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Integrated Disease Management for the Control of Powdery Mildew (*Leveillula taurica* (Lev.) Arn.) in Bell Pepper

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ABSTRACT

Powdery mildew is a serious fungal disease in bell pepper leading to heavy yield losses both under greenhouse and field conditions. Initially the present study focused on the management of powdery mildew disease using several chemical and non-chemical treatments under field evaluation. The treatments included 13 chemical fungicides, 8 biological control agents, 13 plant extracts (botanicals) and the study was conducted in two experimental seasons during 2004-2005 in bell pepper varieties 'California Wonder' and 'Indra'. Dinocap (1 ml l^{-1}) among chemical fungicides, *Ampelomyces quisqualis* (20 g l^{-1}) among biological control agents and neem oil (20 ml l^{-1}) among botanicals recorded as the best components by recording a minimum per cent of disease index and the maximum yield compared to untreated controls. The same trend was observed in both seasons. In a second set of experiments, the most effective components were integrated to further minimize the use of fungicides thus an Integrated Disease Management (IDM) package was developed and tested in the field. By adopting this IDM the yield of 'California Wonder' and 'Indra' bell pepper showed an increase of 342. 8 and 122.3%, respectively; the corresponding values for the control were 93.6 and 93.2%, respectively. This new IDM package made possible to reduce dinocap spray to only one treatment. Hence, the developed technology appears very promising mainly because is economically feasible, increases the yield and is environmentally safe as it reduces the cost and increases the returns.

Keywords: biological control agents, botanicals, California wonder, *Capsicum annuum*, fungicides, Indra

INTRODUCTION

Bell peppers belong to the genus *Capsicum* of the *Solanaceae*. Although this genus includes 25 species, most of the bell peppers cultivated in temperate and tropical areas belong to the species *Capsicum annuum* and are thought to have originated in Mexico and Central America (Andrews 1984). The cultivated bell peppers are herbaceous, frost-sensitive plants that can be grown as an annual or as a perennial crop in the field as well as in greenhouses. This crop is widely used not only as a fresh vegetable or condiment but also for pharmaceutical and cosmetic purposes (Bosland 2003). Bell pepper is one of the most popular and highly remunerative vegetable crops grown for fresh fruits throughout the world. In India, capsicum is grown in 4,783 ha and the production is 42,230 tones (Madavi Reddy 2003) with a productivity of 8.83 t/ha (Sidhu 1998).

Bell pepper consumption in India is increasing nowadays. High market for bell pepper is attributed to an increasing demand by urban consumers. However, its productivity in India is very low compared to western countries because bell pepper can be affected by many diseases, pests and disorders that reduce fruit quality and yield. Damage can be caused by a wide range of biological agents, including fungi, bacteria, viruses, insects, nematodes, birds and mammals (Bosland 2003). The most important diseases caused by fungi and oomycetes are powdery mildew (PM), anthracnose, *Cercospora* leaf spot, charcoal rot, *Choanephora* blight, damping-off, root rot, *Fusarium* stem rot, *Fusarium* wilt, gray leaf spot, gray mold, *Phytophthora* blight, southern blight, white mold and *Verticillium* wilt. Among these fungal diseases PM, caused by *Leveillula taurica* (Lev.) Arn., an obligate pathogen, takes a heavy toll in field conditions every year all over the world (Palti 1988) and 10-15% yield loss under greenhouse conditions (Cerkauskas *et al*. 1999).

For over two decades, many systemic and non systemic fungicides have been reported to control the PM of bell pepper (Maheshwari *et al*. 1992; Fiori *et al*. 1996; Dhruj *et al*. 2000; Manoj Kumar 2007). However, the hybrids grown under intensive cultivation, indiscriminately receive very high doses of fungicides and insecticides resulting in the development of resistance to many diseases, pests, outbreak of secondary pests and accumulation of pesticide residues in the final produce. Environmental and consumer concerns have focused interest on the development of biological control agents as an environmentally friendly strategy for the protection of agricultural and horticultural crops against phyllopathogens (Dunne *et al*. 1998). Hence, biological control agents became an alternative to chemical fungicides (Ravikumar 1998; Biju 2000), and plant products (Amadioha 1998), which have also gained more importance in modern day agriculture to manage plant pathogens. However, there is no single integrated package of all these components for the management of PM in bell pepper.

The aim of this study was to find out an innovative and environmentally safe strategy for the control of PM in bell pepper by integrating chemical fungicides, biological agents and botanicals treatments. The developed Integrated Disease Management (IDM) is a package that would lower the disease incidence and increase the yield.

MATERIALS AND METHODS

A study on the development of an IDM package for bell pepper was carried out in 2004-2005 at the Indian Institute of Horticultural Research, Hessaraghatta, Bangalore (Latitude: 12°58′ N, Longitude: 77°35′ E, Elevation 910 m above mean sea level), India.

