The Pharma Innovation Journal 2023; 12(6): 1781-1788

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(6): 1781-1788

www.thepharmajournal.com
Received: 18-03-2023
Accepted: 23-04-2023

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Survey on the incidence of anthracnose disease of mundu chilli in Ramanathapuram district and its management strategies

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Abstract
An extensive field survey assessed the incidence of anthracnose disease in major chilli growing areas of Ramanathapuram district. Disease incidence was calculated based on evaluations of twenty-one locations, with twenty-five chilli plants assessed for infected fruit. The survey aimed to determine the distribution of the pathogen and its prevalence in the host population. Additionally, three field experiments were conducted in three villages, involving different treatments with seed treatments and foliar sprays of fungicides. Disease incidence was recorded at multiple time points, revealing varying levels of anthracnose incidence. The treatment with the lowest incidence involved *Bacillus subtilis* and chlorothalonil, while the highest incidence was observed with *B. subtilis*, metiram, and dimethomorph. Furthermore, the treatment with the highest yield and cost-benefit ratio employed *Bacillus subtilis* and chlorothalonil. These findings provide valuable insights into anthracnose disease incidence and offer potential management strategies for mundu chilli crops.

Keywords: Chilli anthracnose, survey, disease incidence, disease severity, management

Introduction
Chilli (*Capsicum annuum* L.) holds great significance among the *Solanaceous* crops cultivated in India due to its high nutritional value and versatile uses. It serves as a spice, condiment, culinary supplement, vegetable, and even an ornamental plant. Chilli cultivation has been practiced sustainably for many years in countries like India, where it accounts for a remarkable 25% of the global chilli production (FAO, 2010) [5]. However, the productivity of chilli crops faces numerous challenges, particularly from pests and diseases. Bacterial, viral, and fungal diseases pose significant threats to the quality and yield of chilli. Among fungal diseases, anthracnose, caused by *Colletotrichum*, has emerged as a major menace in chilli production. *Colletotrichum gloeosporioides*, a species belonging to the Kingdom-Fungi, Phylum-*Ascomycota*, Class-Sordariomycetes, Order-Glomerellales, and Family-Glomerellaceae (Agrios, 2005) [1], stands out as the predominant *Colletotrichum* species, capable of infecting around 470 different host genera (Cannon *et al*., 2008) [4]. Anthracnose is a devastating disease that severely impacts the yield and quality of chilli, leading to losses ranging from 10% to 60%, depending on the chilli varieties (Bansal and Grover, 1969) [3]. *Colletotrichum capsici*, a globally significant plant pathogen, is responsible for causing economically important anthracnose. The pathogen can be transmitted through seeds, soil, and air, and it is prevalent in major chilli-growing regions, resulting in losses of 25% to 48% in various parts of India (Rai *et al*., 2020) [12]. Disease incidence is measured by assessing the proportion of the crop population, such as individual plants, branches, or leaves, that are infected, while disease severity refers to the extent of the affected plant area. Given the vital role of chilli and the imperative need for effective disease management, this survey aims to investigate the disease incidence of anthracnose in chilli crops. The findings will contribute to the development of integrated disease control techniques, which are crucial for sustaining the production and quality of chilli crops.

Material and Methods
Survey for assess the disease incidence
An extensive field survey was conducted from major chilli growing areas of Ramanathapuram districts to find out the incidence of anthracnose disease.

The incidence of anthracnose diseases were recorded according to the disease assessments done in Twenty one location. In all Twenty one location 25 chilli plants were assessed out in the field to identify and count the number of chilli fruits were infected. Disease incidence is the number or proportions of plant units that are diseased (i.e. plants, leaves, flower, fruits etc.). The formula used is based on the mean incidence calculated for each area. For estimation of fruit area diseased, the whole fruit surface area was considered as 100 and thereby the infected area was determined by eye estimation for percent of disease index (Hossain *et al.*, 2010; Gupta *et al.*, 2017) [7, 6]. Disease incidence generally tells about the prevalence of the disease in a given areas or host population. Therefore the reason for implementing this survey was necessary to find out the percentage distribution of the pathogen on the host pants.

Percent Disease Index

$$PDI = \frac{\text{Sum of individual rating}}{\text{Total number of samples observed}} x \frac{100}{\text{Maximum grade value}}$$

Management of mundu chilli anthracnose disease

Three field experiments were conducted during 2021 and 2022 in three villages of Ramanathapuram district with eleven treatments and three replications for management of mundu chilli anthracnose disease.

