCH ARTICLE
Legume Research- An International Journal

Integrated Management of Stem and Root Rot of Cowpea Caused by *Macrophomina phaseolina* (Tassi.) Goid. using Fungicides, Bioagents and Organic Manures

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10.18805/LR-5325

ABSTRACT

Background: Cowpea crop is affected by various biotic and abiotic stresses which are responsible for its poor quality and low yield resulting in severe economic losses. Among the root diseases, stem and root rot caused by *Macrophomina phaseolina* is an important disease causing the yield losses ranging from 50-55 per cent. So, there is a need to formulate suitable management practices against root rot.

Methods: Field experiment was laid-out in a randomized complete block design with three replications at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad during *rabi* 2021-22 and 2022-23 to determine the efficacy of economically viable and effective fungicides, bioagents and organic manures against stem and root rot of cowpea. The per cent disease incidence and yield per hectare were taken into consideration for statistical analysis.

Result: In laboratory experiments, it was found that, the seed dressing fungicides mancozeb 50% + carbendazim 25% WP and carboxin 37.5% + thiram 37.5% DS were the most effective against *M. phaseolina*. Similarly, among the bioagents tested, *T. harzianum* was the most effective followed by *T. Viride* and *P. fluorescens*. A two-years evaluation of nine integrated treatment modules for *rabi* seasons revealed that, seed treatment with carboxin 37.5% + thiram 37.5 % WS resulted in the lowest disease incidence and the highest grain yield, 100 seed weight and B:C ratio. Cowpea stem and root rot incidence was increased with soil temperature and decreased with soil moisture.

Key words: Cowpea, Fungicides, *Macrophomina phaseolina*, Stem and root rot.

INTRODUCTION

Cowpea (*Vigna unguiculata* L.) is one of the most ancient human food sources and short duration multipurpose pulse crop grown extensively in tropical and subtropical countries. It belongs to the family Fabaceae. Cowpea forms an important component of farming system, it fits well in a variety of cropping systems and is grown as a cover crop, mixed crop, catch crop or green manure crop in different states of India (Alexandre *et al*., 2016). Cowpea is grown across the world on an estimated 23.4 mha with a production of 18.29 mt and productivity of 637 kg/ha. In India cowpea is grown in an area of 4.00 mha with a production of 2.70 mt and productivity of 567 kg/ha (FAO, 2020). The cowpea crop is affected by number of fungal, bacterial and nematode diseases. Among Stem and root rot incited by *Macrophomina phaseolina* (Tassi.) Goid. has been rated as most devastating disease of cowpea which can cause yield loss up to 5 to 39 per cent (Mohanapriya *et al*., 2017; Gireesha *et al*., 2023). On cowpea, disease symptoms are clearly visible from the time of emergence and can be evaluated at various stages of development of the plant. In grown up plants, *M. phaseolina* causes lesions on stems, spikes, pods and seeds. On stems, lesions are beige and appear at the ramification point of lateral secondary branches. Colonized tissues become gray and covered with abundant minute black punctuations. Initially these punctuations are immersed, becoming gradually more prominent (Bouhot, 1967; Adam, 1986). The most striking symptom is the sudden wilting and drying of the whole plant while most of the leaves remain green. The stem and branches are then covered with black bodies and give the charcoal or ashy appearance of dead plants

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How to cite this article: Gireesha, D., Prabhu, H.V., Patil, P.V., Gowda, G.R.V., Deshpande, S.K., Vijaykumar, K.N. and Doggalli, G. (2024). Integrated Management of Stem and Root Rot of Cowpea Caused by *Macrophomina phaseolina* (Tassi.) Goid. using Fungicides, Bioagents and Organic Manures. Legume Research. DOI: 10.18805/LR-5325.

Submitted: 26-03-2024 **Accepted:** 12-06-2024 **Online**: 03-07-2024

(Chan and Sackston, 1973). Withering can be observed from seedling to maturity stage and is the result of necrosis of roots, stems and mechanical plugging of xylem vessels by microsclerotia, but also by toxin production and enzymatic action (Kuti *et al*., 1997; Jones and Wang, 1997).

The fungus invades host both inter and intracellularly, it produces numerous microsclerotia on host tissue, which measure about 110-130 µ in diameter. Often the conidial or pycnidial stage is produced on the host (Nitharwal, 2019). The fungus is mainly a soil dweller and spreads from plant to plant through irrigation water, implements and cultural operation. The sclerotia and pycnidiospore may also become air borne and cause further spread of the pathogen (Rangaswami and Mahadevan, 2008). With the view to manage stem and root rot disease of cowpea, studies on different aspects comprising of disease management components such as testing of fungicides and biocontrol agents under *in vitro* was carried out by Singh and Srivastava (1988). A review of literature revealed that very limited information is available on management of this disease. By considering the increasing incidence of stem and root rot of cowpea and the economic losses caused by the disease, the present investigation was carried out to formulate suitable management practices against stem and root rot.