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The major disease dealt with during the study was PM. Bell pepper varieties 'Indra' (F_1 hybrid) and 'California Wonder' (CW) (open pollinated) were grown using recommended practices (Berke *et al.* 2003). Seedlings in the nursery were well protected using 80 mesh nylon net to avoid insect attack at the seedling stage. The seedlings were transplanted to an area of 4 m^2 and five replications were maintained for each treatment. A spacing of 60 × 45 cm for 'Indra' and 60 × 30 cm for CW was applied and a dose of 150 N: 100 P: 60 K ('Indra') and120 N: 80 P: 50 K (CW) was applied to the soil.

Chemical and non-chemical treatments

The efficacy of all 13 chemical fungicides (**Table 1**), 8 biological control agents (viz., *Trichoderma harzianum* Rifai, *Trichoderma viride* Pers.:Fr., *Pseudomonas fluorescens* Migula, *Bacillus subtilis* (Ehrenberg) Cohn., *Beauveria bassiana* (Balsamo) Vuillemin., *Ampelomyces quisqualis* Ces., *Verticillium lecanii* (Zimm.) Viegas and *Gliocladium virens* Millar.) and 13 botanicals (**Table 2**) were evaluated under field conditions for two experimental seasons viz., rabi (2004) and kharif (2005) against PM pathogen in 'Indra' and CW.

Preparation of talc based biological control agents

Initially, all the fungal bio-agents were maintained for 7 days on potato dextrose (PD) agar (Himedia Ltd., India) and bacterial cultures for 2 days on nutrient agar (Himedia Ltd.). *Trichoderma*-specific medium (Elad *et al.* 1981) was used to grow *T. harzianum* and *T. viride*, PD broth was used for mass multiplication of *B. bassiana*, *A. quisqualis*, *V. lecanii* and *G. virens*. Nutrient broth (5 g peptone + 3 g beef extract in 1 L of water and autoclave; 7.0 pH) was used for bacterial cultures viz. *P. fluorescens* and *B. subtilis*. These biological control agents were inoculated into different liquid broths and were incubated in a shaker for mass multiplication; fungal bio-agents were incubated at 28°C, 100 rpm for 7 days and bacterial cultures were incubated at 35°C, 120 rpm for 3 days. Later, these fully grown cultures were mixed with talc powder to achieve a concentration of 10^{-8} cfu/g talc. All the biological control agents were applied at 20 g l^{-1} as a foliar application to control PM. This talc formulation was used as foliar spray to test its efficacy on the incidence of PM.

Preparation of PM spore solution

The method follows a previously described protocol (Manoj Kumar *et al*. 2007). In brief, the lower leaves of bell pepper infected by powdery mildew *L. taurica* were freshly collected from the unsprayed control plots of experimental field at I.I.H.R, Bangalore, India. Thus the lower sporulated surface was washed with sterile distilled water to collect conidial spores that were adjusted to 5 × 10^5 spores/ml. A freshly prepared PM spore suspension was uniformly sprayed to the bell pepper plants 25 days after transplantation (DAT) and PM disease was ensured. The inoculum was sprayed in the evenings (after 8 pm) since, the low temperature and high humidity amplify the efficacy of conidial spore germination.

Test procedure and observation

To assess the efficacy of chemical fungicides, biological control agents and botanicals, five sprays of the above components were given to the respective plots at 15 day intervals starting from 35 DAT. The recommended dosage of chemical fungicides (**Table 1**), biological control agents (20 g l^{-1}) and botanicals (**Table 2**) were used for the above spray. Disease scoring using a 0-5 scale (0 = no symptoms, 5 = severe symptoms) (Wheeler 1969). Observations were made on the yield at every harvest and data was pooled.

Statistical analysis

The experiment was conducted in a randomized block design (RBD) and plants were treated with 13 chemical fungicides, 8 biological control agents, 13 botanicals and each treatment had five replications. Per cent disease index (PDI) was calculated by using the following formula proposed by Wheeler (1969).

$$\textbf{PDI} = \frac{\text{Sum of individual ratings}}{\text{No. of plants assessed}} \times \frac{100}{\text{Maximum disease grade}}$$

The PDI was normalized through square root transformation and subjected to analysis of variance (ANOVA) followed by mean separation by the Student Newman-Keul's test (p=0.05). All analyses were performed using the SAS (1996) package.

Table 1 Dosages of fungicides used against powdery mildew of bell pepper.