Treatment Details

Tr. No.	Treatment Details
T1	Seed treatment with *Bacillus subtilis* @ 10 g/kg of seeds and foliar spray of azoxystrobin 11%+ tebuconazole 18.3% SC (0.1%) at 15, 30 and 45 days after noticing the dieback symptoms
T2	Seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of mancozeb 64% + metalaxyl 8% WP (0.2%) at 15, 30 and 45 days after noticing the dieback symptoms
T3	Seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of fenamidone 10%+ mancozeb 50% 60WG (0.1%) at 15, 30 and 45 days after noticing the dieback symptoms
T4	Seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of difenoconazole 25% EC (0.1%) at 15, 30 and 45 days after noticing the dieback symptoms
T5	Seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of kresoxim methyl 50% SC (0.1%) at 15, 30 and 45 days after noticing the dieback symptoms
T6	Seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of metiram 44% + dimethomorph 9% WG (0.25%) at 15, 30 and 45 days after noticing the dieback symptoms
T7	Seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of fluxapyroxad 7% + difenoconazole 4.7% SC (0.1%) at 15, 30 and 45 days after noticing the dieback symptoms
T8	Seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of propineb 70% WP (0.1%) at 15, 30 and 45 days after noticing the dieback symptoms
T9	Seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of chlorothalonil (0.1%) at 15, 30 and 45 days after noticing the dieback symptoms
T10	Seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of COC (0.3%) at 15, 30 and 45 days after noticing the dieback symptoms
T11	Control

Statistical Analysis

The data concerning Percent disease index were analyzed using a one-way analysis of variance (ANOVA) with the statistical software SPSS. Mean separation was achieved through the utilization of the Drunken Range Multiple Test (DMRT), with a significance level of $p<0.05$. The data were presented as mean and CD values. All experiments were conducted using a Randomized Block Design.

Results and Discussion

An intensive survey to assess the incidence of anthracnose disease of munduchilli was conducted in major munduchilli growing areas of Ramanathapuram district. The survey indicated that the anthracnose incidence ranged between 9.04 to 22.52 PDI. The maximum anthracnose incidence of 22.52 PDI was recorded in Kombudhi village followed by Perunali village which recorded the disease incidence of 19.41 PDI. The lowest anthracnose incidence of 9.04 PDI was recorded in Tholur village (Table 1). Similary a survey was carried out by Prasad *et al.* (2016) [10] to evaluate the percentage of anthracnose disease occurrence in chili crops at five locations within the Bulileka area. The results showed that the percentage of anthracnose-affected fruits was higher in green fruits, ranging from 65.5% to 78.5% under field conditions. Consequently, the percent disease index (PDI) indicates that the prevalence of anthracnose poses a significant obstacle to the profitability of chili cultivation in the Bulileka area. The comparable findings also reported by Mishra *et al.* (2018) [9] During the year of 2015-16, a comprehensive survey was carried out in 36 specifically chosen areas across several districts in Uttar Pradesh, including Pratapgarh, Amethi, Sulatanpur, Kanpur, Etawah, Allahabad, Faizabad, Jaunpur, and Mirzapur. The survey aimed to assess the severity of anthracnose disease. The results revealed that the highest recorded anthracnose severity was observed in Jaunpur (54.91%) and Mirzapur (54.00%) districts.

Table 1: Survey on the incidence of mundu chilli anthracnose in Ramanathapuram district

Sl. No.	Village	Block	Anthracnose incidence (PDI)*
1.	Kamuthi	Kamuthi	16.89 (24.26)^{c}
2.	Perunali	Kamuthi	19.41 (26.12)^{b}
3.	Parthipanoor	Paramakudi	12.29 (20.51)^{efgh}
4.	Kombudhi	Kamuthi	22.52 (28.33)^{a}
5.	Alangulam	Ramanathapuram	9.63 (18.04)^{ij}
6.	Sathirakudi	Paramakudi	10.81 (19.17)^{ghij}
7.	Ettivayal	Paramakudi	11.26 (19.60)^{ghi}
8.	Paramakudi	Paramakudi	13.48 (21.54)^{de}
9.	Abiramam	Kamuthi	18.89 (25.74)^{bc}
10.	Pasumpon	Kamuthi	11.30 (19.62)^{ghi}
11.	Antakudi	Paramakudi	12.74 (20.89)^{defg}
12.	Kamuthakudi	Paramakudi	10.52 (18.90)^{hij}
13.	Mudukulathur	Mudukulathur	13.48 (21.54)^{de}
14.	Akkiramesi	Paramakudi	10.37 (18.79)^{hij}
15.	Maraikkulam	Kamuthi	14.37 (22.27)^{de}
16.	Shankugapuram	Kamuthi	14.52 (22.39)^{d}
17.	Thuthinatham	Kamuthi	10.22 (18.63)^{ij}
18.	Anaisei	Mudukulathur	11.41 (19.73)^{fghi}
19.	Thavasikurichi	Kamuthi	9.63 (18.05)^{ij}
20.	Vilathur	Paramakudi	13.33 (21.41)^{def}
21.	Tholur	Paramakudi	9.04 (17.47)^{j}
CD (*P*= 0.05)			1.77

