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Efficacy of Organic Amendments, Biofumigants, and Mulches against *Phytophthora nicotianae* var. *nicotianae* Causing Leaf Blight and Fruit Rot Disease

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ABSTRACT

An experiment was conducted during the 2022 and 2023 growing seasons, from April to August, at the experimental farm of the Department of Plant Pathology, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India. The study aimed to explore the efficacy of various organic amendments, biofumigant crops, and mulches in mitigating losses caused by leaf blight and fruit rot, a significant disease affecting bell pepper production. The disease is prevalent all over the world wherever warm-humid conditions exist during the growing season. Different organic amendments viz; neem cake, cotton cake, mustard cake, vermicompost, sawdust, dried residues of cabbage, cauliflower, mustard and radish @500 g m^{-2}; pine needles, wheat straw and polyethylene mulches were tested in field against the leaf blight and fruit rot disease. The trial was conducted in a completely randomized block design (RBD) keeping three replications in each treatment. Among the various treatments used, black polyethylene mulch, pine needle mulch, dried crop residue powder and oil cakes of mustard, when applied 10 days prior to planting of bell pepper seedlings in field resulted in maximum reduction of fruit rot incidence and leaf blight severity and also significantly increased the fruit yield. Thus, incorporating these treatments for the management of disease offers a promising, sustainable approach for improving the health and productivity of bell pepper, while also supporting sustainable agricultural practices by reducing reliance on chemical treatments.

KEYWORDS: Leaf blight and fruit rot, bell pepper, mulching

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1. INTRODUCTION

Bell pepper (*Capsicum annuum* L. var. *grossum* Sendt.) commonly known as 'Capsicum' and 'Shimla Mirch' is one of the most widely cultivated solanaceous crops and holds significant importance worldwide. The crop is native to Mexico with the secondary centre of origin in Guatemala (Smith and Heiser, 1957). The fruit is a rich source of ascorbic acid (vitamin C) and other essential vitamins such as vitamin A in the form of β-carotene and vitamins of group B. Approximately, 36 mt of bell pepper was produced worldwide from 2 mha area, led by China (46% of the total production), followed by Mexico, Indonesia, and Turkey (Anonymous, 2021). In India, bell pepper is cultivated in an area of 36 thousand hectares of land having total production of 565 thousand MT with productivity of 15.69 mt ha^{-1}. The leading bell pepper growing states in India iincludes Haryana, Karnataka, Jharkhand, Himachal Pradesh, and Maharashtra (Anonymous, 2022). Himachal Pradesh is a northern Indian state in the Himalayas. The cultivated area of bell pepper in the state is around 2.50 thousand hectares with a total production of 48.86 thousand mts ha^{-1} and a productivity of 19.54 mts ha^{-1} (Anonymous, 2022).

In the mid hills, the active growth period of the crop coincides with the arrival of monsoon rains, which favours the development of various fungal and bacterial diseases that affects bell pepper cultivation. Among various fungal diseases, leaf blight and fruit rot of bell pepper is one of the most serious diseases and is considered to be a major constraint in bell pepper production. The disease is prevalent all over the world wherever warm-humid conditions exist during the growing season (Retes-Manjarrez et al., 2020; Quesada-Ocampo et al., 2023). In 1971, Sohi et al., first reported the cases of leaf blight and fruit rot in Solan district of Himachal Pradesh, which were caused by two species of *Phytophthora* i.e *P. capsici* Leon. and *P. nicotianae* (Breda de Haan) var. *nicotianae* Waterhouse. *P. capsici* Leon. Later, Sharma and Bhardwaj (1976) and Verma (1997) observed *Phytophthora nicotianae* var. *nicotianae* to be of common prevalence in Himachal Pradesh. The yield loss of infected plants ranged from 43–100% globally (Liang et al., 1992; Mohammadbagheri et al., 2022). The severity of the leaf blight and fruit rot ranges from 15.60 to 89.60% whereas the incidence of fruit rot ranges from 10 to 60% in various locations of the Solan and Sirmaur districts of Himachal Pradesh (Sharma et al., 2016). Frequent fungicidal sprays have been practiced for managing the disease, which imposes a high danger for pathogens to attain resistance against it. As a result, chances of evolution into new strains of pathogens eruption is high. Furthermore, management through synthetic fungicides results in an adverse effect and has posed various problems such as toxic residues in feed and food, pathogen resistance, toxicity to non-target organisms and environmental pollution. Hence, there is a need to search for alternatives to fungicides. Organic amendments, biofumigant crops and mulches are an effective strategy used to combat soil-borne diseases. They alter the soil's properties and encourage the growth of saprophytes, which provide protection against many soil-borne pathogens. As per Davey (1996), organic matter has a positive impact on soil aeration, structure, drainage, moisture retention, nutrient availability, and microbial ecology. As ecofriendly strategies, these approaches are among the most effective against soil-borne pathogens. Considering the commercial significance of bell pepper in Himachal Pradesh, the present study aims to explore the role of various organic amendments, biofumigant crops and mulches in mitigating losses caused by leaf blight and fruit rot disease in bell pepper.