MATERIALS AND METHODS

Preparation of giant culture of *Macrophomina phaseolina*

The pathogen, *M. phaseolina* was isolated from the stem and root rot infected cowpea plants collected from experimental plots of Department of Plant Pathology at Main Agricultural Research Station (MARS), University of Agricultural Sciences (UAS), Dharwad, Karnataka by tissue segment method on potato dextrose agar (PDA) medium. Sorghum seeds were used as substrate for giant culture preparation. The substrate was prepared by mixing 200 g of crushed sorghum seeds and 50 ml distilled water in 500 ml conical flask and sterilized at 15 psi for one hour for two consecutive days. Flasks was subsequently inoculated with 4-5 discs of seven days old culture of *M. phaseolina* and incubated at 28±1°C for 20 days (Choudhary *et al*., 2011). During incubation, the culture was mixed thoroughly to get uniform growth.

In vitro evaluation of fungicides

The efficacy of different seed dressing fungicides *viz*.,Carbendazim 50% WP, Captan 50% WP, Tebuconazole 5.4% w/w FS, Mancozeb 50% + Carbendazim 25% WP, Captan 70% + Hexaconazole 5% WP, Carboxin 37.5% + Thiram 37.5% DS, Thiophanate Methyl 45% + Pyraclostrobin 5% FS, Penflufen 13.28% w/w + Trifloxystrobin 13.28% w/w FS and Mancozeb 75% WP were tested under *in vitro* condition by poisoned food technique (Nene and Thapliyal, 1973) at 0.1, 0.2 and 0.25 per cent concentrations. Similarly, control was maintained by placing a mycelia disc of the pathogen at the centre of Petri plate containing the medium without any fungicide. The per cent inhibition of mycelial growth was calculated using the formula given by Vincent (1947).

The diameter of fungal colony was measured in each of the treatment when the pathogen growth in control plate was full. The colony diameter inhibited in fungicide treated plates as compared to control was taken as a measure of fungi toxicity. Per cent inhibition over control was calculated as per the formula given by Vincent (1947).

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

Where,
I= Per cent inhibition.
C= Colony diameter in control (mm),
T= Colony diameter in treatment (mm).

In vitro evaluation of biocontrol agents

The efficacy of available fungal and bacterial biocontrol agents *viz*., *Trichoderma harzianum*, *Pseudomonas flourescens* and *Bacillus subtilis* collected from the Institute of Organic Farming (IOF), University of Agricultural Sciences, Dharwad and *Trichoderma viride* from Multiplex Nisarga Company were evaluated under *in vitro* conditions against mycelial growth of *M. phaseolina* by dual culture technique (Dennis and Webster, 1971). Similarly, control was maintained by placing mycelia disc of the test fungus at the centre of Petri plate containing the medium devoid of any biocontrol agents. Percentage inhibition of mycelial growth was calculated as per Vincent (1947) formula.

Observations on colony diameter were recorded when the control plates were fully covered by pathogen and per cent mycelial growth inhibition was calculated as per the formula given by Vincent (1947) as discussed earlier.

Integrated disease management

Field experiment on integrated management of stem and root rot of cowpea was conducted at MARS, University of Agricultural Sciences, Dharwad during *rabi* 2021-22 and 2022-23 by using *in vitro* effective fungicides and biocontrol agents along with organic manures. The experiment was laid out in randomized complete block design (RCBD) with nine treatment schedules including untreated control and three replications. Cowpea variety C-152 was sown at 45 cm × 20 cm spacing with plot size of 2.25 m × 4 m and all the recommended package of practices was followed to raise the crop, except for disease management. Before sowing all the seed furrows were uniformly applied with mass multiplied inoculum of *M. phaseolina* on sterilized sorghum grain medium and the details of the treatments are given in Table 3.

In the field experiment, observations on seedling emergence at 10 days after sowing (DAS) was recorded by counting the number of seeds germinated and total number of seeds sown and per cent seedling emergence was calculated by the following formula:

Per cent seedling emergence =

$$\frac{\text{No. of seeds germinated}}{\text{Total number of seeds sown}} \times 100$$

Disease incidence was recorded at 30, 60 and 75 DAS by counting the total number of plants and number of plants infected and per cent disease incidence at all the above stages of plant growth was calculated by the following formula:

Per cent disease incidence (PDI) =

$$\frac{\text{No. of plants infected}}{\text{Total no. of plants}} \times 100$$

The plots were harvested separately and grain yield was recorded and further converted to quintal per hectare (q/ha). The grains collected from each treatment separately and hundred seed weight was recorded by using digital electronic balance.