Fungicide	Trade name® (Name of company)	Active ingredient/ formulation	Dosage/l
Carbendazim	Bavistin (BASF)	50% WP	1.00 g
Difenconazole	Score (Syngenta)	25% EC	0.50 ml
Hexaconazole	Contaf (Rallis)	5% EC	0.50 ml
Penconazole	Topaz (Syngenta)	10% EC	1.00 ml
Propiconazole	Tilt (Syngenta)	25% EC	0.50 ml
Triadimefon	Bayleton (Bayer)	25% WP	1.00 g
Chlorthalonil	Kavach (Syngenta)	75% WP	2.00 g
Iprobenfos	Kitazin (PCI, Ltd.)	48% EC	1.00 g
Tridemorph	Calixin(BASF)	75 EC	1.00 ml
Wettable sulphur	Sulfex (Excel Industries)	80% WP	3.00 g
Fenarimol	Rubigon (Dupont)	50 EC	0.30 ml
Dinocap	Karathane (Bayer)	48% EC	1.00 ml
Tebuconazole	Folicur (Bayer)	3.6 F	1.00 ml

Table 2 Dosages of botanicals used against powdery mildew of bell pepper.

Trade/common name	Botanicals	Dosage/l
Nimbicidin®	Neem based fungicide	5 ml
Allium cepa	Onion	10 g
Allium sativum	Garlic	10 g
Curcuma longa	Turmeric powder	10 g
NSKE	Neem Seed Kernel Extract	40 g
Zinger officinale	Ginger	10 g
Ocimum sanctum	Tulasi	10 g
Cynodon	*Cynodon* grass	100 g
Ovis	*Lantana* based fungicide	5 ml
Tricure®	-	5 ml
Achook®	-	5 ml
Neem oil (crude)	Oil	20 ml
Pongamia oil (crude)	Oil	20 ml

RESULTS

Both the incidence of PM and yield of bell pepper (CW and 'Indra') in two consecutive seasons, first (August 2004) and second (May 2005) trial were recorded and data is presented in **Tables 3-5**. Most of the treatments were significantly effective in reducing the incidence of PM compared to the untreated control.

Chemical control

In the first trial, PM incidence was observed throughout the cropping period in fungicide-treated plots. The percent disease index (PDI) of *L. taurica* was 7.3 in 'Indra', 8.8 in CW in the dinocap-treated plots followed by triadimefon with 8.8 and 9.8, respectively; on the contrary control plots values were 73.0 and 89.0 for 'Indra' and CW, respectively. The maximum PDI was observed in difenconazole (37.8 in 'Indra', 40.8 in CW) and chlorthalonil (44.8 in 'Indra', 46.5 in CW). However, the other treatments were also compared to the control (**Table 3**). Among the treatments, dinocap recorded a maximum yield of 21.6 and 13.4 t ha^{-1} in 'Indra' and CW respectively, 20.3 and 11.8 t ha^{-1} in triadimefon-treated plots. Minimum yield of 15.5 t ha^{-1} was observed in chlorthalonil-treated plots in 'Indra' and 6.2 t ha^{-1} in CW. Control plots recorded 11.2 and 3.5 t ha^{-1} in 'Indra' and CW,

Table 3 Field evaluation of chemical fungicides against powdery mildew of bell pepper.

