STUDIES ON PEA ROOT ROT/WILT COMPLEX DISEASE

THESIS

By

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(A-2014-30-056)

Submitted to

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CERTIFICATE – I

This is to certify that the thesis entitled **"Studies on pea root rot/wilt complex disease"** submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science (Agriculture)** in the discipline of **Plant Pathology** of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Mrs. Nisha Kumari (A-2014-30-056)** daughter of **Late Sh. Madan Lal** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

Place: Palampur
Dated: , 2016

(Dr. B.R. Thakur)
Major Advisor

CERTIFICATE- II

This is to certify that the thesis entitled **"Studies on pea root rot/wilt complex disease"** submitted by **Mrs. Nisha Kumari (A-2014-30-056)** daughter of **Late Sh. Madan Lal** to the CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture)** in the discipline of **Plant Pathology** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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"In the Name of God, the Most Beneficial the Most Merciful"

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Needless to say, all errors and omissions are mine.

Place: Palampur

Dated ***(NISHA KUMARI)***

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LIST OF ABBREVIATIONS USED

Sr. No.	Abbreviation	Meaning
1	et al.	et alii (and others)
2	i.e	Id est (that is)
3	*viz.*	vi delicet (namely)
4	p.	Page
5	^{o}C	degree Celsius
6	g	Gram
7	kg	Kilogram
8	/	Per
9	%	per cent
10	Fig.	Figure
11	cm	centimeter
12	mm	Millimeter
13	hr	hour(s)
14	&	and
15	q	quintal
16	ha	Hectare
17	sp.	Species
18	ppm	parts per million
19	@	at the rate
20	t	Ton
21	ml	Milliliter
22	f. sp.	Formae specialis
23	w/w	weight by weight
24	µm	Micrometer
25	MT	Metric ton
26	M	1 Molar

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Title of thesis	**:**	Studies on pea root rot/wilt complex disease
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ABSTRACT

The present investigations entitled **"**Studies on pea root rot/wilt complex disease**"** had been undertaken in the Department of Plant Pathology, College of Agriculture, CSK HPKV, Palampur during 2014-2016. Pea root rot /wilt complex had been noticed as an emerging problem in different agro climatic zones of pea growing regions of Himachal Pradesh. The disease has been observed with different intensity levels in different pea growing areas of the state. In Zone IV, the highest disease incidence of 54.7 % was recorded at HAREC, Kukumseri whereas, in Zone III, the disease incidence remained in moderate form i.e. 19.7%. However, in Zone II, highest disease incidence of 35.3% was recorded at Palampur.

The two species of *Fusarium viz., F. solani* f. sp. *pisi* and *F. oxysporum* f. sp. *pisi* were found associated with pea root rot/wilt complex in the state. Both species produced distinct symptoms when inoculated on pea seedlings in test tubes containing Hoagland's solution. *F. solani* f. sp. *pisi* was solely responsible to cause root rots of pea resulting in yellowing of leaves from basal leaf to upward whereas, *F. oxysporum* f. sp. *pisi* was responsible to cause wilting without root rots by clogging of xylem vessels.

For disease management different components *viz.*, composts, bioagents, botanicals, chemicals and germplasm were evaluated *in vitro* to frame the management strategies. Vermicompost showed the maximum mycelial inhibition of 39.7% against *F. oxysporum* f. sp. *pisi* and 36.3% against *F. solani* f. sp. *pisi* followed by Farm Yard Manure with 29.7 and 30.0%, respectively. SMA-5 strain of *Trichoderma harzianu*m showed the maximum mycelial inhibition of 77.4 and 75.9 % against *F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi* respectively. The plant extracts of test botanicals proved to be effective against both the pathogens at 25% concentration resulting in >60% inhibition of mycelial growth. However, *Eupatorium adenophorum* showed maximum inhibition of 83.8 % against *F. oxysporum* f. sp. *pisi* and 77.5% against *F. solani* f. sp. *pisi* followed by *Eucalyptus* sp. resulting 83.1 and 76.1% inhibition respectively. All the test fungicides were found effective even at 50 ppm with >70 % inhibition of mycelial growth against *F. oxysporum* f. sp. *pisi* except Vitavax (carboxin 75 WP). Vitavax power (carboxin 37.5% + thiram 37.5%) and Bavistin (carbendazim 50 WP) gave cent per cent mycelial inhibition even at 500 ppm followed by Tilt (propiconazole 25 EC) and Raxil (tebuconazole 2 DS) with 93.3 and 90.4 % respectively. In case of *F. solani* f. sp. *pisi*, Bavistin (carbendazim 50 WP), Raxil (tebuconazole 2 DS) and Vitavax power (carboxin 37.5% + thiram 37.5%) yielded cent per cent mycelial inhibition at 1000 ppm. Out of one hundred thirteen elite pea lines, five pea genotypes *viz*, EC-329570, EC-329573, DPP-127-R, DPP-100, KS-268 were remained resistant against pea root rot complex.

Management module comprised of soil amendment with Vermicompost : FYM (1:1) @ 15 t/ha carrying *Trichoderma* @ 2.5 kg/t and seed treatment with *E. adenophorum* @ 5.0 ml/kg seed was found most effective in the management of pea root rot /wilt complex pathogens giving maximum increase in yield i.e. 80.7 % as compare to control.

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(Nisha Kumari) **(B.R. Thakur)**
Student **Major Advisor**
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Head of the Department

1. INTRODUCTION

Pea (*Pisum sativum* L.) is a self-pollinating and cool season crop. It belongs to the Fabaceae family and has nitrogen fixing ability (Abi-Ghanem et al. 2013; Olson-Rutz et al. 2010) to improve soil health. Pea is mainly grown as vegetable and also as pulse crop. It has cholesterol-lowering fiber (Knopp et al. 1999) with high protein content (Gatehouse et al. 1988) to be used as a raw for human consumption. It is rich in carbohydrates and vitamins such as B and K (Sarikamis et al. 2010). Being nitrogen fixing legume, its value as a green manure crop has long been recognized. At present, pea is grown as remunerative and a soil building crop in the organic farming system.

In India, pea is cultivated over an area of about 433.56 thousand ha with a production of 3868.63 thousand MT (Anonymous 2014) as a vegetable and pulse crop. In Himachal Pradesh, it is grown in an area of about 23.90 thousand ha with a production 271.06 thousand MT (Anonymous 2014). Pea is grown as an off-season cash crop to bring lucrative returns to the state growers. The districts of Lahaul and Spiti, Kinnaur, Shimla, Kullu and Mandi are the major pea growing areas of the state. The consumers have their special preference for hill grown peas because of its characteristic flavour, sweetness and freshness (Bhardwaj and Vikram 2004).

Pea is attacked by large number of pathogens to cause important diseases such as root rot/wilt complex, ascochyta blight, powdery mildew, bacterial blight, white rot and rust. Among these, Pea root rot/wilt complex disease is an emerging problem and poses serious threat to pea cultivation in the state. The pea cultivars grown in Himachal Pradesh are susceptible to the pathogens associated with the disease. The disease is occurring in all pea growing areas of the state at pre-flowering or flowering stage to affect the initial crop stand of pea. The disease starts either with yellowing of basal leaves and then, proceeds upward or wilting of the infected plants and ultimately collapse of those. The syndromes like seed rot or root rots with yellowing of leaves or wilting with the collapse of infected plants collectively represent a detrimental disease complex and hence, referred as root rot/wilt complex disease. The disease happens to be at initial stage of the pea crop which ultimately results in huge crop losses to

incurre heavy economic losses to the farming community (Negi et al. 2008). The monoculture and extensive cultivation of pea in Zone IV of the state where it is grown as off-season crop, pea root rot/wilt complex disease have become the major constraints in pea productivity (Anonymous 2005).

More than 20 different pathogens i.e. *Fusarium solani* f. sp. *pisi, Fusarium oxysporum* f. sp. *pisi, Aphanomyces euteiches, Phoma medicaginis* var. *pinodella, Rhizoctonia solani, Hycosphaerella pinodes,, Thielaviopsis basicola* and *Pythium* sp. including *P. ultimum, P. vexans, P. splendars, P. debaryanuai, P. aphanidermatum* and *P. irregular* have been reported to be associated with the disease from different parts of the world (USDA 1960). In Himachal Pradesh, pathogens *viz.*, *F. oxysporum, F. solani, R. solani, Sclerotinia sclerotiorum* and *P. medicaginis* var. *pinodella* have been reported to be associated with root rot/wilt complex of pea (Sagar 1996; Dohroo et al. 1998 and Kapoor et al. 2006).