* Mean of three locations
Figures in parentheses are arc sine transformed values
The treatment means are compared using Duncan Multiple Range Test (DMRT).
In a column, mean followed by a common letter(s) are not significantly different (p=0.05)

Field trial – I

The first field trial was conducted in Kombudhi village of Kamuthi taluk during 2021. Foliar spray of different fungicides was undertaken as per the treatment schedule at 15, 30 and 45 days after noticing the dieback symptoms. The anthracnose disease incidence was recorded at different periods *viz*., 75, 90, 105, 120, 135 and 150 DAS. The lowest disease incidence of 6.82 PDI was recorded at 150 DAS in the treatment *viz*., seed treatment with *Bacillus subtilis* @ 10 g/kg of seeds and foliar spray of chlorothalonil (0.1%) at 15, 30, and 45 days after noticing the dieback symptoms followed by seed treatment with *B. subtilis @ 1*0 g/kg of seeds and foliar spray of COC (0.3%) at 15, 30 and 45 days after noticing the dieback symptoms which recorded the disease incidence of 9.33 PDI. The maximum disease incidence of 21.32 PDI was recorded at 150DAS in the treatment viz., seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of metiram 44% + dimethomorph 9%WG (0.25%) at 15, 30 and 45 days after noticing the dieback symptoms (Table 2). The maximum plot yield (3.122 kg/ plot) was recorded in the treatment viz., seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of chlorothalonil (0.1%) at 15, 30 and 45 days after noticing the dieback symptoms followed by seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of COC (0.3%) at 15, 30 and 45 days after noticing the dieback symptoms which recorded the yield of 2.940 kg per plot (20m^2) and both treatments were on par. The highest Cost Benefit ratio (1: 3.30) was recorded in the treatment viz., seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of chlorothalonil (0.1%) at 15, 30, and 45 days after noticing the dieback symptoms followed by seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of COC (0.3%) at 15, 30 and 45 days after noticing the dieback symptoms which were recorded the Cost Benefit ratio of 1: 3.01 (Table 3).

Table 2: Management of anthracnose disease of mundu chilli (trial- I)

Treatment No.	Anthracnose disease incidence (PDI)*					
	75 DAS	90 DAS	105 DAS	120 DAS	135 DAS	150 DAS
T1	7.68 (16.09)^{f}	7.12 (15.48)^{ef}	6.94 (15.27)^{e}	8.42 (16.87)^{f}	10.31 (18.73)^{e}	12.28 (20.51)^{f}
T2	15.84 (23.45)^{b}	15.18 (22.93)^{b}	14.01 (21.98)^{bc}	16.92 (24.29)^{b}	18.01 (25.11)^{b}	19.02 (25.86)^{bcd}
T3	16.12 (23.67)^{b}	15.62 (23.28)^{b}	14.38 (22.28)^{b}	17.24 (24.53)^{b}	18.52 (25.49)^{b}	19.72 (26.36)^{bc}
T4	13.72 (21.74)^{c}	12.92 (21.07)^{c}	12.12 (20.37)^{c}	14.42 (22.32)^{cd}	15.68 (23.33)^{c}	17.23 (24.53)^{d}
T5	15.43 (23.13) ^{bc}	14.61 (22.47)^{bc}	13.72 (21.74)^{bc}	16.21 (23.74)^{bc}	17.72 (24.90)^{b}	18.50 (25.48)^{cd}
T6	16.82 (24.21)^{b}	16.12 (23.67)^{b}	15.72 (23.36)^{b}	17.92 (25.04)^{b}	19.62 (26.29)^{b}	21.32 (27.50)^{b}
T7	11.63 (19.94)^{d}	10.52 (18.93)^{d}	9.62 (18.07)^{d}	12.31 (20.54)^{de}	14.36 (22.27)^{cd}	16.64 (24.07)^{de}
T8	9.26 (17.72)^{e}	8.62 (17.07)^{e}	7.83 (16.25)^{de}	10.69 (19.08)^{e}	12.84 (21.00)^{d}	14.51 (22.39)^{e}
T9	6.18 (14.39)^{g}	5.02 (12.94)^{g}	4.61 (12.39)^{f}	5.82 (13.96)^{g}	6.33 (14.57)^{f}	6.82 (15.14)^{h}
T10	6.54 (14.82)^{fg}	5.72 (13.83)^{fg}	5.32 (13.34)^{f}	6.31 (14.55)^{g}	7.31 (15.69)^{f}	9.33 (17.79)^{g}
T11	28.63 (32.35)^{a}	31.62 (34.22)^{a}	33.18 (35.17)^{a}	35.52 (36.58)^{a}	36.62 (37.24)^{a}	39.72 (39.07)^{a}
CD(P= 0.05)	1.62	1.70	1.90	1.66	1.52	1.82