The cost of production was analyzed in order to find out the most economic treatment of different management practices. Cost and return analysis were done according to the procedure of Kushwah *et al*. (2017) and Bhupender *et al*. (2020). The benefit cost ratio (BCR) was calculated as follows:

$$\text{Benefit cost ratio} = \frac{\text{Gross return per ha}}{\text{Total cost of production per ha}}$$

Effect of soil temperature and soil moisture on disease development

Observations on soil temperature and soil moisture were noted down from flowering to harvesting stage *i.e.* from 40 DAS to 90 DAS at 10 days' interval (40, 50, 60, 70, 80 and 90 DAS) in untreated check plots (T_9) in integrated disease management treatment plots. All the three replications were considered for taking observations and the mean was calculated. Then the data were analyzed statistically. Soil temperature was recorded by using soil thermometer and soil moisture was estimated by digital soil moisture meter (Lutron PMS 714). The correlation was made between the soil temperature, soil moisture and per cent disease incidence of untreated check.

Data analysis

Data was analysed as per the procedures given by Panse and Sukhatme (1978). Data in percentage was converted to angular transformed values and $\sqrt{(X + 1)}$ values, before analysis (Walter, 1967). Analysis of variance and least significance difference (LSD) were determined at 5 and 1 per cent probability. Treatment means were compared using LSD to determine efficacy of different treatments.

RESULTS AND DISCUSSION

In vitro assay of seed dressing fungicides against *Macrophomina phaseolina*

Significantly maximum mean inhibition of mycelial growth of *M. phaseolina* was observed in mancozeb 50% + carbendazim 25% WP (97.59%) which was on par with carboxin 37.5% + thiram 37.5% DS (97.48%) followed by carbendazim 50% WP (92.44%) and tebuconazole 5.4% w/w FS (90.32%). Lowest mycelial inhibition of 60.85 per cent was recorded in captan 50% WP. Among the different concentration tested, maximum mycelial inhibition of 90.26 per cent was noticed in 0.25 per cent concentration and was significantly superior over 0.2 (84.09%) and 0.1 (79.33%) per cent concentrations (Table 1).

The findings align with previous research conducted by Nitharwal (2019), Pathak *et al.* (2019) and Kumari *et al.* (2022). Maruti *et al.* (2017), who reported that carbendazim 12 % + mancozeb 63 % WP and carboxin 37.5% + thiram 37.5% WP demonstrated complete inhibition of *R. bataticola* at all concentrations tested. Similarly, Sangappa and Mallesh (2016) also observed that carbendazim 12% + mancozeb 63% exhibited complete inhibition of mycelial growth at various concentrations, specifically at 0.05, 0.10 and 0.2 per cent. These consistent findings underscore the effectiveness of these fungicidal combinations against the pathogen.

In vitro assay of bioagents against *Macrophomina phaseolina*

In vitro evaluation of bioagents by dual culture technique revealed that there is significant difference in per cent mycelial growth inhibition of *M. phaseolina* by different bioagents tested. Maximum mycelial growth inhibition of 75.53 per cent was noticed with *Trichoderma harzianum* followed by *T. viride* (67.72%) and *Pseudomonas fluorescens* (61.41%). The least mycelial growth inhibition of 56.00 per cent was recorded with *Bacillus subtilis* (Table 2).

The results are in accordance with Kumar and Kelaiya (2021), Gajera *et al.* (2012) who evaluated the *in vitro* potentialities of *Trichoderma species* against *M. phaseolina*. The maximum growth inhibition of test pathogen was observed by antagonist *T. koningi* (74.3%) followed by *T. harzianum* (61.4%). Microscopic study showed that these two antagonists were capable of overgrowing and degrading the mycelium of *M. phaseolina,* coiling around the hyphae with apressoria and hook-like structures. The specific activities of cell wall degrading enzymes such as chitinase, β-1, 3 glucanase, protease and cellulase were also recorded (Silva *et al*., 2004 and Mukherjee *et al*., 2003). Rathore1 *et al.* (2020) and Lakhran and Ahir (2022) also reported the effectiveness of *T. Viride, Bacillus subtilis* and *Pseudomonas fluorescence* on radial growth of *M. phaseolina*.

Table 1: *In vitro* assay of seed dressing fungicides against *M. phaseolina*.