2. MATERIALS AND METHODS

2.1. Evaluation of organic amendments, biofumigants and mulches in field against the disease progress and plant yield parameters

An experiment with respect to evaluation of organic amendments, biofumigant crops and mulches was laid out in the field from April-August. to manage the soil borne pathogen *P. nicotianae* var. *nicotianae,* causing leaf blight and fruit rot of bell pepper consecutively for two years, 2022 and 2023. The trial was conducted in a completely randomized block design (RBD) keeping three replications in each treatment at Experimental Research Farm of the Department of Plant Pathology, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India. Different organic amendments viz; neem cake, cotton cake, mustard cake, vermicompost, sawdust @ 500 g m^{-2}; dried residues of cabbage, cauliflower, mustard and radish @10% w/w; pine needles, wheat straw and polythene mulches were tested in field to analyse their efficacy in managing leaf blight and fruit rot disease. The organic amendments, dried crop residue powder of biofumigants crops and mulches were incorporated in the soil 10 days prior to transplanting of the crop. Forty-five days old healthy seedlings of bell pepper cv. "Solan Bharpur" were transplanted in plots of 1.8×1.25 m^2 size. Spacing of 60×45 cm was maintained between the plants. Commercial fungicide i.e., Ridomil MZ (0.2%) at its standard concentration was used as check treatment. Beds without any treatment were kept as control. The observations on various aspects were recorded which included, disease incidence (%), disease severity (%) and growth parameters naming fruit yield $plot^{-1}$ (kg) and fruit yield ha^{-1} (q).

Fruit rot incidence:

Per cent disease incidence (PI) was calculated by using the following formula:

Fruit rot incidence (%)=(Number of fruits infected/Total number of fruits observed)×100

Leaf blight severity:

On leaves, the severity was recorded by using the 0 to 5 scale adopted by James (1974).

Disease rating	Disease on leaves (%)	Description of symptoms
1	0.0	Plants completely healthy with no blight symptoms
2	25.0	Plants show slight infection roughly one in every four leaves infected, disease mainly on lower leaves
3	50.0	Nearly 50% leaves including upper ones infected, the plants appear to be blighted
4	75.0	Nearly 75% of the foliage infected, the plants appear to be blighted
5	100.0	Almost all the leaves are infected, plants completely defoliated leaving behind the main stem

The per cent leaf blight severity was calculated according to McKinney (1923).

Leaf blight severity (%)=(Sum of observed all numerical ratings/ Total no. of ratings×Maximum disease grade)× 100

Further, per cent reduction in disease incidence and disease index was calculated according to following formula given by Vincent (1947):

Per cent reduction in disease incidence/index (PDI)={(C-T)/C}×100

Where, C: Disease incidence/disease index (%) in untreated control; T: Disease incidence/disease index (%) in treatment

2.1. Statistical analysis

The data obtained from field experiments were subjected to appropriate statistical analysis wherever necessary. The differences exhibited by the treatments in various experiments were tested for their significance using standard procedures (Gomez and Gomez, 1984). Statistical analysis was also performed two-way ANOVA using OPSTAT software (Sheoran et al., 1998).

3. RESULTS AND DISCUSSION

3.1. Evaluation of organic amendments, biofumigants and mulches in field against the disease progress and plant yield parameters

The potential of organic amendments, biofumigant crops and mulches was investigated for the management of leaf blight and fruit rot of bell pepper under field conditions. It was observed that the majority of treatments reduced fruit rot incidence and leaf blight severity compared to the control (Table 1, Figure 1).