Fungicide	Indra				California wonder			
	Kharif (trial I)		Rabi (trial II)		Kharif (trial I)		Rabi (trial II)	
	PDI*	Yield (t/ha)	PDI	Yield (t/ha)	PDI	Yield (t/ha)	PDI	Yield (t/ha)
Carbendazim	34.3 (5.85) g	16.5 (4.06) f	35.3 (5.94) h	15.8 (3.97) f	39.8 (6.30) i	7.2 (2.67) gh	42.5 (6.52) j	6.9 (2.64) hi
Difenconazole	37.8 (6.14) h	15.9 (3.99) g	38.5 (6.20) i	15.4 (3.92) f	40.8 (6.38) i	6.8 (2.61) h	41.5 (6.44) i	6.6 (2.56) i
Hexaconazole	31.3 (5.59) f	17.3 (4.15) e	32.3 (5.68) g	17.2 (4.15) d	34.5 (5.87) h	7.4 (2.72) g	35.8 (5.98) h	7.3 (2.7) gh
Penconazole	26.3 (5.12) e	18.2 (4.27) d	27.3 (5.22) f	16.5 (4.06) e	29.8 (5.45) f	8.6 (2.94) ef	31.3 (5.59) g	8.3 (2.87) f
Propiconazole	20.8 (4.56) d	18.8 (4.33) c	21.0 (4.58) e	17.9 (4.23) c	21.8 (4.66) e	9.2 (3.02) de	23.3 (4.82) f	9.2 (3.02) e
Triadimefon	8.8 (2.96) ab	20.3 (4.50) b	9.0 (3.00) b	19.9 (4.46) b	9.8 (3.12) b	11.8 (3.43) b	11.8 (3.43) c	11.0 (3.32) b
Chlorthalonil	44.8 (6.69) i	15.5 (3.93) g	45.5 (6.75) j	14.7 (3.83) g	46.5 (6.82) j	6.2 (2.48) i	48.3 (6.95) k	5.9 (2.43) j
Iprobenfos	30.8 (5.55) f	17.8 (4.21) de	32.3 (5.68) g	17.3 (4.15) d	32.5 (5.70) g	7.6 (2.75) g	34.3 (5.85) h	7.4 (2.72) g
Calixin	11.8 (3.43) c	17.8 (4.22) d	13.0 (3.61) d	17.3 (4.15) d	14.8 (3.84) d	9.4 (3.07) d	16.3 (4.03) d	9.1 (3.0) e
Wettable sulphur	10.3 (3.20) dc	18.9 (4.35) c	11.3 (3.35) e	18.0 (4.24) c	11.5 (3.39) c	10.2 (3.19) c	12.5 (3.54) c	9.9 (3.15) d
Fenarimol	20.8 (4.56) d	16.7 (4.09) f	21.4 (4.62) e	17.1 (4.13)de	21.0 (4.58) e	8.5 (2.91) f	22.3 (4.72) e	8.2 (2.86) f
Dinocap	7.3 (2.69) a	21.6 (4.65) a	7.2 (2.67) a	21.9 (4.68) a	8.8 (2.96) a	13.4 (3.65) a	9.0 (3.00) a	12.8 (3.58) a
Tebuconazole	9.5 (3.08) abc	19.9 (4.46) b	9.3 (3.04) b	20.1 (4.48) b	10.8 (3.28) bc	11.3 (3.36) b	10.5 (3.24) b	10.5 (3.24) c
Control	73.0 (8.54) j	11.2 (3.35) h	76.3 (8.72) k	11.0 (3.32) h	89.0 (9.43) k	3.5 (1.87) j	90.3 (9.50) l	3.2 (1.77) k
CD (P=0.05%)	2.37	0.51	1.16	0.65	1.08	0.56	0.85	0.42
S.Em ±	0.83	0.18	0.41	0.23	0.37	0.19	0.29	0.14

Means followed by common letters within a column are non significant at 5%.
Figures in parentheses are square root transformed values.
*PDI: Percent Disease Index

Table 4 Field evaluation of different biological control agents against powdery mildew of bell pepper.

Biological control agents	Indra				California wonder			
	Kharif (trial I)		Rabi (trial II)		Kharif (trial I)		Rabi (trial II)	
	PDI*	Yield (t/ha)	PDI	Yield (t/ha)	PDI	Yield (t/ha)	PDI	Yield (t/ha)
Trichoderma viride	66.0 (8.12) f	16.3 (4.03) c	68.3 (8.26) f	16.2 (4.02) e	76.8 (8.76) e	5.7 (2.38) e	79.5 (8.92) g	6.1 (2.47) d
Trichoderma harzianum	66.8 (8.17) f	15.3 (3.91) d	69.3 (8.32) g	15.2 (3.9) f	75.3 (8.67) d	5.8 (2.40) e	77.5 (8.80) f	6.0 (2.44) d
Pseudomonas fluorescens	59.8 (7.73) c	15.0 (3.87) d	62.3 (7.89) e	17.2 (4.14) d	69.3 (8.32) c	6.7 (2.59) c	70.0 (8.37) c	7.0 (2.65) c
Bacillus subtilis	62.3 (7.89) d	17.3 (4.15) b	61.3 (7.83) d	17.7 (4.20) c	70.3 (8.38) c	6.4 (2.53) d	71.3 (8.44) d	6.9 (2.63) c
Beauveria bassiana	64.3 (8.02) e	17.3 (4.15) b	51.3 (7.16) c	18.4 (4.28) b	75.3 (8.67) d	5.7 (2.38) e	76.3 (8.73) e	6.0 (2.44) d
Ampelomyces quisqualis	43.3 (6.58) a	19.3 (4.39) a	45.5 (6.75) a	19.3 (4.39) a	55.8 (7.47) a	8.9 (2.99) a	56.0 (7.48) a	9.0 (3.00) a
Verticillium lecanii	47.5 (6.89) b	18.6 (4.32) a	48.3 (6.95) b	19.0 (4.36) a	61.0 (7.81) b	7.1 (2.66) b	62.3 (7.89) b	7.6 (2.75) b
Gliocladium virens	65.5 (8.09) ef	17.4 (4.17) b	62.8 (7.92) e	17.5 (4.18) cd	75.3 (8.67) d	5.2 (2.29) f	76.0 (8.72) e	5.9 (2.42) d
Control	73.0 (8.54) g	11.2 (3.35) e	76.3 (8.72) h	11.0 (3.32) g	89.0 (9.43) f	3.5 (1.88) g	90.3 (9.50) h	3.2 (1.77) e
CD (P=0.05%)	1.36	0.73	0.98	0.30	1.16	0.13	0.89	0.21
S.Em ±	0.46	0.25	0.34	0.10	0.39	0.04	0.31	0.07

Means followed by common letters within a column are non significant at 5%.
Figures in parentheses are square root transformed values.
*PDI: Percent Disease Index

respectively.