Contact fungicides	Per cent inhibition of mycelial growth			
	Concentration (%)			Mean
	0.1	0.2	0.25	
Captan 50% WP	55.29 (48.02)*	57.57 (49.33)	69.69 (56.57)	60.85[g] (51.25)
Penflufen 13.28% w/w + Trifloxystrobin 13.28% w/w FS	80.35 (63.66)	86.63 (68.52)	95.41 (77.60)	87.46a[d] (69.24)
Captan 70% + Hexaconazole 5% WP	71.10 (57.46)	76.04 (60.67)	78.90 (62.63)	75.35[f] (60.21)
Mancozeb 50% + Carbendazim 25% WP	92.78 (74.39)	100.00 (89.96)	100.00 (89.96)	97.59[a] (81.05)
Carbendazim 50% WP	86.75 (68.62)	90.59 (72.11)	100.00 (89.96)	92.44[b] (74.02)
Carboxin 37.5% + Thiram 37.5% DS	92.43 (74.00)	100.00 (89.96)	100.00 (89.96)	97.48[a] (80.83)
Tebuconazole 5.4% w/w FS	85.88 (67.90)	87.45 (69.22)	97.65 (81.14)	90.32[c] (71.85)
Thiophanate Methyl 45% + Pyraclostrobin 5% FS	69.41 (56.40)	74.12 (59.40)	81.18 (64.26)	74.90 [f](59.91)
Mancozeb 75% WP	80.00 (63.41)	84.43 (66.73)	89.53 (71.09)	84.65[e] (66.91)
Mean	79.33 (62.93)	84.09 (66.47)	90.26 (71.79)	84.56 (66.84)
	S.Em.±		**C.D. @ 1%**	
Fungicide (F)	0.30		1.13	
Concentration (C)	0.17		0.65	
F×C	0.51		1.96	

*Angular transformed values.

Table 2: *In vitro* assay of bioagents against *M. phaseolina.*

Bioagents	Per cent inhibition of mycelial growth
Trichoderma harzianum	75.53[a] (60.33)*
Trichoderma viride	67.72[b] (55.35)
Pseudomonas fluorescens	61.41[c] (51.58)
Bacillus subtilis	56.00[d] (48.43)
S.Em.±	0.55
C.D. @ 1%	2.25

*Arcsine values.

Integrated management of stem and root rot of cowpea

Among the nine integrated treatment modules evaluated during *rabi* 2021-22 and 2022-23 revealed that, seed treatment with carboxin 37.5% + thiram 37.5% WS @ 2g/kg seeds (T_1) recorded significantly highest seed germination (95.17%), least per cent disease incidence (14.46) with highest grain yield (13.35 q/ha) and 100 seed weight (11.47 g). The treatment T_1 was on par with the treatment T_2 involving seed treatment with mancozeb 50% + carbendazim 25% WS @ 2 g/kg seeds (94.83% seed germination) (16.18 PDI) (12.67 q/ha) (10.88 g). Lowest per cent seed germination (78.00), highest per cent disease incidence (55.58), least grain yield (4.37 q/ha) and 100 seed weight (5.86 g) was recorded in untreated control (T_9) (Table 3a and 3b). Assessing the cost-benefit ratio is a crucial element of managing plant diseases economically. The findings in the table indicate that the highest benefit-to-cost ratio of 2.78 was achieved through the application of carboxin 37.5% + thiram 37.5% DS at a rate of 2 g/kg of seeds (T_1 treatment). Following closely was the seed treatment with Mancozeb 50% + Carbendazim 25% WP at the same application rate (T_2), which is of 2.66. In contrast, the untreated control (T_9) had the lowest cost-benefit ratio of 0.76.

The outcomes align with the findings of Jambhulkar *et al.* (2015), Nagamani *et al.* (2011) and Kullalli (2019). A research conducted by Sunkad *et al.* (2018), where it was reported that seed treatment involving Mancozeb 50% + Carbendazim 25% WS @ 3.5 g/kg, followed by soil drenching with the same fungicide (3 g/L), achieved the most substantial reduction in dry root rot incidence in chickpea, with the highest seed yield and a test weight. In a field study on integrated management of dry root rot in cowpea caused by *Rhizoctonia bataticola*, dry seed dressing with carbendazim was found most effective followed by seed treatment and soil application of *T. viride* combined with *P. fluorescens* enriched with FYM (Koli, 2019). Under field conditions, maximum root rot (*M. phaseolina*) reduction (83.76%) with highest pod yield of chickpea (19.5 q/ha) and net return (Rs 39,826/ha) was recorded in treatment involving seed treatment with tebuconazole 50% + trifloxystrobin 25% WG @ 1.5 g/kg along with soil application of *T. harzianum* @ 10 kg/ha (Malagi *et al*., 2023). Seed treatment with *P. flourescens* (10 g/kg) and soil application of neem cake (2.5 kg/ha) recorded the least

Table 3a: Integrated management of stem and root rot of cowpea.