Since the disease is caused by soil-borne pathogens and is very difficult to manage with the existing management practices. All the commercial cultivars are highly susceptible to the disease. Though the chemicals were used as seed dresser in the management of the disease. Even then the disease has assumed alarming status in pea growing areas of the state and is not under the check. Many workers worked upon the management modules to overcome the menace but no satisfactory results have obtained with those against the disease. Hence, the present studies entitled **"Studies on pea root rot/wilt complex disease"** have been undertaken to study the nature/complexity of the disease and then, to evaluate the management components such as the use of composts, botanicals, fungicides and bioagents to frame management strategy against the disease with the following objectives:

- To determine the pathogen(s) associated with the disease and their predominance in the pea growing areas
- To evaluate the management practices against the disease.

2. REVIEW OF LITERATURE

The literature pertaining to the present studies entitled **"Studies on pea root rot/wilt complex disease"** has been discussed under the following sub headings:-

2.1. Disease occurrence and associated pathogens

2.2. Management practices

2.2.1. Evaluation of composts

2.2.2. Evaluation of bio agents

2.2.3. Evaluation of botanicals

2.2.4. Evaluation of chemicals

2.2.5. Evaluation of germplasm

2.3. Disease management

2.1. Disease occurrence and associated pathogens

In India, the disease was first reported from Pune and later was found to be widespread in North India (Sukapure et al. 1957). Crop losses 50 to 74% have been reported by the various workers (Sen and Majumdar, 1974, Basu et al. 1976, Anonymous, 1983).

Pathogens like *Fusarium solani* f. sp. *pisi, F. oxysporum* f. sp. *pisi,* (Sukapure et al. 1957; Sharma et al. 1989), *Rhizoctonia solani* (Chauhan and Duhan 1987) and *Phoma medicaginis* var. *pinodella* (Rastogi and Saini 1984) have been reported with root rot complex disease from India.

Pea root rot/wilt is a complex disease and more than 20 different fungi have been reported to be associated with this disease in different regions of world (USDA, 1960).

Blume and Harman (1979) reported *F. solani, A. euteiches, Pythium* sp., *R. solani* and *Thielaviopsis basicola* to cause pea root rot complex disease from New York.

Maheshwari et al. (1983) reported 14-95 per cent losses due to root rot complex disease in India. Tu (1987) reported the complete failure of the crop has been reported under favourable environmental conditions in Ontario (Canada). Hwang and Chang (1989) reported an incidence of disease upto 31 percent from North East Alberta and found that *Fusarium* sp. as major while *R. solani* and *Pythium* sp. as occasional association pathogens with root rot/wilt complex of pea.

Oyarizun (1993) suggested the method for predicting the severity of pea root rot caused by soil borne pathogens predominantly *F. solani* f. sp. *pisi*, *T. basicola* and *A. euteiches*. In a bioassay studies, pea cultivar Finale was sown in a composite soil sample from each field in pots under standardized conditions in the greenhouse. Each year, root rot readings in the bioassay and disease severity readings for field plants at flowering and green pod stages were linearly correlated ($P<0.001$). As the degree of root rot in the field crop increased, there was a proportionally lower yield. In heavily infested fields, up to 50 percent yield reduction occurred. Results indicated that the bioassay is a reliable method for predicting root rot severity in sampled pea fields.

Sagar (1996) noticed in general moderate to severe form of this disease in Himachal Pradesh while highest incidence of 45.2 per cent was recorded in Lahaul valley and four fungal pathogens associated *viz., F. oxysporum, F. solani, R. solani, P. medicaginis* var. *pinodella* were found associated with the disease.

Dohroo et al. (1998) observed that Fusarium wilt and root rot of peas is one of the most destructive diseases of pea crop and is of worldwide occurrence. They further reported that *F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi* to be the cause of the disease.

Maheshwari et al. (1998) observed that *F. solani* f. sp. *pisi and F. oxysporum* f. sp. *pisi* were the pathogens to cause root rot of pea in northern India. They further discussed the factors affecting disease development. For the management of disease, they suggested the cultural and chemical measures.

Xue (2003) reported pea root rot complex caused by *Alternaria alternata, Aphanomyces euteiches, F. oxysporum* f. sp. *pisi, F. solani* f. sp. *pisi*, *Mycosphaerella pinodes, Pythium* sp, *R. solani*, and *S. sclerotiorum* was a major yield-limiting factor

for field pea production in Canada. The most common pathogens causing root rot of pea are *A. euteiches, P. ultimum, F. solani* f. sp. *pisi* and *R. solani* and other fungi such as *T. basicola, F. oxysporum, Aschochyta pinodella* and *S. sclerotiorum* can be associated with root rots of pea (Anonymous, 2004).

Jones et al. (2011) reported root rot of pea caused by *F. solani,* as the most common root disease of field pea (*Pisum sativum* L.) in western Canada. Sharma (2011) confirmed the predominance of *Fusarium* spp. by an array of pathogenicity tests involving pathogen spores and metabolites in Jabalpur district of India. He further concluded that *F. oxysporum* FP-02/G [NFCCI-2195] isolated from Ghana village of Jabalpur district was found to show severe pathogenicity on pea varieties commonly grown in Jabalpur.

2.2. Management practices

2.2.1. Evaluation of composts

Various organic inputs have been reported to possess antifungal activity against soil borne pathogens. Aqueous extracts of vermi compost and other organic composts showed inhibition of the mycelial growth of *Botrytis cinerea, Sclerotinia sclerotiorum, Sclerotium rolfsii, R. solani and Fusarium oxysporum* f. sp. *lycopersici* (Nakasone et al. 1999).

Raja et al. (2004) reported the presence of large number of bacteria in animal excreta *viz.*, *Pseudomonas*, *Bacillus*, *Serratia*, *Flavobacterium* and *Streptomyces*, majority of which had the capacity to degrade cellulose, hemicelluloses and pectin.

Sugha (2005) evaluated the antifungal potential of panchgavya against *R. solani, S. rolfsii*, *F. solani, S. sclerotiorum* and *Phytophthora colocasiae* and observed that the mycelial bits dipped for 6 hr in panchgavya resulted in complete suppression of mycelial growth of *R .solani*.

Yadav et al. (2006) studied the effect of organic manures and panchgavya spray on yield attributes of rice and showed that panchgavya significantly increased the yield attributes by controlling sheath blight of rice. Dogra (2006) reported 97-100 per cent inhibition in the mycelial growth of soil borne pathogens with bacterial isolates present in panchgavya.

Khaing et al. (2008) stated that ten species of beneficial microbes such as *Serratia marcescens, Bacillus megaterium, Azotobacter chroococcum, Pseudomonas medocina* and *Flavobacterium* spp. present in vermi wash showed their antifungal potential against soil borne pathogens.

Sinha et al. (2010) studied the antifungal properties of vermi - compost and vermi - wash against soil borne pathogens (*P. ultimum, R. solani* and *Fusarium* spp.) and reported 51-72 per cent inhibition in mycelial growth of pathogens.

2.2.2. Evaluation of bio agents

Biological control of plant pathogens specially soil borne by utilizing the beneficial microorganisms, such as specialized fungi and bacteria, has become very important and preferred strategy of Integrated Pest Management. Beneficial micro-organisms that are used for biological control are known as biological control agents (BCAs). The potential use of *Trichoderma* sp. as BCA was first suggested by Weindling in 1932. *T. harzianum* has been recognized as a strong mycoparasites against soil borne pathogens such as *R. solani, S. rolfsii, F. oxysporum* (Papavizas 1985 and Chet 1987).

Jahagirdar et al. (2002) found that *T. viride* to be promising in bringing down the wilt incidence considerably.

Xue et al. (2003) identified a strain ACM941 (ATCC 74447) of *Clonostachys rosea* (syn. *Gliocladium roseum*) as a mycoparasite against the *A. alternata, A. euteiches, F. oxysporum* f. sp. *pisi, F. solani* f. sp. *pisi*, *Mycosphaerella pinodes*, *Pythium* sp, *R. solani*, and *S. sclerotiorum*.

Poddar et al. (2004) reported the *T. viride* and *T. harzianum* as the best antagonists against several soil and seed borne plant pathogens.

Kapoor et al. (2005) reported the efficacy of biological control agents (*Trichoderma viride* isolate SMA-7, *T. koningii* isolate DMA-8 and *T. harzianum* isolates SMA-4 and JMA-11 along with Neem-based biopesticides Wanis, Spictaf, Neemgold, Achook and Neemazal and suggested integrated control measures (biological control, biopesticide application, cultural practices and amendment with *Lantana camara*) against pea root rot/wilt complex caused by *F. oxysporum* f. sp. *pisi*

and *F. solani* f. sp. *pisi* during 2001-04. They further suggested Pea-kuth (*Saussurea lappa*) sequence in zone IV and pea-rice/maize sequence in zone II reduce the incidence of root rot/wilt complex in peas. Kapoor et al. (2006) reported that soil application of *T. koningii* (RMA-8) at 2.5 kg/65 kg of FYM/ha reduced the pea root rot/wilt complex disease whereas *T. harzianum* (SMA-4) was more effective against white rot.