* Mean of three replications
Figures in parentheses are arc sine transformed values
The treatment means are compared using Duncan Multiple Range Test (DMRT).
In a column, mean followed by a common letter(s) are not significantly different (p=0.05)

Table 3: Yield parameters (trial- I)

Treatment No.	Yield *			CB ratio
	Kg/Plot (20 m^2)	Percent Increase	Kg /ha	
T1	2.812^{b}	64.25	1406.000	1: 2.46
T2	2.032^{de}	18.69	1016.000	1: 1.15
T3	1.935^{ef}	13.03	967.500	1: 0.78
T4	2.345^{c}	36.97	1172.500	1: 1.63
T5	2.237^{cd}	30.67	1118.500	1: 1.29
T6	1.825^{ef}	6.60	912.500	1: 0.18
T7	2.422^{c}	41.47	1211.000	1: 2.37
T8	2.742^{b}	60.16	1371.000	1: 2.96
T9	3.122^{a}	82.36	1561.000	1: 3.30
T10	2.940^{ab}	71.73	1470.000	1: 3.01
T11	1.712^{f}	-	856.000	-
CD(*P*= 0.05)	0.268			

* Mean of three replications
The treatment means are compared using Duncan Multiple Range Test (DMRT).
In a column, mean followed by a common letter(s) are not significantly different (p=0.05)

Field trial – II

The second field experiment was undertaken inSathirakudi village of Paramakudi taluk during 2021. Different fungicides were sprayed as per the treatment schedule at 15, 30 and 45 days after noticing the dieback symptoms. The anthracnose disease incidence was recorded at different periods viz., 75, 90, 105, 120, 135 and 150 DAS. The minimum disease incidence (8.65 PDI) was recorded at 150 DAS in the treatment *viz.*, seed treatment with *Bacillus subtilis* @ 10 g/kg of seeds and foliar spray of chlorothalonil (0.1%) at 15, 30, and 45 days after noticing the dieback symptoms. The maximum anthracnose incidence (22.78 PDI) was noted at 150DAS in the treatment viz., seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of metiram 44% + dimethomorph 9%WG (0.25%) at 15, 30 and 45 days after noticing the dieback symptoms (Table 4). The highest yield (3.015 kg/ plot) was recorded in the treatment viz., seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of chlorothalonil (0.1%) at 15, 30 and 45 days after noticing the dieback symptoms followed by seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of COC (0.3%) at 15, 30 and 45 days after noticing the dieback symptoms which recorded the yield of 2.842 kg per plot (20m^2) and both treatments were on par. The highest Cost Benefit ratio (1: 3.21) was registered in the treatment viz., seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of chlorothalonil (0.1%) at 15, 30, and 45 days after noticing the dieback symptoms followed by seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of COC (0.3%) at 15, 30 and 45 days after noticing the dieback symptoms which registered the Cost Benefit ratio of 1: 2.92 (Table 5).

Table 4: Management of anthracnose disease of mundu chilli (trial- II)

Treatment No.	Anthracnose disease incidence (PDI)*					
	75 DAS	90 DAS	105 DAS	120 DAS	135 DAS	150 DAS
T1	9.41 (17.86)^{e}	8.72 (17.18)^{f}	7.61 (16.01)^{f}	10.39 (18.80)^{e}	12.43 (20.64)^{e}	13.78 (21.79)^{gh}
T2	17.12 (24.44)^{bc}	16.21 (23.74)^{bc}	14.72 (22.56)^{bcd}	17.64 (24.84)^{bc}	19.32 (26.08)^{bc}	20.64 (26.91)^{bcd}
T3	17.64 (24.84)^{bc}	16.52 (23.98)^{b}	15.34 (23.06)^{bc}	18.14 (25.21)^{b}	20.63 (27.01)^{b}	22.32 (28.19)^{bc}
T4	15.31 (23.03)^{cd}	14.28 (22.20)^{c}	13.10 (21.22)^{d}	15.74 (23.37)^{c}	16.82 (24.21)^{cd}	18.20 (25.25)^{de}
T5	16.93 (24.30)^{bc}	15.73 (23.37)^{bc}	13.92 (21.91)^{cd}	16.82 (24.21) ^{bc}	18.79 (25.69)^{bc}	19.64 (26.31)^{cde}
T6	18.21 (25.26)^{b}	17.23 (24.53)^{b}	16.72 (24.14)^{b}	18.76 (25.67)^{b}	21.29 (27.24)^{b}	22.78 (28.51)^{b}
T7	13.62 (21.66)^{d}	12.36 (20.58)^{d}	10.61 (19.01)^{e}	13.42 (21.49)^{d}	15.69 (23.33)^{d}	17.14 (24.46)^{ef}
T8	11.23 (19.58)^{e}	10.64 (19.04)^{e}	9.72 (18.17)^{e}	12.31 (20.54)^{d}	14.72 (22.56)^{d}	15.38 (23.09)^{fg}
T9	6.32 (14.56)^{f}	5.68 (13.79)^{g}	4.82 (12.68)^{g}	6.20 (14.42) ^{g}	7.68 (16.08)^{g}	8.65 (17.10)^{i}
T10	6.94 (15.27)^{f}	6.12 (14.32)^{g}	6.22 (14.44)^{f}	8.71 (17.17)^{f}	10.33 (18.75)^{f}	11.74 (20.04)^{h}
T11	29.48 (32.89)^{a}	32.40 (34.70)^{a}	35.62 (36.64)^{a}	37.14 (37.55)^{a}	38.60 (38.41)^{a}	41.53 (40.12)^{a}
CD(P= 0.05)	1.79	1.46	1.70	1.57	1.85	1.90