Treatments	Per cent seed germination				Per cent disease incidence (PDI)			
	Rabi 2021-22	*Rabi* 2022-23	Pooled	Per cent increase over control	*Rabi* 2021-22	*Rabi* 2022-23	Pooled	Per cent reduction over control
T_1: Seed treatment with Carboxin 37.5% + Thiram 37.5% DS @ 2 g/kg of seeds.	96.00^{a} (78.43)*	94.33^{a} (76.20)	95.17^{a} (77.27)	19.27	13.58^{g} (21.64)	15.33^{g} (23.06)	14.46^{h} (22.34)	73.99
T_2: Seed treatment with Mancozeb 50% + Carbendazim 25% WP @ 2 g/kg of seeds.	95.00^{ab} (77.05)	94.67^{a} (76.62)	94.83^{a} (76.83)	18.98	15.34^{g} (23.07)	17.02^{g} (24.37)	16.18^{h} (23.71)	70.89
T_3: Seed treatment with *T. harzianum* @ 10 g/kg of seeds	88.00^{ef} (69.70)	89.33^{b} (70.91)	88.67^{de} (70.3)	13.35	36.23^{bc} (37.02)	39.42^{bc} (38.91)	37.83^{c} (37.94)	31.94
T_4: Seed treatment with *P. fluorescens* @ 10 g/kg of seeds	87.33^{f} (69.12)	88.33^{b} (70.00)	87.83^{e} (69.56)	12.53	39.19^{b} (38.78)	43.09^{b} (41.05)	41.14^{b} (39.88)	25.98
T_5: Seed treatment with *T. harzianum* (10 g/kg seeds) + soil application of FYM based *T. harzianum* (1 Kg *T. harzianum* + 100 Kg FYM) @ 500 kg/ha.	93.33^{bc} (75.01)	92.00^{ab} (73.54)	92.67^{bc} (74.26)	17.09	23.65^{e} (29.11)	25.65^{ef} (30.44)	24.65^{f} (29.76)	55.65
T_6: Seed treatment with *P. fluorescens* (10 g/kg seeds) + soil application of FYM based *P. fluorescens* (1 Kg *P. Fluorescens* + 100 Kg FYM) @ 500 kg/ha.	90.67^{de} (72.18)	89.67^{b} (71.22)	90.17^{de} (71.70)	14.79	32.95^{c} (35.05)	34.56^{cd} (36.03)	33.76^{d} (35.51)	39.26
T_7: Seed treatment with *T. harzianum* (10 g/kg seeds) + soil application of vermicompost based *T. harzianum* (1 Kg *T. harzianum*+100 Kg vermicompost) @ 500 kg/ha.	94.33^{ab} (76.20)	92.33^{ab} (73.9)	93.33^{ab} (75.01)	17.68	19.84^{f} (26.46)	21.54^{f} (27.67)	20.69^{g} (27.05)	62.77
T_8: Seed treatment with *P. fluorescens* (10 g/kg seeds) + soil application of vermicompost based *P. fluorescens* (1 Kg *P. fluorescens* + 100 Kg vermicompost) @ 500 kg/ha	91.00^{cd} (72.51)	90.67^{ab} (72.18)	90.83^{cd} (72.35)	15.42	28.44^{d} (32.24)	30.20^{de} (33.35)	29.32^{e} (32.77)	47.25
T_9: Untreated control	78.00^{g} (62.00)	75.67^{c} (60.42)	76.83^{f} (61.2)	-	53.41^{a} (46.98)	57.75^{a} (49.48)	55.58^{a} (48.18)	-
S.Em.±	0.84	1.47	0.77		0.70	1.06	0.55	
C.D. @ 5%	2.51	4.41	2.31		2.09	3.16	1.65	

*Arcsine values

Table 3b: Integrated management of stem and root rot of cowpea.

Treatments	Grain yield (q/ha)				100 seed weight (g)				BC ratio
	Rabi 2021-22	*Rabi* 2022-23	Pooled	Per cent increase over control	*Rabi* 2021-22	*Rabi* 2022-23	Pooled	Per cent increase over control	
T_1: Seed treatment with Carboxin 37.5% + Thiram 37.5% DS @ 2 g/kg of seeds	13.68^{a}	13.02^{a}	13.35^{a}	67.27	12.43^{a}	10.5^{a}	11.47^{a}	48.90	2.78
T_2: Seed treatment with Mancozeb 50% + Carbendazim 25% WP @ 2 g/kg of seeds	13.02^{a}	12.32^{a}	12.67^{ab}	65.51	11.72^{a}	10.05^{ab}	10.88^{a}	46.16	2.66
T_3: Seed treatment with *T. harzianum* @ 10 g/kg of seeds	6.85^{de}	6.61^{de}	6.73^{ef}	35.03	7.86^{de}	6.6^{de}	7.23^{d}	18.97	1.37
T_4: Seed treatment with *P. fluorescens* @ 10 g/kg of seeds	6.06^{de}	6.08^{de}	6.07^{fg}	27.99	7.15^{e}	6.05^{de}	6.6^{de}	11.21	1.21
T_5: Seed treatment with *T. harzianum* (10 g/kg seeds) + soil application of FYM based *T. harzianum* (1 Kg *T. harzianum* + 100 Kg FYM) @ 500 kg/ha	10.2^{bc}	9.47^{bc}	9.83^{cd}	55.56	9.86^{bc}	9.69^{ab}	9.78^{b}	40.06	1.93
T_6: Seed treatment with *P. fluorescens* (10 g/kg seeds) + soil application of FYM based *P. fluorescens* (1 Kg *P. Fluorescens* + 100 Kg FYM) @ 500 kg/ha	7.95^{cd}	7.45^{cd}	7.7^{ef}	43.25	9.04^{cd}	7.71^{cd}	8.37^{c}	30.02	1.51
T_7: Seed treatment with *T. harzianum* (10 g/kg seeds) + soil application of vermicompost based *T. harzianum* (1Kg *T. Harzianum* + 100 Kg vermicompost) @ 500 kg/ha	11.6^{ab}	10.6^{ab}	11.1^{bc}	60.64	12.08^{a}	11.4^{a}	11.74^{a}	50.09	1.95
T_8: Seed treatment with *P. fluorescens* (10 g/kg seeds) + soil application of vermicompost based *P. fluorescens* (1 Kg *P. Fluorescens* + 100 Kg vermicompost) @ 500 kg/ha	8.61^{cd}	8.49^{bcd}	8.55^{de}	48.91	10.83^{ab}	8.37^{bc}	9.6^{b}	38.95	1.50
T_9: Untreated control	4.65^{e}	4.08^{e}	4.37^{g}	-	6.29^{e}	5.43^{e}	5.86^{e}	-	0.76
S.Em.±	0.82	0.80	0.67		0.51	0.54	0.35		
C.D. @ 5%	2.45	2.39	2.01		1.54	1.63	1.04		