Figure 1: Overview of field trial

The observational studies (2022–2023) on fruit rot incidence and leaf blight severity of bell pepper revealed the usage of black polyethylene mulch as the most effective treatment. It resulted in minimum fruit rot incidence and leaf blight severity of 28.89% and 23.42% with maximum reduction of 69.41% and 73.64%, respectively (Figure 2a). Our results align with the findings of Glass et al. (2001), where a significant difference was reported between the plots covered with black polythene mulch and without mulch. Here, the occurrence of tuber blight caused by *Phytophthora infestans* in the mulched plot averaged to 32%±4% which was notably lower when compared to the plot without mulch with an average of 56%±4%. Another study by Shtienberg et al. (2010) also observed the importance of polythene mulch in suppressing the tomato late blight disease, caused by *Phytophthora infestans* with a control efficacy of 83.6+/-5.5%.

Figure 2: Effect of different treatments on reduction of leaf blight and fruit rot disease of bell pepper: a: Polyethylene mulch; b: Pine-needle mulch; c: Control plot without any treatment

Pine-needle mulch and mustard crop residue powder used as biofumigant crop was our next best treatment with minimum fruit rot incidence of 34.28% and 38.29% and leaf blight severity of 29.09% and 33.55%, respectively with a reduction in fruit rot incidence of 63.71% and 59.45% and leaf blight severity of 67.27% and 62.23%, respectively (Figure 2b). The findings by Spaulding and Hansbrough

Table 1: Field evaluation of organic amendments, biofumigants and mulches on suppression of fruit rot incidence and leaf blight severity of bell pepper

Treatments	Fruit rot incidence (%)			Reduction in fruit rot incidence (%)			Leaf blight severity (%)			Reduction in leaf blight severity (%)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Biofumigants (Crop residues)												
Cabbage	53.52 (47.00)	59.33 (50.36)	56.43 (48.68)	42.94 (40.92)	37.54 (37.77)	40.24 (39.35)	47.67 (43.64)	58.00 (49.58)	52.83 (46.61)	45.52 (42.41)	35.56 (36.59)	40.54 (39.50)
Cauliflower	46.85 (43.18)	54.26 (47.42)	50.55 (45.30)	50.05 (45.01)	42.88 (40.89)	46.47 (42.95)	42.44 (40.64)	47.33 (43.45)	44.89 (42.04)	51.50 (45.84)	47.40 (43.49)	49.45 (44.67)
Mustard	36.26 (37.01)	40.33 (39.41)	38.29 (38.21)	61.35 (51.54)	57.54 (49.32)	59.45 (50.43)	30.44 (33.47)	36.67 (37.25)	33.55 (35.36)	65.21 (53.83)	59.26 (50.32)	62.23 (52.07)
Radish	60.00 (50.75)	67.00 (54.92)	63.50 (52.83)	36.04 (36.88)	29.47 (32.87)	32.76 (34.87)	55.17 (47.95)	64.00 (53.11)	59.58 (50.53)	36.94 (37.40)	28.89 (32.50)	32.91 (34.95)
Oil cakes												
Neem	51.33 (45.75)	56.34 (48.62)	53.83 (47.18)	45.28 (42.27)	40.70 (39.62)	42.99 (40.95)	44.00 (41.54)	51.00 (45.55)	47.50 (43.55)	49.71 (44.82)	43.33 (41.15)	46.52 (42.98)
Cotton	71.96 (58.01)	78.33 (62.24)	75.15 (60.13)	23.29 (28.84)	17.54 (24.74)	20.42 (26.79)	62.67 (52.32)	70.67 (57.19)	66.67 (54.75)	28.39 (32.17)	21.48 (27.59)	24.94 (29.88)
Mustard	41.11 (39.86)	45.41 (42.35)	43.26 (41.10)	56.18 (48.53)	52.20 (46.24)	54.19 (47.39)	36.00 (36.85)	42.11 (40.44)	39.05 (38.65)	58.85 (50.08)	53.21 (46.82)	56.03 (48.45)
Manures												
Vermicompost	77.78 (61.85)	84.67 (66.95)	81.22 (64.40)	17.09 (24.40)	10.88 (19.19)	13.98 (21.79)	71.50 (57.73)	75.00 (59.99)	73.25 (58.86)	18.29 (25.26)	16.67 (24.05)	17.48 (24.66)
Saw dust	67.33 (55.12)	73.67 (59.10)	70.50 (57.11)	28.23 (32.08)	22.46 (28.27)	25.34 (30.18)	58.67 (49.97)	67.33 (55.12)	63.00 (52.55)	32.95 (35.02)	25.18 (30.11)	29.07 (32.56)
Mulches												
Polyethylene (Black)	27.11 (31.36)	30.67 (33.61)	28.89 (32.49)	71.10 (57.46)	67.72 (55.36)	69.41 (56.41)	21.17 (27.38)	25.67 (30.43)	23.42 (28.90)	75.81 (60.51)	71.48 (57.70)	73.64 (59.11)
Pineneedle	32.00 (34.43)	36.56 (37.19)	34.28 (35.81)	65.89 (54.25)	61.52 (51.64)	63.71 (52.94)	25.67 (30.43)	32.52 (34.75)	29.09 (32.59)	70.67 (57.19)	63.87 (53.03)	67.27 (55.11)
Wheat straw	43.82 (41.43)	52.67 (46.51)	48.24 (43.97)	53.29 (46.87)	44.56 (41.86)	48.92 (44.36)	38.00 (38.04)	45.33 (42.30)	41.67 (40.17)	56.57 (48.75)	49.63 (44.77)	53.10 (46.76)
Ridomil MZ	8.00 (16.42)	11.00 (19.36)	9.50 (17.89)	91.47 (72.99)	88.42 (70.08)	89.95 (71.53)	4.50 (12.23)	8.00 (16.42)	6.25 (14.33)	94.86 (76.88)	91.11 (72.62)	92.99 (74.75)
Control	93.81 (75.58)	95.00 (77.05)	94.41 (76.32)	–	–	–	87.50 (69.27)	90.00 (71.54)	88.75 (70.40)	–	–	–
Mean	50.78 (45.55)	56.09 (48.93)		49.40 (44.77)	44.11 (41.37)		44.67 (41.53)	50.97 (45.51)		52.71 (46.94)	46.70 (43.13)	
Factors	C.D	SE(d)	SE(m)	C.D	SE(d)	SE(m)	C.D	SE(d)	SE(m)	C.D	SE(d)	SE(m)
Factor (A)-Years	0.41 (0.27)	0.20 (0.13)	0.14 (0.09)	0.50 (0.34)	0.25 (0.17)	0.17 (0.12)	0.64 (0.38)	0.32 (0.19)	0.22 (0.13)	0.78 (0.49)	0.39 (0.24)	0.27 (0.17)
Factor (B)-Treatments	1.09 (0.72)	0.54 (0.36)	0.38 (0.25)	1.27 (0.86)	0.63 (0.43)	0.45 (0.30)	1.69 (1.01)	0.84 (0.50)	0.59 (0.36)	1.98 (1.24)	0.98 (0.62)	0.70 (0.44)
Factor (A X B)	1.54 (1.01)	0.77 (0.50)	0.54 (0.36)	1.80 (1.22)	0.89 (0.60)	0.63 (0.43)	2.39 (1.43)	1.19 (0.71)	0.84 (0.50)	2.80 (1.32)	1.39 (0.87)	0.98 (0.62)