* Mean of three replications
Figures in parentheses are arc sine transformed values
The treatment means are compared using Duncan Multiple Range Test (DMRT).
In a column, mean followed by a common letter(s) are not significantly different (p=0.05)

Table 5: Yield parameters (trial- II)

Treatment No.	Yield *			CB ratio
	Kg/Plot (20m^2)	Percent Increase	Kg /ha	
T1	2.723 ^{b}	61.89	1361.500	1: 2.27
T2	1.987 ^{efg}	18.13	993.500	1: 1.06
T3	1.845 ^{fgh}	9.69	922.500	1: 0.57
T4	2.232 ^{de}	32.70	1116.000	1: 1.41
T5	2.055 ^{ef}	22.18	1027.500	1: 0.92
T6	1.722 ^{gh}	2.38	861.000	1: 0.06
T7	2.342 ^{cd}	39.24	1171.000	1: 2.15
T8	2.557 ^{bc}	52.02	1278.500	1: 2.36
T9	3.015 ^{a}	79.25	1507.500	1: 3.21
T10	2.842 ^{ab}	68.97	1421.000	1: 2.92
T11	1.682 ^{h}	-	841.000	-
CD(*P*= 0.05)	0.286			

* Mean of three replications
The treatment means are compared using Duncan Multiple Range Test (DMRT).
In a column, mean followed by a common letter(s) are not significantly different (p=0.05)

Field trial – III

The third field trail was conducted in Perunali village of Kamuthi taluk during 2022. Foliar spray of different fungicides was carried out as per the treatment schedule at 15, 30 and 45 days after noticing the dieback symptoms. The anthracnose disease incidence was recorded at different periods viz., 75, 90, 105, 120, 135 and 150 DAS. Among the treatments, seed treatment with *Bacillus subtilis* @ 10 g/kg of seeds and foliar spray of chlorothalonil (0.1%) at 15, 30, and 45 days after noticing the dieback symptoms recorded the lowest anthracnose incidence of 5.93 PDI at 150DAS followed by seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of COC (0.3%) at 15, 30 and 45 days after noticing the dieback symptoms which had the disease incidence of 6.22 PDI and both treatments were on par. The maximum disease incidence (18.52 PDI)was recorded in the treatment viz., seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of metiram 44% + dimethomorph 9% WG (0.25%) at 15, 30 and 45 days after noticing the dieback symptoms (Table 6). The maximum plot yield (3.167 kg/ plot) was recorded in the treatment viz., seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of chlorothalonil (0.1%) at 15, 30 and 45 days after noticing the dieback symptoms followed by seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of COC (0.3%) at 15, 30 and 45 days after noticing the dieback symptoms which were recorded the yield of 3.077 kg per plot (20m^2) and both treatments were on par. The highest Cost Benefit ratio (1 : 3.18) was recorded in the treatment viz., seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of chlorothalonil (0.1%) at 15, 30, and 45 days after noticing the dieback symptoms followed by seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of COC (0.3%) at 15, 30 and 45 days after noticing the dieback symptoms which were recorded the Cost Benefit ratio of 1 : 3.02 (Table 7).