Similarly, in the second trial dinocap recorded the minimum PDI of 7.2 in 'Indra', 9.0 in CW vs. 76.3 and 90.3 in control plots respectively for 'Indra' and CW. This was followed by triadimefon (9.0 in 'Indra', 11.8 in CW), tebuconazole (9.3 in 'Indra', 10.5 in CW). On the other hand, maximum PDI was observed in chlorthalonil (45.5 in 'Indra', 48.3 in CW). Correspondingly, dinocap recorded maximum yield (21.9 and 12.8 t ha^{-1} in 'Indra' and CW, respectively) vs. control (11.0 and 3.2 t ha^{-1} in 'Indra' and CW). This was followed by triadimefon (19.9 and 11.0 t ha^{-1} in 'Indra' and CW) and tebuconazole (20.1 and 10.5 t ha^{-1} in 'Indra' and CW) and remaining treatments were also recorded significantly high yield compared to control (**Table 3**).

Non-chemical control

Biological control agents

In trial I, the minimum PDI of 43.3 in 'Indra' and 55.8 in CW was observed in *A. quisqualis*, followed by *V. lecanii* (47.5 in 'Indra' and 61.0 in CW). The maximum PDI of 66.8 in 'Indra' and 76.8 in CW, respectively, was recorded in *T. harzianum*. Results were very similar when plants of both cultivars were treated with *T. viride* However, untreated control plots recorded 73.0 in 'Indra' and 89.0 in CW. Among the treatments, *A. quisqualis* recorded a maximum yield of 19.3 and 8.9 t ha^{-1} in 'Indra' and CW, respectively followed by *V. lecanii* (18.6 t ha^{-1} in 'Indra', 7.1 t ha^{-1} in CW). The minimum yield was observed in *P. fluorescens* (15.0 t ha^{-1} in 'Indra') and *G. virens* (5.2 t ha^{-1} in CW). However, control plots recorded 11.2 t ha^{-1} in 'Indra' and 3.5 t ha^{-1} in CW (**Table 4**).

In trial II, the minimum PDI was observed from plots treated with *A. quisqualis* (45.5 in 'Indra' and 56.0 in CW) followed by *V. lecanii* (48.3 in 'Indra' and 62.3 in CW). The maximum PDI of 69.3 and 79.5 in 'Indra' and CW, respectively was observed for *T. harzianum* and *T. viride*. However, control plots recorded 76.3 and 90.3 in 'Indra' and CW, respectively. Similarly, maximum yield was observed in *A. quisqualis* (19.3 and 9.0 t ha^{-1} in 'Indra' and CW, respectively) followed by *V. lecanii* (19.0 and 7.6 t ha^{-1} in 'Indra' and CW). Minimum yield was observed in *T. harzianum* (15.2 t ha^{-1} in 'Indra') and *G. virens* (5.9 t ha^{-1} in CW). However, control plots recorded 11.0 and 3.2 t ha^{-1} in 'Indra' and CW (**Table 4**).

Botanicals

In the first trial, the PDI of *L. taurica* was 16.8 in 'Indra', 20.3 in CW in neem oil-treated plots compared to 73.0 and 89.0 in control, respectively. This was followed by pongamia oil (19.5 in 'Indra', 21.5 in CW) and *Cynodon* (25.8 and 27.0). *Curcuma longa* showed a maximum PDI of 41.3 in 'Indra' and 40.8 in CW. However, the remaining treatments also performed well compared to control (**Table 5**). Among the treatments, neem oil recorded maximum yield of 19.6 and 16.3 t ha^{-1} in 'Indra' and CW respectively, 18.5 and 15.7 t ha^{-1} in pongamia oil-treated plots; minimum yield of 11.1 in plots of 'Indra' treated with *A. cepa* and 9.2 t ha^{-1} in plots of CW treated with *C. longa* was recorded. However, controls plots recorded 11.2 and 3.5 t ha^{-1} for 'Indra'

Table 5 Field evaluation of different plant products against powdery mildew of bell pepper.