Rojo et al. (2006) reported the potentiality of *Trichoderma* spp. as biocontrol agents of phytopathogenic fungi in several crops especially to *Fusarium* spp. and *Rhizoctonia* spp. Under greenhouse assay the optimum inoculum concentration of *T. harzianum* isolate ITEM 3636 and *T. longibrachiatum* isolate ITEM 3635 showed that both seed treatments(seeds coated with a conidial suspension using carboxymethylcellulose (CMC) as sticker and seeds coated with the antagonist fungal biomass on Biodac particles) of *T. harzianum* isolate ITEM 3636 was more effective than *T. longibrachiatum* isolate ITEM 3635 in decreasing the mean disease severity index (MSI) and increasing the frequency of healthy plants and boosting yield to confirm *T. harzianum* isolate ITEM 3636 as the plant growth promoter.

Hamid et al. (2012) observed that the *T. harzianum* exhibited highest mycelial inhibition of pathogens (78.60%) followed by *T. viride (*75.72%), *Gliocladium virens* (69.52%) and *P. fluorescens* (68.37%). They further stated that seed treatment with biocontrol agents revealed the highest germination percentage in pots treated with *T. harzianum* and carbendazim (90% each) followed by *T. viride* (86%), *P. fluorescens* (83%) and *G. virens* (82%) as 61 % in control. Disease incidence and severity was lowest in the pots treated with carbendazim (14.64 and 4.98%) followed by *T. harzianum* (21.30 and 10.94%), *T. viride* (25.30 and 12.02%), *P. fluorescens* (29.28 and 14.98%) and *G. virens* (38.64 and 17.58%) as in control (54.64 and 32.02%) respectively.

Kapoor et al. (2012) evaluated the efficacy of different microbes for their antagonistic ability *in-vitro* against *F. oxysporum* f. sp *pisi* by dual culture method. He found that *T. viride* and *P. fluorescens*-I exhibited maximum antagonistic activity against this pathogens.

Koli et al. (2014) reported the efficacy of test biocontrol agents *T. viride, T. harzianum* and *G. virens* against *F. solani* f. sp. *pisi* by using dual culture method and found that *T. harzianum* was most effective against the fungus *in vitro* and *in viv*o (i.e. pot condition). Maximum reduction in root rot incidence was observed when seeds were treated with *T. harzianum***.**

Negi et al. (2014) found that *T. harzianum* and *P. fluorescens* combination are quite effective against root rot complex pathogen (PDI 11.9 %), followed by *P. fluorescens* (PDI 15.4%) and *T. harzianum + P. fluorescens + T. virens* (PDI 15.9%) as compared to untreated control (PDI 21.6%) on 0-9 scale for disease severity.

2.2.3. Evaluation of botanicals

Kumar and Tripathi (1991) tested leaf extracts of eighteen plant species belonging to eleven families of higher plants for the control of soil borne pathogens as *P. debaryanum, F. oxysporum, R. solani* and *S. rolfsii* and found that *Eupatorium cannabinum* extracts completely inhibited mycelial growth of all the test pathogens at a minimum dilution of 1:1. Bansal and Gupta (2000) reported the toxicity of *Lantana camara* against *F. oxysporum*.

Usha et al. (2002) studied the methanolic extracts of sixteen plant species belonging to twelve families *in vitro* for their antifungal property against five seed borne fungi *Colletotrichum graminicola, Drechslera sorokiniana, F. solani, Macrophomina phaseolina and Phomopsis sojae* and found that the extracts of *Vitex negundo, Calotropis gigantea* and *C. procera* were the most promising and effective for plant disease management.

Meena and Paul (2005) reported the fungi toxic activities of extracts of ten plant species *viz., Melia azedarach, E. adenophorum, Cannabis sativa, Ranunculus muricatus, Ocimum sanctum, L. camara, V. negundo, Camellia sinensis and Datura stramonium* against the pea root rot /wilt complex pathogens (*F. solani, F. oxysporum, R. solani* and *S. sclerotiorum*). The effects of these extracts were also studied on four resident strains of *Trichoderma* i.e. JMA-4, SMA-5, DMA-8 and JMA-11. The *R. muricatus* extract completely inhibited the growth of all the pathogens. They further suggested that *E. adenophorum* was found to be highly effective against *F. solani, F. oxysporum* and *R. solani* causing more than 50 per cent

inhibition and did not affect the growth of any of the biological control agents and could safely be integrated with JMA-11 for better disease management. Kapoor et al. (2006) reported that Neem-based biopesticides Wanis at 0.1% was most effective against *F. oxysporum* f. sp. *pisi*, and *F. solani* f. sp. *pisi* and *S. sclerotiorum*.

Joseph et al. (2008) reported that different plant extracts *viz., Azardiachta indica, Artemessia annua, Eucalyptus globules, O. sanctum and Rheum emodi* were found effective against *F. solani*. Among the different extracts, 20 percent of *A. indica* was found most effective against the test fungus followed by *R. emodi, E. globulus, A. annua* and *O. sanctum.*

2.2.4. Evaluation of chemicals

Chemical management is one of the best methods of disease management. *In vitro* evaluation of chemicals against a particular pathogen is the primary step to test their efficacy. If found effective, then further field evaluation confirms the true efficacy of fungicide against the disease.

Tu (1987) achieved good control of pea root rot in Ontario (Canada) through seed treatments (80g ai/100kg) with Captan+Gelben+Ridomil and Captan+Dowco+ Ridomil. He also reported the ineffectiveness of seed treatment with Captan alone against the disease. Seed treatment with benomyl has also been reported effective against the mixed infection of *F. solani* f. sp. *pisi* and *F. oxysporum* f. sp. *pisi* by Maheshwari and Jhooti (1987). Gupta et al. (1988) recorded least plant mortality due to *Fusarium* wilt and root rot with Bavistin (carbendazim) treated seeds followed by Captan.

Harvey et al. (1992) suggested that seed treatment with a mixture of fosetyle aluminium+thiram+thiobendazole (2.9 g/kg) was effective against root rot fungi such as *F. solani, P. ultimum* and *Ascochyta* sp.

Kumar et al. (2011) reported that the seed treatment with Vitavax gave best management i.e. 64.3 percent and resulted in highest green pod yield (83.5 q/ha) in peas.

Dutta et al. (2013) recorded highest yield of 66.55 q/ha in pea when seed treatment with carbendazim and soil application of green manure+neem cake+antagonist were applied.

Kumar (2013) evaluated six modules of disease management against pea root rot/wilt complex, white rot and powdery mildew diseases in garden pea. The module M IV (seed treatment with carbendazim @ 2.5 g/kg of seed followed by spray of triadimefon @ 0.4 g/L followed by spray of carbendazim @ 1.0 g/L at 50% flowering after 15 days of first spray followed by spray of triadimefon @ 0.4 g/L after 15 days of second spray) gave the highest disease control on pooled mean basis i.e. 77.3, 51.7 and 74.4%.

Koli et al. (2014) reported Bavistin as most effective with complete inhibition of mycelium growth of the fungus at 300 ppm concentrations followed by Topsin−M + Thiram, Topsin−M, Thiram, Indofil M -45 and Blitox -50. Seed treatment with Bavistin+ Thiram @ 2.5 g/kg seed was found to be most effective with minimum pre and post emergence mortality of pea seeds against *F. solani* f. sp. *pisi*.

2.2.5. Evaluation of germplasm

Khadija N (2004) evaluated twenty six germplasm lines for resistance of pea against the foot rot and root rot caused by *F. solani*, *S. rolfsii* and *R. solani* under artificial inoculated and natural field condition. Among these, only one line (G-127) was found highly resistant, eight were moderately resistant and seventeen were moderately susceptible to *F. solani*. In case of *S. rolfsii* only one line (G-205) was moderately resistant, twelve were moderately susceptible and thirteen were highly susceptible. While all the germplasm were highly susceptible to *R. solani*.

Kapoor et al. (2006)) evaluated the lines against root rot / wilt complex of pea and reported that DPP 54, KS 268, LP3 and UN536 lines were resistant to root rot / wilt complex. Pea lines NDVP5, PMR19, Palam Priya, and VL3 showed low incidence whereas, KS221, Azad P1, EC381813, EC381854 and JI2438 were highly susceptible.

George et al. (2010) evaluated the reaction of thirty seven pea varieties against root rot pathogens in replicated greenhouse tests and then root rot severity was assessed on a scale of 1 (no visible disease symptoms, healthy) to 9 (>75 percent of roots and stem tissues affected and at a late stage of decay). Ratings of 1 – 3, >3 – 6, and >6 – 9 are considered as resistant, tolerant/intermediate, and susceptible, respectively.

2.3. Disease management

Cole and Zvenyikam (1988) achieved control of *R. solani* and *F. solani* in peas by adding *T. harzianum* to methyl bromide fumigated seed beds before sowing. Tu (1987) developed an integrated disease management by using resistant cultivars, suitable herbicide and use of inter season green manure crops to control Fusarium wilt (*F. oxysporum*) and root rot (*F. solani*) of green peas.