Table 6: Management of anthracnose disease of mundu chilli (trial- III)

Treatment No.	Anthracnose disease incidence (PDI)*					
	75 DAS	90 DAS	105 DAS	120 DAS	135 DAS	150 DAS
T1	7.11 (15.46)^{ef}	6.52 (14.79)^{ef}	6.37 (14.62)^{e}	7.85 (16.27)^{e}	8.15 (16.58)^{e}	8.59 (17.04)^{e}
T2	14.96 (22.76)^{bc}	14.37 (22.28)^{b}	13.33 (21.29)^{bc}	16.29 (23.81)^{b}	17.04 (24.38)^{b}	17.63 (24.83)^{b}
T3	15.26 (22.99)^{bc}	14.52 (22.39)^{b}	13.78 (21.79)^{b}	16.59 (24.04)^{b}	17.18 (24.49)^{b}	17.93 (25.05)^{b}
T4	12.89 (21.04)^{c}	12.29 (20.52)^{c}	11.41 (19.74)^{c}	12.44 (20.65)^{c}	13.63 (21.67)^{c}	14.52 (22.40)^{c}
T5	14.22 (22.16)^{bc}	13.48 (21.54)^{bc}	12.74 (20.91)^{bc}	15.56 (23.23)^{b}	16.74 (24.15)^{b}	17.18 (24.49)^{b}
T6	15.41(23.11)^{b}	14.96 (22.76)^{b}	14.07 (22.03)^{b}	17.33 (24.60)^{b}	18.22 (25.27)^{b}	18.52 (25.49)^{b}
T7	10.52 (18.93)^{d}	9.63 (18.08)^{d}	8.59 (17.04)^{d}	10.67 (19.06)^{cd}	11.26 (19.61)^{d}	12.15 (20.40)^{d}
T8	8.74 (17.19)^{de}	7.71 (16.12)^{e}	7.26 (15.63)^{de}	9.04 (17.49)^{de}	9.48 (17.93)^{de}	10.07 (18.50)^{de}
T9	5.33 (13.32)^{g}	4.59(12.35)^{g}	3.70 (11.07)^{f}	5.03 (12.95)^{f}	5.63 (13.71)^{f}	5.93 (14.09)^{f}
T10	5.78 (13.90)^{fg}	5.18 (13.16)^{fg}	4.74 (12.57)^{f}	5.48 (13.54)^{f}	6.07 (14.27)^{f}	6.22 (14.44)^{f}
T11	26.22 (30.80)^{a}	29.78 (32.88)^{a}	30.96 (33.81)^{a}	31.70 (34.27)^{a}	35.70 (36.69)^{a}	38.52 (38.36)^{a}
CD(P= 0.05)	1.98	1.74	1.76	1.80	1.87	1.95

* Mean of three replications
Figures in parentheses are arc sine transformed values
The treatment means are compared using Duncan Multiple Range Test (DMRT). In a column, mean followed by a common letter(s) are not significantly different (p=0.05)

Table 7: Yield parameters (trial- III)

Treatment No.	Yield *			CB ratio
	Kg/Plot ($20m^2$)	Percent Increase	Kg /ha	
T1	2.980^{ab}	65.83	1490.000	1: 2.71
T2	2.190^{fg}	21.87	1095.000	1: 1.37
T3	2.032^{gh}	13.08	1016.000	1: 0.83
T4	2.525^{de}	40.51	1262.500	1: 1.87
T5	2.307^{ef}	28.38	1153.500	1: 1.26
T6	1.945^{h}	8.24	972.500	1: 0.23
T7	2.617^{cd}	45.63	1308.500	1: 2.07
T8	2.843^{bc}	58.21	1421.500	1: 2.87
T9	3.167^{a}	76.24	1583.500	1: 3.18
T10	3.077 ^{ab}	71.23	1538.500	1: 3.02
T11	1.797^{h}	-	898.500	-
CD(P= 0.05)	0.240			

* Mean of three replications

The treatment means are compared using Duncan Multiple Range Test (DMRT). In a column, mean followed by a common letter(s) are not significantly different (p=0.05)

Pooled Analysis

Three field experiments were conducted in three villages of Ramanathapuram district. The pooled analysis of three trials revealed that seed treatment with *Bacillus subtilis* @ 10 g/kg of seeds and foliar spray of chlorothalonil (0.1%) at 15, 30, and 45 days after noticing the dieback symptoms recorded the lowest anthracnose incidence of 7.13 PDI at 150DAS followed by seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of COC (0.3%) at 15, 30 and 45 days after noticing the dieback symptoms which had the disease incidence of 9.10 PDI and both treatments were on par. The maximum disease incidence (20.87 PDI)was recorded in the treatment viz., seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of metiram 44% + dimethomorph 9%WG (0.25%) at 15, 30 and 45 days after noticing the dieback symptoms (Table 8).The maximum yield (3.101 kg/ plot) was recorded in the treatment viz., seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of chlorothalonil (0.1%) at 15, 30 and 45 days after noticing the dieback symptoms followed by seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of COC (0.3%) at 15, 30 and 45 days after noticing the dieback symptoms which were recorded the yield of 2.953 kg per plot ($20m^2$) and both treatments were on par. The highest Cost Benefit ratio (1: 3.21) was recorded in the treatment viz., seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of chlorothalonil (0.1%) at 15, 30, and 45 days after noticing the dieback symptoms followed by seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of COC (0.3%) at 15, 30 and 45 days after noticing the dieback symptoms which had the Cost Benefit ratio of 1: 2.92 (Table 9).