Figures in parentheses are arc sine transformed values

(1943) also suggested the usage of blight-affected needles as mulch to promote the development of tree species. Hao and Subbarao (2003) noted the significant decrease in the number of sclerotia of *S. minor* in the soil after using broccoli as a green manure. Kasuya et al. (2006) reported that dried residues of plants such as *Brassica rapa*, *Arachis hypogaea*, and *Trifolium pratense* when used at 1% (w/w) showed highly effective resistance against *Rhizoctonia solani* in sugar beet damping off. Fritz (2007) has also reported that furrow application of rape seed powder can manage the pea root rot disease caused by *Aphanomyces euteiches.*

The use of mustard oil cake against leaf blight and fruit rot disease was also found superior compared to control and resulted in fruit rot incidence of 43.26% and leaf blight severity of 39.05%, with a considerable reduction of 54.19% and 56.03%, respectively. The application of mustard oil cake in the management of soil borne diseases has so far been reported in various studies. In a supporting study by Akhtera et al. (2015), the application of mustard oil cake has shown significant inhibition of the radial growth of *Rhizoctonia solani* infecting different crops, and lead to increased crop productivity. Thakkar et al. (2018) tested six organic amendments at various concentrations against *Sclerotium rolfsii*. The findings showed an inhibition of 76.74%, 91.71%, and 98.55% with castor cake at 10%, 20%, and 30% concentrations respectively. Similarly, neem cake at concentrations of 10%, 20% and 30% exhibited 38.11%, 55.52%, 80.97% inhibition respectively.

Ridomil MZ (0.2%) emerged as the most efficacious treatment in disease management, yielding minimum fruit rot incidence and leaf blight severity of 9.50% and 6.25%, respectively, with a maximum reduction of 89.95% and 92.99%.