According to Hwang and Chakravarty (1992), Rhizoctonia root rot of *Pisum sativum* was effectively controlled by combining a bioagent (*Bacillus subtilis*) and chemical treatments. Kaur and Mukhopadhyay (1992) used *T. harzianum* with fungicide seed treatment to control the chickpea wilt complex.

Gowily et al. (1995) suggested that seed coating with bioagents (*T. viride, B. subtilis, Pencillium citrinum*) and chemical Benomyl gave good management of Fusarium root rot of chickpea. Chattopadhyay et al. (1996) carried out pot and field experiments and concluded that seed treatment with *T. viride*+Bavistin and soil application of potassium chloride gave 74.14 percent reduction in Fusarium wilt of muskmelon.

Paul and Rathour (1997) successfully integrated the use of apparently healthy seed, seed treatment and sprays for managing pea diseases. Dasgupta (1997) suggested that suitable integration of disease management practices like soil amelioration, natural enemies, pathogen suppressant fungi and manipulation of rhizosphere microflora led to optimum and economical management of soil borne diseases. Disease problems of vegetable crops are enormous and require judicious management with minimum cost and integration of disease management pratices for suitable vegetable production (Sokhi and Thind, 1997).

Dohroo et al. (1998) worked on integrated disease management programme which focuses on chemical, cultural, biological and host resistance to combat the disease.

Kaur (1999) observed that the integration of cultural, biological and chemical measures for the disease management is superior to other practices in the control of wilt/root rot complex of pea.

Kumar and Dubey (2001) reported that seed treatment with Captan+*T. harzianum* successfully controlled the collar rot of pea caused by *F. solani* f. sp. *pisi*. Tewari and Mukhopadhyay (2003) stated that seed treatment with *G. virens* + Carboxymethyl cellulose+Vitavax proved to be good in the control of root rot and collar rot of chick pea caused by S. *rolfsii, R. solani* and *F. oxysporum*.

Sagar and Sugha (2004) reported that soil amendment and repeated cropping with different non-host crops such as wheat, oats, maize and sorghum reduced the population of *F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi* in the soil and the severity of pea root rot due to these pathogens. *F. solani* f. sp. *pisi* was more sensitive to soil amendment, and wheat and especially maize were more effective than the other two non-host crops. Repeated cropping of non-host species was more effective than a single crop. No relation was established between the *Fusarium* populations and severity of pea root rot.

Kapoor et al. (2006) reported that among the different integration levels, amendment with *L. camara* (10t/ha) + bioagent Tricoguard @ 2.5kg/ 62 kg FYM/ ha + spray with carbendazim at pre flowering stage was most effective in managing the root rot-wilt complex disease in pea.

Kumar et al. (2012) reported that seed treatment with Vitavax Power (carboxin 37.5% + thiram 37.5%) @ 2.5 g/kg seed gave maximum disease control of 64.3% and increase in green pod yield of 46.5% followed by carbendazim @ 2.5 g/kg seed with 56.5% disease control and 22.8% increase in yield.

3. MATERIALS AND METHODS

The present investigation entitled **"Studies on pea root rot/wilt complex disease"** was undertaken in the Department of Plant Pathology, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur. All *in vitro* and *in vivo* studies were carried out in the Department. Materials and Methods applied for present investigation have been discussed under the following sub-headings:

3.1. Disease occurrence

3.2. Casual organism(s)

3.2.1. Isolation of Pathogen

3.2.2. Pathogenicity test

3.2.3. Pathogen identification

3.3. Management practices

3.3.1. Evaluation of composts

3.3.2. Evaluation of bio agents

3.3.3. Evaluation of botanicals

3.3.4. Evaluation of chemicals

3.3.5. Evaluation of germplasm

3.4. Disease management

3.5. Statistical analysis

3.1. Disease occurrence

To assess the occurrence of pea root rot/wilt complex in Himachal Pradesh, an extensive surveillance was conducted in different agro climatic zones of pea growing area of Himachal Pradesh. The disease incidence was recorded in the pea growing regions of the state during the crop season. Five observations were taken from each location by marking 2m x 2m area to assess the disease. The incidence was worked out as per formula given below. The plants showing the symptoms of wilt/root rot

complex disease were uprooted and also collected in paper envelops from different regions with proper label. These were brought to the laboratory of Department of Plant Pathology, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur for further studies. The per cent incidence was worked as follow:

$$\text{Per cent Disease Incidence} = \frac{\text{Number of diseased plants}}{\text{Total number of observed plants}} \times 100$$

3.2. Casual organism(s)

3.2.1. Isolation and maintenance of pure cultures

Isolations were made from diseased samples collected from pea growing areas of the state during survey and surveillance, to ascertain the predominance of pathogen (s) associated with pea root rot/wilt complex disease. For isolation of pathogen, diseased samples of seedling stage were collected to isolate the pathogen (s) inciting the disease. Isolations were made on Potato Dextrose Agar (PDA) medium. The diseased samples were initially washed in tap water and bits were taken from the transition zone of root rots/vascular discoloration. These bits were later surface sterilized with 0.1% $HgCl_2$ solution for 15 seconds followed by three washings in sterilized water under aseptic conditions in Laminar Air Flow. The sterilized bits were dried in two folds of sterilized filter papers to remove excess moisture and then, placed on PDA slants in test tubes under aseptic conditions. The inoculated test tubes were incubated in BOD incubator for seven days at 26 ± 1^0C. Diseased bits were also kept in sterilized Petri plates lined with moistened (sterilized water) filter papers and incubated at room temperature for 48 hours to observe the fungal growth for preliminary observations. The pure cultures of each isolates were obtained by single hyphal tip method. The pure cultures were preserved at 5^0C in refrigerator for further studies. Revival of preserved pure cultures of isolates was done on PDA again.

3.2.2. Pathogenicity test

Rapid Technique of Dyer and Ingram (1990) was employed for conducting the pathogenicity tests of isolated pathogens. Seeds of "Azad P-1" pea were surface sterilized for five minutes in 2.5% sodium hypochlorite solution and washed thoroughly with sterilized distilled water. These seeds were sown in sterilized sand in trays and irrigated with sterilized half strength Hoagland's solution (Hoagland and Aron, 1950). Fourteen days old pea plants (3-5 nodal stage) were uprooted and roots

were washed with sterilized water to remove sand particles. A uniform suspension of spores (10-12 spores per microscopic field at 10x40 X) were prepared in half strength Hoagland's solution and was referred to as "standard inoculum". The pea seedlings were inserted into glass tubes (25x150 mm size) containing 40 ml of standard inoculum. Seedlings were held in position by cotton plugs in such a way that roots were immersed in spore suspension "standard inoculum", leaving air gap of 2 cm between the plug and spore suspension. Seedlings in sterilized half strength Hoagland's solution without "standard inoculum" served as control. Sterilized half strength Hoagland's solution was added in tubes after every 48 hours to recover the loss of solution. Three replications were maintained in case of each of the isolate. Fifteen days after inoculation, data on wilted seedlings were recorded for the confirmation of the disease and the pathogens were re-isolated and re-inoculated to carry pathogenicity tests for confirmation in the similar way.

3.2.3. Identification of pathogens

Microscopic observations were made to observe the morphological (mycelial and conidial) characteristics of the isolates to identify the pathogens as per keys given below:

Parameter	***Fusarium solani***	***Fusarium oxysporum***
Colour of colony on PDA	White to cream colonies growing rapidly with aerial mycelium becoming bluish-brown when sporodochia formed.	Cottony white colonies growing rapidly with aerial mycelium becoming purple to orange or dark blue to dark purple when sporodochia formed.
Growth on PDA	4.5 cm in four days	4.5 cm in four days
Macroconidia	Macroconidia of 28-42 x 4-6 µm with three to five-septa and fusiform, cylindrical, oftenly moderately curved, with an indistinct pedicellate at foot cell and a short blunt apical point.	Macro conidiaof 23-54 x 3-4.5 µm mostly with three septate are fusiform in shape and slightly curved with pointed end at the tip and basal cells pedicellate.
Microconidia	Cylindrical to oval micro conidia of 8-16 x 2-4.5 µm with one to two-celled are abundantly present.	Ellipsoidal to cylindrical (straight or often curved) microconidia of 5-12 x 2.3-3.5 µm are mostly non-septate.
Chlamydospores	Smooth to rough-walled chlamydospores of 6-10 µm borne singly or in pairs on short lateral hyphal branches or intercalary	Smooth to rough-walled chlamydospores of 5-13 µm borne terminal or intercalary.

a) Morphological

Microscopic observations were made to observe the morphological (mycelial and conidial) characteristics of the isolated fungus causing pea root rot/wilt complex disease. To ascertain the pathogens their peculiar characteristics like shape and size of conidia (macro- and micro-) and chlamydospores were observed under the compound microscope at 10x40 X and the measurement of spores were taken with help of micrometery.

b) Cultural characteristics

The cultural characteristics of isolates were also observed for colony growth and colour of seven days old cultures on PDA. Mycelial bits of 5 mm in diameter of different isolates were cut with the help of cork borer from the margin of an actively growing colonies of the isolates and placed in the centre of plates containing medium (PDA). The inoculated cultures were incubated at 26±1 ^{o}C in a BOD incubator. Each isolate was replicated thrice. Observations were made for appearance of mycelium growth and colour of colonies.