Table 8: Management of anthracnose disease of mundu chilli (Pooled Analysis)

Treatment No.	Anthracnose disease incidence (PDI)*					
	75 DAS	90 DAS	105 DAS	120 DAS	135 DAS	150 DAS
T1	8.07 (16.47)^{f}	7.45 (15.82)^{e}	6.97 (15.30)^{ef}	8.89 (17.31)^{f}	10.30 (18.65)^{f}	11.55 (19.78)^{f}
T2	15.97 (23.38)^{bc}	15.25 (22.81)^{bc}	14.02 (21.99)^{bc}	16.95 (24.31)^{b}	18.12 (25.19)^{b}	19.10 (25.90)^{bc}
T3	16.34 (23.83)^{b}	15.55 (23.22)^{b}	14.50 (22.38)^{b}	17.32 (24.59)^{b}	18.78 (25.51)^{b}	19.99 (26.34)^{b}
T4	13.97 (21.94)^{c}	13.16 (21.26)^{c}	12.21 (20.45)^{c}	14.20 (22.12)^{cd}	15.38 (23.07)^{cd}	16.65 (24.06)^{cd}
T5	15.53 (23.19)^{bc}	14.61 (22.46)^{bc}	13.46 (21.52)^{bc}	16.20 (23.73)^{bc}	17.75 (24.91)^{bc}	18.44 (25.42)^{bc}
T6	16.81 (24.20)^{b}	16.10 (23.65)^{b}	15.50 (22.98)^{b}	18.00 (25.10)^{b}	19.71 (26.35)^{b}	20.87 (27.17)^{b}
T7	11.92 (20.17)^{d}	10.84 (19.15)^{d}	9.61 (18.04)^{d}	12.13 (20.06)^{de}	13.77 (21.74)^{de}	15.31 (22.98)^{de}
T8	9.74 (18.16)^{e}	8.99 (17.41)^{e}	8.27 (16.68)^{de}	10.68 (19.04)^{ef}	12.35 (20.50)^{ef}	13.32 (21.33)^{ef}
T9	5.94 (14.10)^{g}	5.10 (13.04)^{f}	4.38 (12.06)^{g}	5.68 (13.78)^{g}	6.55 (14.80)^{g}	7.13 (15.45)^{g}
T10	6.42 (14.67)^{g}	5.67 (13.77)^{f}	5.43 (13.45)^{fg}	6.83 (15.08)^{g}	7.90 (16.16)^{g}	9.10 (17.42)^{g}
T11	28.11 (32.01)^{a}	31.27 (33.99)^{a}	33.25 (35.21)^{a}	34.79 (36.13)^{a}	36.97 (37.45)^{a}	39.92 (39.19)^{a}
CD(P= 0.05)	1.63	1.69	1.86	2.18	1.98	2.09

* Pooled Mean

Figures in parentheses are arc sine transformed values

The treatment means are compared using Duncan Multiple Range Test (DMRT). In a column, mean followed by a common letter(s) are not significantly different (p=0.05)

Table 9: Yield parameters (Pooled Analysis)

Treatment No.	Yield *			CB ratio
	Kg/Plot ($20m^2$)	Percent Increase	Kg /ha	
T1	2.838bc	64.05	1419.167	1: 2.27
T2	2.070fg	19.65	1034.833	1: 1.06
T3	1.937gh	11.97	968.667	1: 0.57
T4	2.367de	36.82	1183.667	1: 1.41
T5	2.200ef	27.17	1099.833	1: 0.92
T6	1.831h	5.84	915.333	1: 0.06
T7	2.460d	42.20	1230.167	1: 2.15
T8	2.714c	56.88	1357.000	1: 2.36
T9	3.101a	79.25	1550.667	1: 3.21
T10	2.953ab	70.69	1476.500	1: 2.92
T11	1.730h	-	865.167	-
CD(P= 0.05)	0.213			

* Pooled Mean

The treatment means are compared using Duncan Multiple Range Test (DMRT). In a column, mean followed by a common letter(s) are not significantly different (p=0.05)