Cost of seeds @ Rs. 5500/q, Cost of fungicides/bioagents in Rs./kg: Carboxin 37.5%+ Thiram 37.5% WS (2130), Mancozeb 50% + Carbendazim 25% WS (1276), *T. harzianum* (130), *P. fluorescens* (150), FYM (1.5) vermicompost (8). *Angular transformed values.

Table 4: Effect of soil temperature and soil moisture on stem and root rot incidence.

Days after sowing	Soil temperature (°C)	Soil moisture (%)	Per cent disease incidence
40	25.00	58.65	3.08
50	30.00	53.21	7.34
60	27.00	47.95	9.01
70	30.00	38.27	17.20
80	32.00	34.01	37.67
90	36.00	27.71	46.15

Table 5: Correlation of soil temperature and soil moisture with disease development.

	Soil temperature (°C)	Soil moisture (%)	Per cent disease incidence
Soil temperature (°C)	1		
Soil moisture (%)	-0.885**	1	
Per cent disease incidence	0.909**	-0.941**	1

**Significant at 1%.

root rot (*M. phaseolina*) incidence in cowpea (Vengadeshkumar *et al*., 2019).

Effect of soil temperature and soil moisture on disease development

The incidence of stem and root rot of cowpea with respect to variation in soil temperature and moisture was noted down from 40 DAS to 90 DAS in untreated control plots. The results indicated that there was increased incidence of disease due to increased soil temperature coupled with optimum soil moisture. Soil temperature of 36°C coupled with soil moisture of 29.88 per cent was most favourable for *M. phaseolina* infection which resulted in maximum disease incidence of 46.65 per cent (Table 4). Correlation studies was made between soil temperature, soil moisture and disease incidence. Results revealed that significant positive correlation (0.939) was observed between high soil temperature and disease incidence whereas, negative correlation (-0.995) was noticed with high soil moisture and disease incidence (Table 5).

The results were in conformity with Bashir (2017), Arora and Pareek (2013). Sharma and Pandey (2013) reported that rate of infection increases with higher soil temperature and low soil moisture because hot and dry soil conditions resulted into pathogen grow faster and produce large amount of microsclerotia that causes more infection.

CONCLUSION

Among the seed dressing fungicides evaluated against *M. phaseolina*, mancozeb 50% + carbendazim 25% WP and carboxin 37.5% + thiram 37.5% DS were found most effective. Among the bioagents tested, *T. harzianum* was the most effective in inhibiting the mycelial growth of *M. phaseolina* followed by *T. viride* (67.72%) and *P. fluorescens* (61.41 %). Among the nine integrated treatment modules evaluated during *rabi* 2021-22 and 2022-23 revealed that, seed treatment with carboxin 37.5% + thiram 37.5% WS @ 2 g/kg seeds (T1) recorded significantly least per cent disease incidence (14.46) with highest grain yield (13.35 q/ha) and 100 seed weight (11.47 g) with B:C ratio of 2.78.

Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

Adam, T. (1986). Contribution à la connaissance des maladies du niébé [*Vigna unguiculata* (L.) Walp.] au Niger avec mention spéciale au *Macrophomina phaseolina* (Tassi) Goid. Université de Renne I. Thèse de doctorate, pp-117.