3.3. Management practices

3.3.1. Evaluation of composts

Five organic composts *viz.*, Vermicompost, Farm yard manure, Cow pit pat, NADEP and Himcompost were evaluated against *F. solani* f. sp. *pisi and F. oxysporum* f. sp. *pisi in vitro* conditions on PDA media using Poisoned Food Technique (Falck 1907) in three replicates. All these organic inputs were procured from Department of Organic Agriculture, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur. The 15 days old aqueous extracts (1:1 w/v) of these organic composts were evaluated against both *F. solani* f. sp. *pisi and F. oxysporum* f. sp. *pisi.* The aqueous extracts of these organic composts were mixed with equal quantity of double strength sterilized PDA medium and poured aseptically in sterilized Petri plates. Medium mixed with equal quantities of sterilized distilled water without any treatment (aqueous extracts of composts) served as check (control). Seven days old mycelial bits (5mm) of *F. solani* f. sp. *pisi and F. oxysporum* f. sp. *pisi* were placed in the centre of Petri plates and incubated at 26±1°C. Regular

observations were made and finally colony diameter was measured after the control plates were completely covered by the growth of pathogens and per cent mycelial inhibition was determined as per McKinney (1923) formula:

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

Where,

I (%) = Per cent mycelial inhibition

C = mycelial growth in control

T = mycelial growth in treatment.

3.3.2. Evaluation of bio agents

Four resident strains of *Trichoderma*, two each of *T. harzianum* (JMA-4 and SMA-5) and *T. koningii* (DMA-8 and JMA-11) along with two more newly isolated strains of *Trichoderma viz*., *T. harzianum* (Th-M) and *T. viride*, were obtained from the Department of Plant Pathology, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur. These strains of *Trichoderma* were evaluated against both *F. solani* f. sp. *pisi* and *F. oxysporum* f. sp. *pisi in vitro* conditions on PDA using Dual Culture Technique (Huang and Hoes 1976). The experiment was replicated thrice. With the help of sterilized cork borer and needle, culture discs of 5 mm from the margins of seven days old pure culture of pathogens and biocontrol agents were transferred under aseptic conditions to 90 mm diameter Petri plates containing PDA on opposite sides. The only discs of pathogens on the PDA served as check (control). The inoculated Petri plates were incubated at 26±1°C. The linear growth of the bioagents and the pathogens from the centre of the disc towards the centre of the plates was measured when pathogens cultures covered Petri plates completely kept as a check (control). Per cent mycelial inhibition of the pathogen was determined as per McKinney (1923) formula as mentioned above.

3.3.3. Evaluation of botanicals

The aqueous and alcoholic extracts of five locally available botanicals *viz., Vitex negundo, Eucalyptus* sp., *Melia azedarach, Lantana camera* and *Eupatorium adenophorum* were evaluated against both *F. solani* f. sp. *pisi* and *F. oxysporum* f. sp. *pisi* using Poisoned Food Technique (Falck 1907) in three replications. Aqueous extracts of leaves of test botanicals were made with distilled water (1:1 w/v). Desired concentrations of botanicals 10, 20, 30, 40 and 50 % were obtained from the stock solution through serial dilution with distilled water. These concentrations were mixed with equal quantity (50 ml) of double strength sterilized PDA medium and poured aseptically in sterilized Petri plates get test concentrations of 5, 10, 15, 20 and 25 %. Double strength sterilized PDA mixed with equal quantity of sterilized distilled water served as check (control). Alcoholic extracts of test botanicals were obtained with the help of acetone (1:1 w/v) and stock solution were made by adding distilled water. The test concentrations of 5, 10, 15, 20 and 25 % were obtained with similar procedure. For both alcoholic and aqueous experiments seven days old mycelial bits of 5 mm of both *F. solani* f. sp. *pisi* and *F. oxysporum* f. sp. *pisi* were placed in the centre of plates. Each treatment was replicated thrice and incubated at 26±1°C. Regular observations were made and finally colony diameter was measured after the control plates were completely covered by the growth of pathogens. Per cent mycelial inhibition was calculated by using formula given by McKinney (1923) as mentioned above.

3.3.4. Evaluation of chemicals

Six fungicides *viz.,* Bavistin (carbendazim 50 WP), Tilt (propiconazole 25 EC), Raxil (tebuconazole 2 DS), Thiram 75 DS, Vitavax power (carboxin 37.5% + thiram37.5%) and Vitavax (carboxin 75 WP), were evaluated through Poisoned Food Technique (Falck 1907) for their efficacy against both *F. solani* f. sp. *pisi* and *F. oxysporum* f. s*p. pisi* in three replications. Double strength test concentrations of each fungicide were prepared in 50 ml sterilized distilled water and added individually to equal volume of double strength PDA to get desired concentrations of 50, 100, 250, 500, 750,1000, 1500, 2000 and 2500 ppm. Double strength PDA mixed with equal quantities of sterilized distilled water served as check (control). PDA plates in three

replication incorporated with each fungicide at desired concentrations were inoculated with 5 mm mycelial bits of seven days old cultures of both *F. solani* f. sp. *pisi and F. oxysporum* f. sp. *pisi* and incubated at 26±1°C. Regular observations were made and finally colony diameter was measured after the control plates were completely covered by the growth of pathogens and per cent mycelial growth inhibition over control was calculated by McKinney (1923) formula to work out the efficacy of fungicides against test pathogens.

3.3.5. Evaluation of germplasm

Mass multiplication of pathogens

The pure cultures of both *F. solani* f. sp. pisi *and F. oxysporum* f. sp. *pisi* were mass multiplied on sterilized sand maize meal (9:1 w/w) medium and incubated at 26 ± 1 °C for 15 days.

Preparation of sick soil

For pot experiments, initially the soil was sterilized and then made sick by thoroughly mixing pathogens inoculums @ 100 g/kg soil. The sick soil was filled in the surface sterilized plastic pots thoroughly moistened with water.

Evaluation of elite pea lines

One hundred and thirteen elite pea lines were procured from the Department of Plant Pathology and Department of Vegetable and Floriculture. These elite pea lines were subjected to sick soil under pot condition in the growth chamber of Department of Plant Pathology, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur. Pots were marked with level of entries and kept in the green house. Pots were sprinkled regularly with water to maintain moisture. Watering of plants was done regularly twice a day in the morning and evening. Disease scoring was done when seedlings collapse completely in susceptible pea cultivar “Azad P-1” on 0-5 disease scale given by Carver et al. 1996 as: 0 = healthy plants–Highly Resistant (HR); 1 = initial signs of wilting (yellowing)–Resistant (R); 2 = up to 25% of the leaves with symptoms–Moderately Resistant (MR); 3 = up to 50% of the leaves with symptoms–Moderately Susceptible (MS); 4 = up to 75% of the leaves with symptoms–Susceptible (S); 5 = plants dead–Highly Susceptible (HS).

3.4. Disease management

***In vivo* studies**

Pot experiment was conducted in the growth chamber of the department and field experiment was conducted in the farm of the department to integrate the management practices against the disease with following treatments in three replications:

Treatments	
T_1	Soil amendment with Vermicompost : FYM (1:1) @ 15 t/ha
T_2	Soil amendment with with Vermicompost : FYM (1:1) mixed with *Trichoderma* @ 2.5 kg/t
T_3	Seed treatment with *Trichoderma* @ 5.0 g/kg seed
T_4	Seed treatment with *Eupatorium adenophorum* @ 5.0 ml/kg seed
T_5	$T_1 + T_3$
T_6	$T_1 + T_4$
T_7	$T_2 + T_3$
T_8	$T_2 + T_4$
T_9	Seed treatment with Bavistin @ 2.5g/kg seed (check)
T_{10}	Control (No treatment)

The field experiment was conducted with above treatments in three replications and each treatment of 2m x 2m plot size were randomized. The pot experiment was conducted with pots of 15 inches, filled with sick soil containing cultures of both *F. solani* f. sp. pisi and *F. oxysporum* f. sp., in randomized form with each treatment replicated thrice. Fifteen seeds of susceptible cultivar ‘Azad P-1’ were sown in pots at equidistant from each other. Three pots kept in row were marked with level of treatment and kept in the green house. Pots were sprinkled regularly with water to maintain moisture. Watering of plants was done regularly twice a day in the morning and evening.