However, treatment with vermicompost resulted in a maximum fruit rot incidence of 81.22% and leaf blight severity of 73.25%, with a minimum reduction of 13.98% and 17.48%, respectively. In the control plots, a fruit rot incidence of 94.41% and leaf blight severity of 88.75% was observed (Figure 2c) Also, the analysis of comparative studies for two years (2022 and 2023) on bell pepper revealed that fruit rot incidence and leaf blight severity was comparatively higher in the 2023 season. Treatment with vermicompost resulted in a maximum fruit rot incidence in 2023, i.e. 84.67%, and a leaf blight severity of 75.00%. Meanwhile, in the control plots, a fruit rot incidence of 95.00% and a leaf blight severity of 90.00% was observed.

3.2. *Yield parameters of bell pepper*

The majority of the tested organic amendments, biofumigant crops and mulches increased the yield of bell pepper under field conditions compared to the control, as depicted in Table 2.

Table 2: Field evaluation of organic amendments, biofumigants and mulches on yield parameters of bell pepper infected with *P. nicotianae* var. *nicotianae* causing leaf blight and fruit rot disease

Treatments	Fruit yield plot^{-1} (kg)		
	2022	2023	Pooled
Biofumigants (Crop residues)			
Cabbage	7.10	6.46	6.78
Cauliflower	8.92	7.84	8.38
Mustard	10.37	9.52	9.95
Radish	5.77	5.14	5.45
Oil cakes			
Neem	7.99	7.15	7.57
Cotton	3.83	3.06	3.45
Mustard	9.96	8.72	9.34
Manures			
Vermicompost	3.22	2.66	2.94
Saw dust	4.58	3.99	4.28
Mulches			
Polyethylene	11.45	10.36	10.91
Pineneedle	10.97	9.85	10.41
Wheat straw	9.31	8.15	8.73
Ridomil MZ	12.33	11.91	12.12
Control	1.60	1.15	1.38
Mean	7.67	6.85	
Factors	C.D	SE(d)	SE(m)
Factor (A)-Years	0.06	0.03	0.02
Factor (B)-Treatments	0.16	0.08	0.06
Factor (A×B)	0.23	0.11	0.08

Observational studies conducted in 2022 and 2023 on the yield parameters of bell pepper revealed that black polyethylene mulch was the most effective treatment, providing a significantly maximum yield of 10.91 kg plot$^{-1.}$ It was followed by the application of pine-needle mulch which resulted in yield of 10.41 kg plot^{-1}. Various studies have pointed out the role of mulching in elevating the bell pepper yield under field conditions. In a supporting study by Liang et al. (2011), a significant increase was seen in the hot pepper yield. The yield increased by 82.30%, 65.00%, and 111.50% in 2008 under wheat straw mulch, plastic film mulch, and in no mulch conditions respectively. In contrast, lower increase of yield was observed in 2009 and 2010 as 38.10%, 17.40%, 46.50% and 14.30%, 6.50%, 19.60%, respectively under heat straw mulch, plastic film mulch, and in no mulch conditions, respectively. Plastic film mulch reportedly produced better quality fruits comparatively. Choudhary et al. (2012) recorded the highest yield of pepper while using black polyethylene mulch. The observed elevation was greater than paddy straw mulch (6.25%), transparent plastic mulch (26.12%) and the no-mulch condition (28.48%), respectively.

The use of mustard crop residue powder and mustard oil cake, which yielded 9.95 and 9.34 kg plot^{-1}, respectively, were our next best treatments in improving the yield parameters of bell pepper. The application of brassica cover crops for the purpose of biofumigation was investigated by Hansen and Keinath (2013) in the cultivation of bell pepper. The key compounds causing pesticidal activity in brassicas, isothiocyanates (ITCs), are high in concentrations when mustard was incorporated, followed by rapeseed production. Yield of pepper was observed to be greater in biofumigation treatments than control plots.

The standard check, Ridomil MZ (0.2%), resulted in the maximum yield of bell pepper (12.12 kg plot^{-1}). However, vermicompost recorded the minimum yield among all the treatments (2.94 kg plot^{-1}), and the control plots gave the lowest yield of bell pepper at 1.38 kg plot^{-1}.

4. CONCLUSION

Among the various treatments used, black polyethylene mulch, pine needle mulch; biofumigant mustard crop, and mustard oil cakes applied @ 500 g m^{-2} ten days prior to transplanting of bell pepper seedlings exhibited the most significant reduction in fruit rot incidence and leaf blight severity, while also enhancing the fruit yield.

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