Alexandre, G., Piebiep, G., Ana, B., Rau, D., Henriquem, T., Eduardo, R., Luis, F., Miguel, R. (2016). Cowpea [*Vigna unguiculata* (L.) Walp], a renewed multipurpose crop for a more sustainable agri food system: Nutritional advantages and constraints. Journal of Food Science and Agriculture. 96(9): 2941-2951.

FAO, (2020). World Food and Agriculture-Statistical Yearbook. pp-43-57. http://www.fao.org/faostat/en/#data.

Arora, M., Pareek, S. (2013). Effect of soil moisture and temperature on the severity of *Macrophomina* charcoal rot of sorghum. Indian Journal of Scientific Research. 4(1): 155-158.

Bashir, M.R. (2017). Impact of global climate change on charcoal rot of sesame caused by *Macrophomina phaseolina*. Journal of Horticulture. 4(1): 100-106.

Bhupender, K.A., Kumari, K., Kumari, S., Singh, K.M. (2020). An economic analysis of production and marketing of clusterbean in Rajasthan. Multilogic in Science. 10(35): 1210-1216.

Bouhot D. (1967). Étude du *Macrophomina phaseoli* sur arachide. Journal of Tropical Agriculture. 22: 1165-1171.

Choudhary, S., Choudhary, A.K., Sharma, O.P. (2011). Screening of mungbean (*Vigna radiata)* genotypes to identify source of resistant to dry root rot. Journal of Food Legumes. 24(2): 117-119.

Chan, Y.H., Sackston, W.E.,(1973). Non-specificity of the necrosis inducing toxin of Sclerotium bataticola. Canadian Journal of Botany. 51: 690-692.

Dennis, C., Webster, J. (1971). Antagonistic properties of species group of *Trichoderma* III hyphal interaction. Transactions of British Mycological Society. 57: 363-369.

Gajera, H.P., Bambharolia, R.P, Patel, S.V., Khatrani, T.J., Goalkiya, B.A. (2012). Antagonism of *Trichoderma* spp. against *Macrophomina phaseolina*: Evaluation of coiling and cell wall degrading enzymatic activities. Journal of Plant Pathology and Microbiology. 3: 7. doi: 10.4172/2157-7471.1000149.

Gireesha, D., Virupaksha, P.H., Patil, P.V., Deshpande, S.K., Hosmath, J.A. (2023). Identification of resistant sources to stem and root rot of cowpea (*Vigna unguiculata* L.) caused by *Macrophomina phaseolina* (Tassi) Goid. The Pharma Innovation Journal. 12(11): 1467-1470.

Jambhulkar, P.P., Sharma, P., Meghwal, M.L. (2015). Additive effect of soil application with *Trichoderma* enriched FYM along with seed treatment and drenching with *Trichoderma* formulation for the management of wet root rot caused by *Rhizoctonia solani* in chickpea. Journal of Pure and Applied Microbiology. 9(1): 1-8.

Jones, R.W., Wang, H.Y. (1997). Immunolocalization of a beta-1,4-endoglucanase from *Macrophomina phaseolina* expressed in planta. Canadian Journal of Microbiology. 43: 491-495.

Koli, K. (2019). Studies on dry root rot of cowpea [*Vigna unguiculata* (L.) Walp.] incited by *Rhizoctonia bataticola* (Taub.) Butler. M.Sc (Agri.) Thesis, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, Madhya Pradesh (India).

Kullalli, K. (2019). Studies on stem and root rot of sesame caused by *Macrophomina phaseolina* (Tassi) Goid. M.Sc. (Agri.) Thesis, University of Agricultural Sciences, Dharwad (India).

Kumar, M.B., Kelaiya, S.D. (2021). *In vitro* Efficacy of different bioagents against dry root rot disease of groundnut. International Journal of Current Microbiology and Applied Sciences. 10(6): 451-457.

Kumari, N., Meena, A.K., Godara, S.L., Gahlot, V.S., Reddy, K.D.S. (2022). Evaluation of bio-agents, botanicals and fungicides under *in vitro* conditions against *Macrophomina phaseolina* (Tassi) Goid causing charcoal rot of cowpea. Biological Forum. 14(2): 84-90.

Kushwah, A.S., Rawat, G.S., Gupta, S., Patil, D., Prajapati, N. (2017). Production and profitability assessment of clusterbean [*Cyamopsis tetragonoloba* (L.) Taub.] based intercropping systems under different row arrangement. Legume Research. 40(5): 916-919. doi: 10.18805/LR-3809.

Kuti, J.O., Schading, R.L., Latigo, G.V., Braford, J.M. (1997). Differential responses of guayule (*Parthenium argentatum* Gray) genotypes to culture filtrate and toxin from *Macrophomina phaseolina* (Tassi) Goidanich. Journal of Phytopathology. 145: 305-311.