Plant products	Indra				California wonder			
	Kharif (trial I)		Rabi (trial II)		Kharif (trial I)		Rabi (trial II)	
	PDI*	Yield (t/ha)	PDI	Yield (t/ha)	PDI	Yield (t/ha)	PDI	Yield (t/ha)
Nimbicidin	30.0 (5.48) d	16.3 (4.03) cd	32.0 (5.66) cde	15.7 (3.97) d	31.5 (5.61) c	12.1 (3.48) de	35.0 (5.92) e	11.6 (3.40) f
Allium cepa	33.8 (5.81) e	11.1 (3.34) g	36.3 (6.02) f	10.5 (3.24) g	37.5 (6.12) e	10.2 (3.19) gh	40.8 (6.38) f	9.9 (3.15) h
Allium sativum	38.3 (6.18) f	11.4 (3.38) fg	40.3 (6.34) g	11.7 (3.42) f	39.5 (6.28) f	9.9 (3.14) h	42.3 (6.50) fgh	9.4 (3.07) h
Curcuma longa	41.3 (6.42) g	12.5 (3.54) f	43.5 (6.60) h	12.0 (3.46) e	40.8 (6.38) f	9.2 (3.03) i	43.8 (6.61) h	8.9 (2.99) i
NSKE	29.3 (5.41) d	16.3 (4.04) cd	29.3 (5.41) c	15.8 (3.97) d	32.3 (5.68) c	12.8 (3.57) d	35.0 (5.92) e	12.6 (3.55) e
Zinger officinale	33.0 (5.74) e	15.4 (3.92) d	34.0 (5.83) ef	15.0 (3.88) d	34.3 (5.85) d	13.4 (3.65) c	35.8 (5.98) e	13.4 (3.65) cd
Ocimum sanctum	29.5 (5.43) d	13.9 (3.73) e	31.0 (5.57) cd	13.7 (3.69) e	30.5 (5.52) c	13.8 (3.71) bc	31.0 (5.57) d	13.8 (3.71) c
Cynodon	25.8 (5.07) c	17.1 (4.13) c	26.3 (5.12) b	16.9 (4.11) c	27.0 (5.20) b	14.5 (3.80) b	28.5 (5.34) c	14.5 (3.80) b
Ovis	29.3 (5.41) d	14.0 (3.73) e	32.5 (5.70) de	13.6 (3.68) e	30.3 (5.50) c	12.8 (3.57) d	31.8 (5.63) d	12.8 (3.57) de
Tricure	39.3 (6.26) fg	12.5 (3.54) f	41.0 (6.40) gh	12.1 (3.48) e	39.0 (6.20) ef	11.3 (3.36) ef	41.5 (6.44) fg	11.3 (3.36) f
Achook	39.8 (6.30) fg	11.4 (3.38) fg	45.5 (6.75) i	10.9 (3.30) g	40.8 (6.38) f	10.6 (3.26) fg	43.3 (6.58) gh	10.6 (3.26) g
Neem oil	16.8 (4.09) a	19.6 (4.43) a	20.3 (4.50) a	19.2 (4.38) a	20.3 (4.50) a	16.3 (4.04) a	20.8 (4.56) a	16.3 (4.04) a
Pongamia oil	19.5 (4.42) b	18.5 (4.30) b	21.3 (4.61) a	18.2 (4.27) b	21.5 (4.64) a	15.7 (3.97) a	22.8 (4.77) b	15.7 (3.97) a
Control	73.0 (8.54) h	11.2 (3.35) g	76.3 (8.75) j	11.0 (3.32) f	89.0 (9.43) g	3.5 (1.86) j	90.3 (9.50) i	3.2 (1.77) j[j]
CD (P=0.05%)	2.41	1.04	2.71	1.02	1.99	0.65	1.90	0.60
S.Em ±	0.84	0.36	0.95	0.36	0.69	0.23	0.66	0.21

Means followed by common letters within a column are non significant at 5%.
Figures in parentheses are square root transformed values.
*PDI: Percent Disease Index

Table 6 Final field trial of Integrated Disease Management (IDM) package against powdery mildew of bell pepper.

Genotype/Treatment	PDI*	PDI decreased over control	Yield of capsicum (t/ha)	Percent increase in yield over control
IDM: Indra	5.00	93.2	24.9	122.3
Dinocap	7.80	83.3	21.5	91.9
Ampelomyces quisqualis	44.0	39.7	19.2	71.4
Neem oil	19.8	72.9	18.0	60.7
Control: Indra	73.0	-	11.2	-
IDM: California Wonder	5.20	93.6	15.5	342.8
Dinocap	9.50	88.2	13.1	274.8
Ampelomyces quisqualis	55.5	30.9	9.1	160.0
Neem oil	21.5	73.2	15.0	328.5
Control: California Wonder	80.3	-	3.50	-

*PDI: Percent Disease Index

and CW, respectively.