Data were recorded for per cent mortality and crop stand against pea root rot/wilt complex disease for the both experiments. In case of pot experiment, data were recorded right from germination to completely collapse of seedlings in the control whereas, in field experiment, data were recorded right from germination to last picking of green pods of peas at weekly intervals.

3.5 Statistical analysis

The data of different experiments were pooled and subjected to appropriate statistical analysis using square root and arc sine transformations, wherever necessary. Transformed values of mean have been put in parenthesis. All the data were analyzed in the computer using CPCS-1 software. The significance of treatments was taken at 5 per cent level of significance.

4. RESULTS AND DISCUSSION

Pea root rot/wilt complex disease is one of the most destructive diseases of pea. The present investigations entitled **"Studies on pea root rot/wilt complex disease"** had been undertaken to ascertain the pathogen(s) associated with the disease and then, to evaluate the management practices for integration against the disease. Results obtained in the current investigation are presented and discussed here in the light of the documented literature under the following sub-headings:

4.1. Disease occurrence

4.2. Causal organism (s)

4.2.1. Pathogen identification

4.2.2. Prevalence of pathogen (s)

4.3. Management practices

4.3.1. Evaluation of composts

4.3.2. Evaluation of bio agents

4.3.3. Evaluation of botanicals

4.3.4. Evaluation of chemicals

4.3.5. Evaluation of germplasm

4.4. Disease management

4.1. Disease occurrence

Pea root rot /wilt complex had been noticed as an emerging problem in pea growing regions of Himachal Pradesh. The disease had been occurring with different disease intensity in different agro climatic zones of pea growing areas of the state (Table 1). In Zone IV, the highest disease incidence of 54.7% was recorded at HAREC, Kukumseri followed by Dalang (54.3%), Kishori (46.0%), Sissoo (32.0%) and Karpat (24%). In Zone III, the disease incidence varies from 17.7 (Bajaura) to 197% (Nagwain). In Zone II, the highest disease incidence of 35.3% was recorded at Departmental Farm of CSKHPKV, Palampur followed by Kachhiyari (30.7%) and Sagoor (22.0%).

Table 1. Incidence of pea root rot/wilt complex in Himachal Pradesh

Agro climatic Zone	Location	Per cent Disease incidence
Zone II	Plant Pathology Farm, CSKHPKV Palampur	35.3
	Kachhiyari	30.7
	Sagoor	22.0
Zone III	Nagwain	19.7
	Bajaura	17.7
Zone IV	HAREC Kukumseri	54.7
	Karpat	24.3
	Dalang	54.3
	Sissoo	32.0
	Kishori	46.0

The results have also been shown in the Fig. 1. The data on incidence clearly depicted that pea root rot /wilt complex disease was present in all pea growing areas of the state and the disease had assumed the severe form. Sagar (1996) also noticed moderate to severe form of this disease in Himachal Pradesh and highest incidence of 45.2 per cent was reported from Lahaul valley due to four fungal pathogens associated *viz., F. oxysporum, F. solani, R. solani, P. medicaginis* var. *pinodella.*

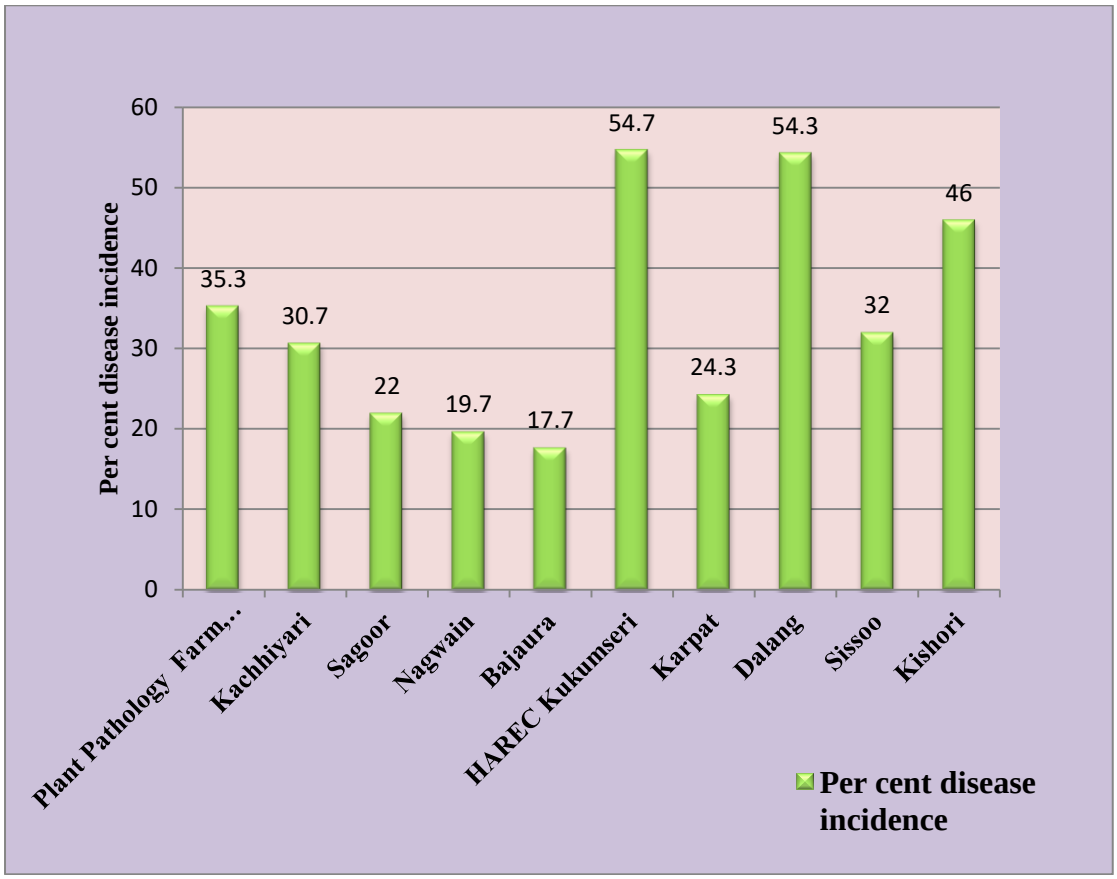


Fig. 1. Incidence of pea root rot/wilt complex in Himachal Pradesh.

4.2. Causal organism (s)

4.2.1. Pathogen identification

a) Isolation of Pathogen (s) and maintenance of cultures

Isolations were made from diseased samples collected from different agro climatic zones of pea growing areas of the state during survey and surveillance. Around 15 isolates were obtained from the diseased samples and two types of cultures were found. Pure cultures of these isolates were procured through single hyphal tip method and were maintained on PDA medium at 26 ± 1º C for further studies.

b) Morphological, cultural and pathogenic characteristics

Pure cultures of isolates were also observed for their morphological, cultural and pathogenic characteristics (Table 2). Pure cultures of isolates were observed for their morphological and cultural characteristics for their identification following keys given below:

Keys for identification :

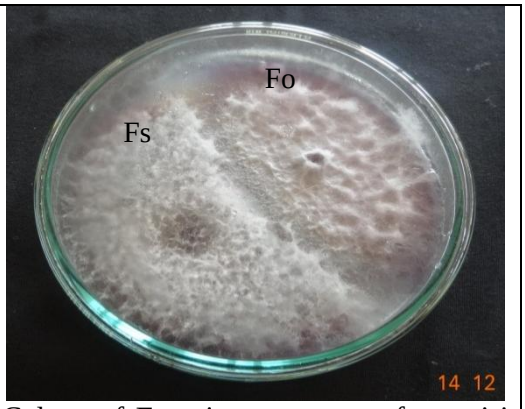
Parameter	***Fusarium solani***	***Fusarium oxysporum***
Colour of colony on PDA	White to cream colonies growing rapidly with aerial mycelium becoming bluish-brown when sporodochia formed.	Cottony white colonies growing rapidly with aerial mycelium becoming purple to orange or dark blue to dark purple when sporodochia formed.
Growth on PDA	4.5 cm in four days	4.5 cm in four days
Macroconidia	Macroconidia of 28-42 x 4-6 µm with three to five-septa and fusiform, cylindrical, oftenly moderately curved, with an indistinct pedicellate at foot cell and a short blunt apical point.	Macroconidia of 23-54 x 3-4.5 µm mostly with three septateare fusiform in shape and slightly curved with pointed end at the tip and basal cells pedicellate.
Microconidia	Cylindrical to oval microconidia of 8-16 x 2-4.5 µm with one to two-celled are abundantly present.	Ellipsoidal to cylindrical (straight or often curved) microconidia of 5-12 x 2.3-3.5 µm are mostly non-septate.
Chlamydospores	Smooth to rough-walled chlamydospores of 6-10 µm borne singly or in pairs on short lateral hyphal branches or intercalary	Smooth to rough-walled chlamydospores of 5-13 µm borne terminal or intercalary.