Lakhran, L., Ahir, R.R. (2022). Evaluation of fungicides, plant extracts and bio-agents against dry root rot of chickpea (*Cicer arietinum*). Indian Journal of Agricultural Sciences. 92(1): 36-49.

Malagi, N.C., Kumhar, D.R., Yadav, A.L., Kumar, V., Kumar, R., Choudhary, A., Mimrot, M.K. (2023). Screening of different bioagents and fungicides against dry root Rot of chickpea incited by *Macrophomina phaseolina* (Tassi) goid. Agricultural Science Digest. 1(8). doi: 10.18805/ag.D-5649.

Maruti, S.A.S., Sunkad, G., Mahalinga, D., Patil, M.G. (2017). Incidence of dry root rots of pigeon pea in North Eastern Karnataka, India. International Journal of Current Microbiology and Applied Science. 6(11): 1071-1078.

Mohanapriya, R., Naveenkumar, R., Balabaskar, P. (2017). Survey, virulence and pathogenicity of root rot incidence of cowpea in selected districts of Tamil Nadu caused by *Macrophomina phaseolina* (Tassi.) goid. International Journal of Current Microbiology and Applied Science. 6: 694-705.

Mukherjee, P.K., Latha, J., Hadar, R., Horwitz, B.A. (2003). TmkA, a mitogen-activated protein kinase of *Trichoderma virens*, is involved in biocontrol properties and repression of conidiation in the dark. Eukaryote Cell. 2: 446-455.

Nene, Y. L., Thapliyal, P.N., (1973). Fungicides in Plant Disease Control. Oxford and IBH Publishing house, New Delhi, India. p. 163.

Nagamani, P., Viswanath, K., Babu, T.K. (2011). Management of dry root rot caused by *Rhizoctonia bataticola*in chickpea. Current Biotica. 5(3): 364-369.

Nitharwal, N. (2019). Management of stem and root rot of cowpea [*Vigna unguiculata* (L.) Walp.] incited by *Macrophomina phaseolina* (Tassi.) Goid. M.Sc. (Agri.) Thesis, Sri Karan Narendra Agriculture University, Jobener, Rajastan (India).

Panse, V.G., Sukhatme, P.V. (1985) Statistical Methods for Agricultural Workers. ICAR Publ. New Delhi, p. 359.

Pathak, D.M., Patel, R.R. (2019). *In vitro* evaluation of fungicides and organic extracts against *Macrophomina phaseolina* (Tassi) Goid. isolated from pigeonpea [*Cajanus cajan* (L.) Millsp.]. International Journal of Plant Protection. 12(2): 147-151.

Rangaswami, G., Mahadevan, A. (2008). Diseases of Crop Plants in India (4th ed). New Delhi, PHI Learning Pvt. Ltd., pp. 275-278.

Rathore, J., Gupta, K.N., Verma, B., Kaur, G. (2020). Evaluation of bio-control agents against *Macrophomina phaseolina* causing root and stem rot disease of sesamum. International Journal of Current Microbiology and Applied Sciences. 9(9): 411-417.

Sangappa, G., Mallesh, S.B. (2016). Effect of bioagents and chemicals for the management of aerial blight and dry root rot of black gram incited by *Rhizoctonia bataticola*. International Journal of Plant Protection. 9(2): 424- 429.

Sharma, M., Pandey, S. (2013). Unravelling effects of temperature and soil moisture stress response on development of dry root rot [*Rhizoctonia bataticola* (Taub.)] butler in chickpea. American Journal of Plant Science. 4: 584-589.

Silva, R.N., Silva, S.P., Brandao, R.L., Ulhoa, C.J. (2004). Regulation of N-acetyl-beta- D-glucosaminidase produced by *Trichoderma harzianum*: Evidence that cAMP controls its expression. Research in Microbiology. 155: 667-671.

Singh, S.K., Srivastava, H.P. (1988). Symptoms of *Macrophomina phaseolina* infection on moth bean seedlings. Annals of Arid Zone. 27: 151-152.

Sunkad, G., Sharma, M., Mallesh, S.B., Mannur, D.M., Sreenivas, A.G. (2018). Integrated management of dry root rot caused by *Rhizoctonia bataticola* in chickpea. International Journal of Current Microbiology and Applied Sciences. 7(4): 201-209.

Vengadeshkumar, L., Kalaiselvi, M., Meera, T., Sanjayghandhi, S., Udaykumar, R., Rajamohan, K., Sudhasha, S. (2019). Effect of neem compared with *Pseudomonas fluorescens* on the management of cowpea root rot diseases. Journal of Biopesticide. 12(2): 232-238.

Vincent, J.M. (1947). Distortion of fungal hyphae in presence of certain inhibitors. Nature. 22: 159-850.

Walter, T.F. (1967). Experimental Design: Theory and Application (2nd Edition). Oxford and IBH Publishing Company, New York.