Similarly, in the second trial neem oil-treated plots were found to be the best in minimizing the incidence of PM, 20.3% in 'Indra' and 20.8% in CW. The second best result was 21.3 and 22.8% in pongamia oil-treated plots for 'Indra' and CW, respectively. Maximum PDI of 45.5 and 43.5% in achook and *C. longa* were recorded respectively in 'Indra'. In CW the recorded values were 43.8 and 43.3% in *C. longa* and achook, respectively. However, the PDI of the untreated control was 76.3% in 'Indra' and 90.3% in CW. Among the treatments neem oil recorded maximum yield of 19.2 and 16.3 t ha^{-1} in 'Indra' and CW, respectively; 18.2 and 15.7 t ha^{-1} in pongamia oil-treated plots. Minimum yield of 10.5 t ha^{-1} was observed in *A. cepa*-treated plots for 'Indra' and 8.9 t ha^{-1} in *C. longa* for CW. However, control plots recorded 11.0 and 3.2 t ha^{-1} for 'Indra' and CW, respectively.

Development of IDM package

With the objective of developing an effective IDM package for bell pepper against PM, the information was generated with different DM (using chemical fungicides, biological control treatments and botanicals) strategies. The results obtained in this study made possible to identify biological control agents and botanicals that were used alone or in combination with fungicides.

Among the fungicides, dinocap resulted to be effective in minimizing PM disease and increasing fruit yield in 'Indra' and CW during the first and second trial. Hence, dinocap was adopted as the fungicidal component in the IDM package to be tested. Besides the chemical fungicide, a fungal antagonist *A. quisqualis* and the botanical neem oil were also found to be effective an thus these two components were adopted as the biological control agent and botanical in the IDM package to be tested (**Tables 3-5**).

Spray schedule for IDM package developed and tested

The selected chemical fungicide, biological control agent and botanical were the components of IDM which was tested in the field on 'Indra' and CW against PM. These components were applied in the following sequence starting from 30 DAT, i.e 1) A spray of *Ampelomyces quisqualis* at 20 g l^{-1} 30 DAT, 2) 20 ml neem oil/l of water at 40 DAT and 3) Dinocap at 1 ml l^{-1} 60 DAT against PM. If the crop is prolonged the sequence mentioned above can be repeated.

IDM package

A field trial was performed against PM disease in bell pepper using the above developed IDM package. The observations recorded on PDI and yield during final trials are presented in **Table 6**. 'Indra' grown with IDM recorded a 5.0% PDI vs. 7.8, 44.0 and 19.8 in dinocap, *A. quisqualis* and neem oil respectively. Similarly, the PDI decreased over control was 83.3, 39.7 and 72.9 respectively in dinocap, *A. quisqualis* and neem oil. In contrast, 'Indra', when grown adopting IDM, recorded a 93.2% PDI decrease over control. Similarly, CW grown with IDM recommendations recorded 5.2% PDI vs. 9.5, 55.5 and 21.5 in dinocap, *A. quisqualis* and neem oil, respectively with the decrease in PDI being 88.2, 30.9 and 73.2 more than the control. CW, however, when grown with the adopted IDM recorded a 93.6% decrease in PDI over control.

'Indra' grown with IDM recorded a yield of 24.9 t ha^{-1} vs. 21.5, 19.2 and 18.0 in dinocap, *A. quisqualis* and neem oil respectively. Similarly, the percent increase in yield over control was 91.9, 71.4 and 60.7 t ha^{-1} respectively in dinocap, *A. quisqualis* and neem oil. 'Indra' grown adopting IDM showed a 122.3% increase in yield over control. Similarly, CW grown with IDM recorded yield of 15.5 t ha^{-1} vs.

13.1, 9.1 and 15.0 t ha^{-1} in dinocap, *A. quisqualis* and neem oil, respectively with the percent increase in yield being 274.8, 160 and 328.5% more than the control. CW grown adopting IDM recorded a 342.8 percent increase in yield over control. However, absolute control plots had high incidence of PM disease and low yield (**Table 6**).

DISCUSSION

Powdery mildew is one of the most serious fungal disease of bell pepper causing heavy yield losses. Detailed investigations were undertaken in the present study focusing on the development of an IDM package for the control of PM in bell pepper based on the information generated on the use of chemical fungicides, biological control agents and botanicals. Among these, the most effective components were integrated to further minimize the use of fungicides and a package was thus developed and tested.

Among the thirteen fungicides evaluated for their field efficacy against PM of bell pepper in CW and 'Indra' for kharif and rabi seasons, dinocap resulted to be the best fungicide by recording a minimum PDI and maximum yield. Observations recorded for both seasons followed the same trend. Dinocap (0.1%) treatment considerably reduced the PM disease incidence in chilli (Pawar *et al*. 1985; Saroj Singh and Satish Lodha 1985; Sridhar 1987), pea (Panja and Chaudhuri 1994) and fenugreek (Dhruj *et al*. 2000) as compared to the untreated controls. In the present study triadimefon (0.1%), tebuconazole (0.1%) and wettable sulphur (0.3%) were the next best chemicals found effective in controlling PM. Fiume (1997) reported tetraconazole (0.03%) as the most effective treatment in controlling PM. Tsror *et al*. 2003 reported that sulfur-containing compounds efficiently controlled PM of bell pepper. However, triadimenol (17.5 g a.i./100 L H_2O) efficiently controlled PM in the greenhouse (Souza *et al*. 2003).