Microscopic observations and pathogenic behaviour revealed that two different species of *Fusarium viz*; *F. solani* f. sp. *pisi* and *F. oxysporum* f. sp. *pisi* were associated with pea root rot / wilt complex disease as per key given above for identification (plate 1 & 2). In case of *F. solani* f. sp. *pisi,* dull grey white mycelium was observed with moderately curved macro conidia of 30-40 µm X 4.5-6.0 µm having thick walls and 3-5 septation which were not sharply curved at the end point. Micro conidia of *F. solani* f. sp. *pisi* 8-15 µm X 2-4 µm are spherical to oval in shape. Rough walled chlamydospores of 6-9 µm on hyphal branches or intercalary. Pathogenicity test showed that this pathogen produced characteristic symptoms of root rots (necrotic and macerated root tissues) upto collar regions showing yellowing of basal leaf to upward when inoculated with spore suspension of *F. solani* f. sp. *pisi* in the test tubes containing Hoagland's solution (Plate 2). In case of *F. oxysporum* f. sp. *pisi*, cottony white mycelium with tints of the stroma colouring (commonly of purple-red, blueish-grey or yellowish-tan) was observed with typically dorsa-ventrally curved sickle- shaped macro conidia of 25-45 µm X 3-5 µm with thin walls having 3-5 septation and were sharply curved with tapering ends. Oval to ellipsoidal micro conidia of *F. oxysporum* f. sp. *pisi* of 5-12 µm X 3-5µm were present in abundance. Rough-walled chlamydospores of 5-12 µm borne terminal or intercalary. Pathogenicity test showed that the second species of *Fusarium* produced characteristic symptoms of wilting without root rots with clogging of xylem vessels and then, ultimately collapse of pea seedlings when inoculated with spore suspension of *F. oxysporum* f. sp. *pisi* in the test tubes containing Hoagland's solution (Plate 2).

Table 2. Morphological, cultural and pathogenic characteristics of isolates

Isolates	Morphology	Culture	Pathogenicity	Symptom	Pathogen
I-Type (Fs1-Fs9)	Dull white mycelium was observed with sickle to oval shaped macro conidia of 30-40 µm X 4.5-6.0 µm having 3-5 septation with thick walls, not sharply curved at the end. Micro conidia of 8-15 µm X 2-4 µm are spherical to oval in shape. Rough walled chlamydospores of 6-9 µm on hyphal branches or intercalary.	Dull white cottony colour mycelium	+	Necrotic and macerated root tissues upto collar regions (root rots) with yellowing starts from basal leaf to upper leaves.	*Fusarium solani* f. sp. *pisi*
II-Type (Fo1-Fo6)	Dorsa-ventrally curved sickle-shaped macro conidia of 25-45 µm X 3-5 µm with 3-5 septation with thin walls and sharply curved or tapering toward the ends. Micro conidia of 5-12 µm X 3-5 µm, oval to ellipsoidal in shape, were present in abundance. Rough-walled chlamydospores of 5-12 µm borne terminal or intercalary.	light white mycelium with tints of the stroma colouring, commonly of purple-red, blueish-grey or yellowish-tan	+	Wilting with vascular discolouration and then, collapse of pea seedlings	*Fusarium oxysporum* f. sp. *pisi*

+=Pathogenic

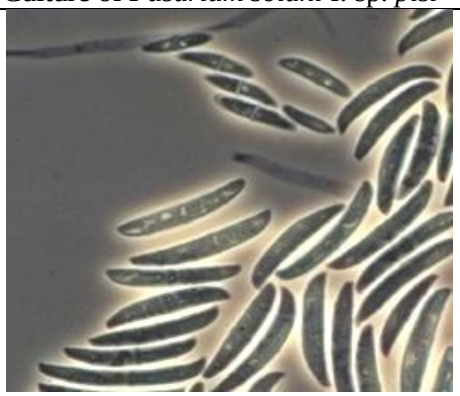


Culture of *Fusarium oxysporum* f. sp. *pisi* (Fo) and *Fusarium solani* f. sp. *pisi* (Fs)

Culture of *Fusarium oxysporum* f. sp. *pisi*

Culture of *Fusarium solani* f. sp. *pisi*

Conidia of *Fusarium oxysporum* f. sp. *pisi*



Conidia of *Fusarium oxysporum* f. sp. *pisi*

Plate 1. Morphological and cultural characteristics of *Fusarium oxysporum* f. sp. *pisi* and *Fusarium solani* f. sp. *pisi.*

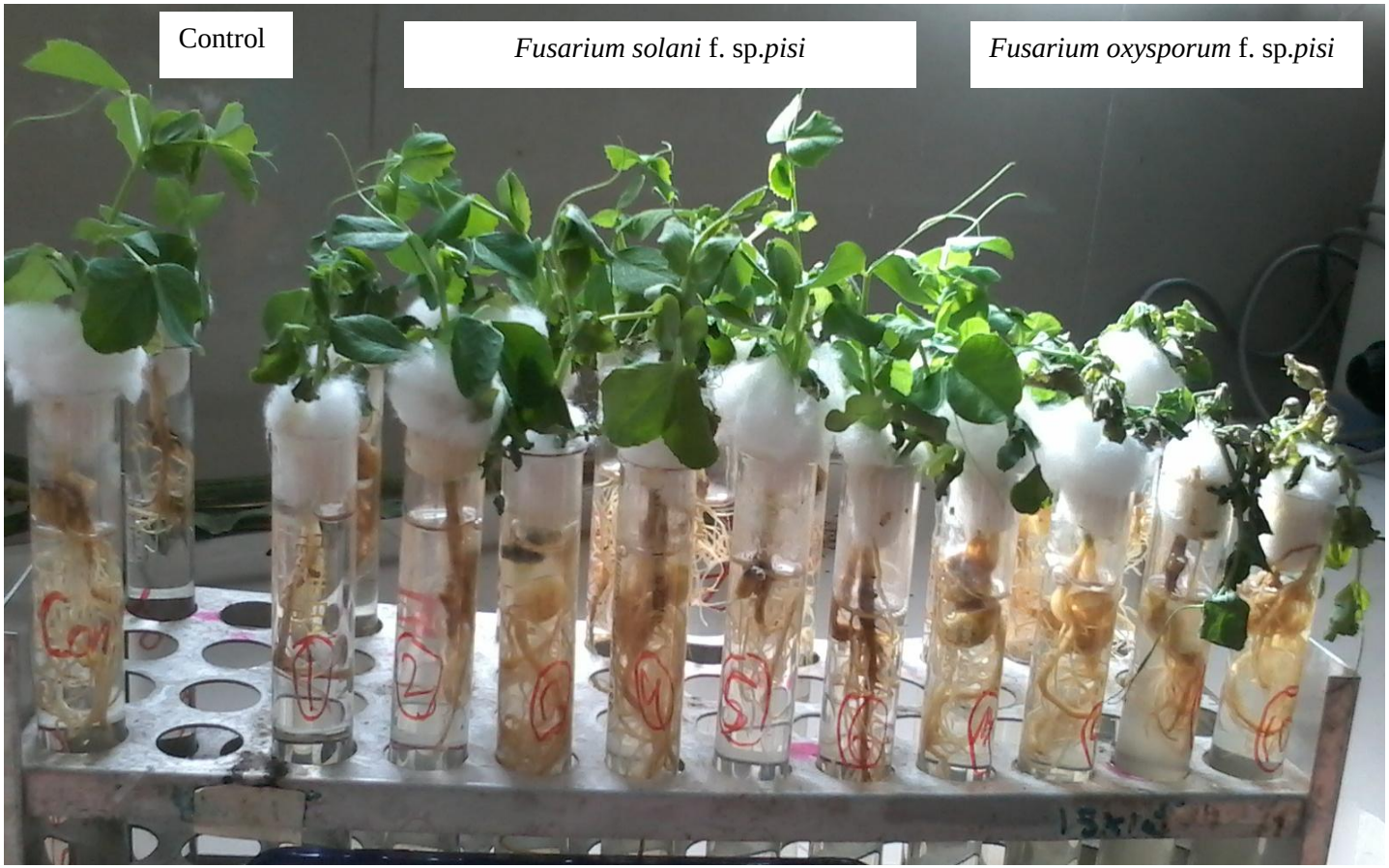


Plate 2. Pathogenicity tests of *Fusarium oxysporum* f. sp. *pisi* and *Fusarium solani* f. sp. *pisi* .