Seed treatment with *Bacillus subtilis* @ 10 g/kg of seeds and foliar spray of chlorothalonil (0.1%) at 15, 30, and 45 days after noticing the dieback symptoms recorded the lowest anthracnose incidence of 7.13 PDI at 150DAS followed by seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of COC (0.3%) at 15, 30 and 45 days after noticing the dieback symptoms which had the disease incidence of 9.10 PDI and both treatments were on par. The maximum yield (3.101 kg/ plot) was recorded in the treatment viz., seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of chlorothalonil (0.1%) at 15, 30 and 45 days after noticing the dieback symptoms followed by seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of COC (0.3%) at 15, 30 and 45 days after noticing the dieback symptoms which were recorded the yield of 2.953 kg per plot ($20m^2$) and both treatments were on par. The highest Cost Benefit ratio (1: 3.21) was recorded in the treatment viz., seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of chlorothalonil (0.1%) at 15, 30, and 45 days after noticing the dieback symptoms followed by seed treatment with *B. subtilis* @ 10 g/kg of seeds and foliar spray of COC (0.3%) at 15, 30 and 45 days after noticing the dieback symptoms which had the Cost Benefit ratio of 1: 2.92.

The first field trial conducted in Kombudhi village evaluated different treatments, and the results showed that the combination of seed treatment with *Bacillus subtilis* and foliar spray of chlorothalonil resulted in the lowest disease incidence (6.82 PDI). Conversely, the treatment involving seed treatment of *B. subtilis* and foliar spray of metiram + dimethomorph had the highest disease incidence (21.32 PDI). Furthermore, the treatment with seed treatment of *B. subtilis* and foliar spray of chlorothalonil not only exhibited the lowest disease incidence but also yielded the highest plot yield (3.122 kg) and had the highest cost-benefit ratio (1:3.30) in the first field trial. Similarly Madhavan *et al.* (2017) [18] reported the effectiveness of the fungicide Cabrio Top in inhibiting the radial growth of various test fungi was highly significant, requiring only a minimal inhibitory concentration of 250 ppm. In the field trial, the application of Cabrio Top at a rate of 1750 g/ha proved to be the most successful in both controlling anthracnose and improving crop yield. In Trial I, the control plots yielded the lowest at 2132 kg/ha, while Trial II recorded a slightly higher yield at 2507 kg/ha. Conversely, using Cabrio Top at a rate of 1750 g/ha resulted in the highest yields, reaching 3091 kg/ha in Trial I and 3304 kg/ha in Trial II. Additionally, the foliar application of the powder formulation of *Burkholderia* sp. strain TNAU-1 demonstrated a comparable level of disease control and yield increase to that achieved by foliar application with Cabrio Top in field conditions. In another study, Anand *et al.*, (2010) [2] found that the combined application of a talc-based formulation of *Pseudomonas fluorescens* Pf1 at a rate of 2.5 kg/ha and azoxystrobin at a rate of 250 ml/ha exhibited superior efficacy in managing chili anthracnose disease compared to individual treatments of azoxystrobin (500 ml/ha) or Pf1 (2.5 kg/ha).

In the second field trial conducted in Sathirakudi village, similar treatments were evaluated, and once again, the treatment with seed treatment of *B. subtilis* and foliar spray of chlorothalonil demonstrated the lowest disease incidence (8.65 PDI). Conversely, the treatment involving seed treatment of *B. subtilis* and foliar spray of metiram + dimethomorph showed the highest disease incidence (22.78 PDI). Consistently, the treatment with seed treatment of *B. subtilis* and foliar spray of chlorothalonil also yielded the highest (3.015 kg) and had the highest cost-benefit ratio (1:3.21) in the second field trial. Similarly, Singh *et al.* (2016) [11] reported that foliar application of azoxystrobin in combination with *Pseudomonas* and *Bacillus* sp. proved to be effective in controlling foliar diseases in wheat and resulted in increased grain yield. It is worth noting that the endophytic colonization of bioagents sprayed on foliage plays a critical role in their ability to antagonize fungal pathogens in plants (Singh, 2016) [11].

These findings highlight the effectiveness of specific treatments, such as seed treatment with Bacillus subtilis and foliar spray of chlorothalonil, in managing anthracnose disease in mundu chilli cultivation. These treatments not only reduced disease incidence but also positively impacted yield and cost-benefit ratios.

Conclusion

Seed treatment with *Bacillus subtilis* @ 10 g/kg of seeds and foliar spray of chlorothalonil (0.1%) at 15, 30, and 45 days after noticing the dieback symptoms recorded the lowest anthracnose incidence, highest yield and highest Cost Benefit ratio. Other treatments involving different fungicides were less effective in controlling the disease and had lower yields. Overall, the findings emphasize the effectiveness of seed treatment with *Bacillus subtilis* and foliar spray of chlorothalonil in managing anthracnose disease in mundu chilli cultivation. Implementing these treatments can lead to improved disease control, increased yields, and higher economic returns for farmers in the region.

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