Biological control is now gaining more importance as an eco-friendly means of disease management. Among the different fungal antagonists, *Trichoderma* species have been extensively used by plant pathologists due to their high efficacy, broad-spectrum activity and ease of isolation and mass multiplication. In present days *Ampelomyces quisqualis* a deuteromycetes fungus, is gaining more importance as a hyperparasites to powdery mildews. Among the bacterial antagonists, *P. fluorescens* has a great potential for the control of plant diseases and for its ability to protect seeds and roots from fungal infection (Girija Ganeshan and Manoj Kumar 2006). It is known to enhance plant growth and reduce the severity of many fungal diseases (Hoffland *et al.* 1996; Wei *et al.* 1996). Three foliar sprays of *A. quisqualis* (~1.8 × 10^{11} spores/ha) were effective against PM of peppers (Tsror *et al*. 2003).

In the present study all treatments were statistically significant with respect to control. However, the fungal antagonist, *Ampelomyces quisqualis* significantly reduced the disease and increased the yield in kharif and rabi. Overall the results indicated that all treatments performed better than the untreated control. It can be suggested that four aerial sprays of *A. quisqualis* at 15-day intervals could effectively protect the crop from PM and increase the yield. The next best fungal antagonist was *V. lecanii* (~1 × 10^{12} spores/ha). Tsror *et al*. (2003) observed that AQ10 (*A. quisqualis* at ~1.8 × 10^{11} spores/ha) significantly reduced PM on bell pepper. Similarly, *T. harzianum* T39 (TRICHODEX at 0.4%) and AQ10 (*A. quisqualis* at ~1.8 × 10^{11} spores/ha) in a warm greenhouse climate resulted in effective disease control (Brand *et al*. 2002). The present results are in agreement with the findings of Dik and Wubben (2002) who reported that *A. quisqualis*, *V. lecanii* and *T. harzianum*, independently or in combination, controlled PM in cucumber, tomato, pepper, rose and kalanchoe.

Use of botanicals in an agro-ecosystem is now emerging as one of the prime means to protect crop produce and environment from pesticide pollution, which is a global problem. Botanicals possess an array of properties including antifungal, insecticidal, antiviral, and antibacterial properties. In the field evaluation of botanicals carried out in this study on, neem oil emerged as the best botanical in the control of PM; furthermore it was able to increase the yield in both 'Indra' and CW during both seasons. Venkatrao (1997) and Ravikumar (1998) and Biju (2000) demonstrated that commercially available nimbicidin® at 0.4, 0.5 and 0.4% effectively reduced the PM incidence of green gram, rose and pea respectively.

Based on field investigations in two seasons the best fungicide, biological control agent and botanical were selected and an IDM package was developed and tested on 'Indra' and CW in a final field trial. As a result bell pepper grown by adopting IDM recorded a 342.8 and 122.3% increase in yield over control in CW and 'Indra', and the disease decreased over control was 93.6 and 93.2%, respectively.

Sequential spray of mancozeb, *P. fluorescens*, hexaconazole, *T. harzianum*, dinocap, hexaconazole, and *B. subtilis* was found effective in reducing powdery mildew disease (PDI = 20.36) and increasing the yield (14.3 t/ha) in chilli, whereas the untreated control recorded a PDI of 30.2 and yield of 11.5 t/ha. Bioagents alone did not significantly succeed in both reducing the disease and increasing the yield as compared to control (Anonymous 2007). In another study, integrated management of botrytis grey mould of chickpea was adopted during 2003-05 which resulted in mean yields that exceeded 1 t ha^{-1}, making chickpea very competitive with other cropping options for the Rabi season (http://www.aciar.gov.au/project/CIM/2001/039). In our study by adopting the above developed IDM package the number of dinocap sprays was reduced to only one. If the crop is prolonged the sequence mentioned in the package can be repeated. Overall, the treatments with biological control agents, botanicals and fungicides were minimized to one spray at 30, 45 and 60 DAT. In IDM technology, the use of biological control agents (*A. quisqualisi*) and botanicals (neem oil) for the control of PM of bell pepper has been found to be more effective than spraying chemical fungicide alone. Since, the number of synthetic fungicides sprays was drastically reduced, thereby reducing the health hazards associated with indiscriminate spraying of chemical fungicides. Further, it is less harmful to the environment. The technology needs to be popularized and made sustainable after addressing the constraints of non-availability of botanicals expressed by the farmers From the present research the developed IDM package is a commendable one and can be adopted by farmers for high production with less input.

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