4.2.2. Prevalence of pathogen (s)

The two species of *Fusarium* viz., *F. solani* f. sp. *pisi* and *F. oxysporum* f. sp. *pisi* were found associated with pea root rot/wilt complex in Himachal Pradesh (Table 2 & Plate 1). Both species of *Fusarium* viz., *F. solani* f. sp. *pisi* and *F. oxysporum* f. sp. *pisi* produced two distinct types of symptoms (Plate 2) in pathogenicity tests. One with root rots resulting in yellowing of leaves from basal leaf to upward whereas, other one shows wilting without root rots. However, it has been observed that *F. solani* f.sp *pisi* was solely responsible to cause root rots of peas whereas, *F. oxysporum* f. sp. *pisi* was responsible to cause wilt of the same. Further it has been ascertained that pea root rot/wilt complex syndrome with rotting of roots accompanied with clogging of xylem vessels was caused by both the species of *Fusarium viz*; *F. solani* f. sp. *pisi* and *F. oxysporum* f. sp. *pisi* in the state.

Sagar (1996); Dohroo et al. (1998); Maheshwari et al. (1998); Kapoor et al. (2005) and Kapoor et al. (2006) also reported that *F. oxysporum* f. sp. *pisi, F. solani* f. sp. *pisi, R. solani, Sclerotinia sclerotiorum* and *Phoma* sp. as casual organisms of pea root rot/wilt complex in Himachal Pradesh.

The predominance of both the species of *Fusarium viz*; *F. solani* f. sp. *pisi* and *F. oxysporum* f. sp. *pisi* has been ascertained to be associated with root rots and wilt of peas and other pathogens reported by workers might be present rarely in pea growing areas.

4.3. Management practices

4.3.1. Evaluation of composts

Five organic composts *viz.*, NADEP, Farm Yard Manure (FYM), Cow Pit Pat (CPP), Him-compost and Vermi-compost were evaluated *in vitro* conditions against both the pathogens i.e. *F. oxysporum* f. sp. *pisi and F. solani* f. sp. *pisi* (Table 3).

Table 3. *In vitro* evaluation of organic composts against *F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi*

Composts	*Fusarium oxysporum* f. sp. *pisi*		*Fusarium solani* f. sp. *pisi*	
	Mycelial growth (mm)	Mycelial inhibition (%)	Mycelial growth (mm)	Mycelial inhibition (%)
Vermicompost	54.3	39.7	57.3	36.3
NADEP	73.7	18.1	76.7	14.8
FYM	63.3	29.7	63.0	30.0
Cow Pit Pat	71.3	20.8	72.3	19.7
Himcompost	67.3	25.2	65.0	27.8
Control (No treatment)	90.0	-	90.0	
CD (P=0.05)	**0.9**		**1.3**	

The data in the table 3 revealed that Vermicompost showed the maximum mycelial inhibition of 39.7% against *F. oxysporum* f. sp. *pisi* and 36.3% against *F. solani* f. sp. *pisi* followed by Farm Yard Manure with 29.7 and 30.0% respectively. NADEP were found least effective against the pathogens with 18.1 and 14.8% mycelial inhibition against *F. oxysporum* f. sp. *pisi and F. solani* f. sp. *pisi* respectively.The results obtained have also been shown Fig. 2 and Plate 3. Various organic inputs have been reported to possess antifungal activity against soil borne pathogens like *P. ultimum, R. solani, S. sclerotiorum* and *Fusarium* sp. (Nakasone et al. 1999). Sinha et al. (2010) also studied the antifungal properties of vermi compost and vermi wash against soil borne pathogens (*P. ultimum, R. solani* and *Fusarium* sp.) and recorded 51-72 per cent inhibition in mycelial growth of pathogens.

Hence, studies revealed that Vermicompost was the best one among all the organic composts to be used in the management of pea root rots / wilt complex disease and if not available, can be replaced by FYM.

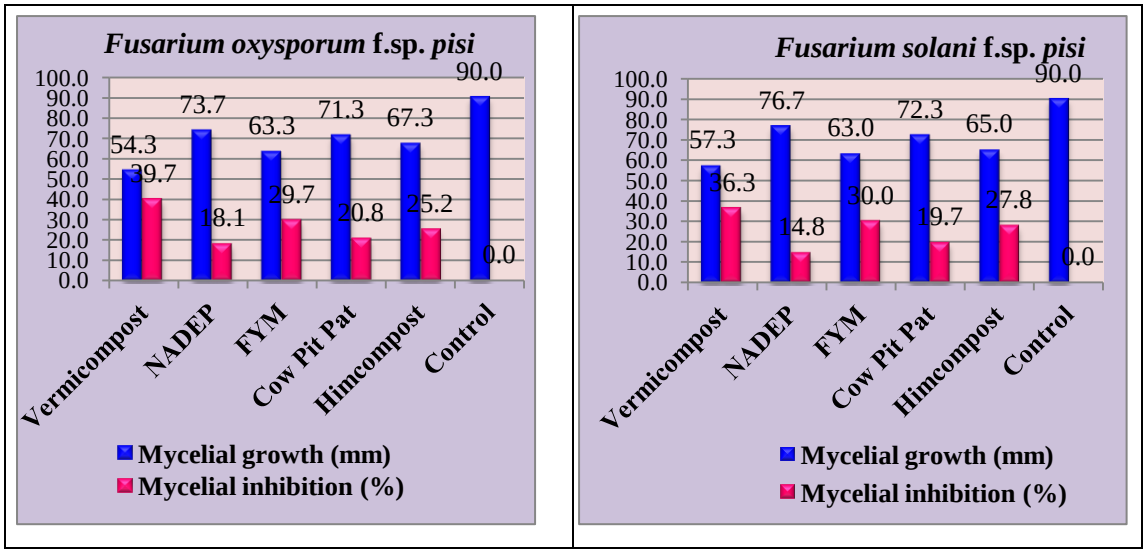
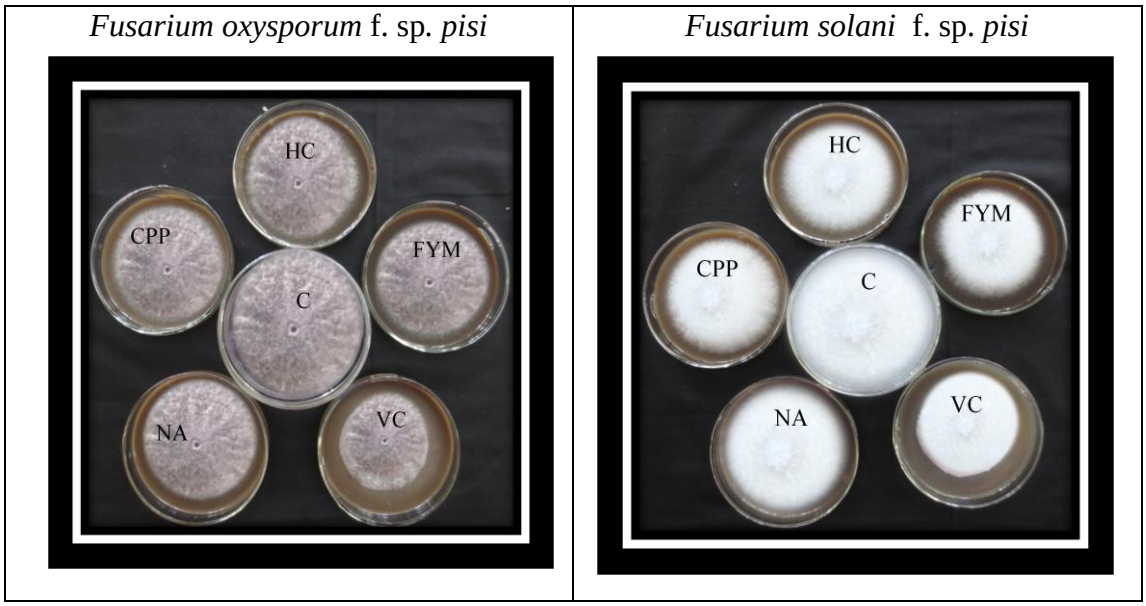


Fig. 2. Mycelial inhibition of *Fusarium oxysporum* f. sp. *pisi* and *Fusarium solani* f. sp. *pisi* by different organic composts.



NA- NADEP, **CPP-** Cow Pit Pat, **HC-** Himcompost, **FYM-** Farm Yard Mannure, **VC-** Vermicompost and **C-**Control

Plate 3. Mycelial inhibition of the *Fusarium oxysporum* f. sp. *pisi* and *Fusarium solani* f. sp. *pisi* by organic composts.

4.3.2. Evaluation of bioagents

Six local resident strains of bioagents *viz*., JMA-4 and SMA-5 of *T. harzianum*; DMA-8 and JMA-11 of *T.* koningii; T. *harzianum* (Th-M) and *T. viride* were evaluated *in vitro* conditions for their antagonistic activity through dual culture technique against both *F. oxysporum* f. sp. *pisi and F. solani* f. sp. *pisi* (Table 4).The data revealed that SMA-5 strain of *T. harzianu*m showed the maximum mycelial inhibition against *F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi* i.e. 77.4 and 75.9 % respectively followed by *T. viride* and DMA-8 of *T.* koningii and were statistically at par with each other. The results obtained have also been shown in Fig. 3 and Plate 4.

Table 4. *In vitro* evaluation of bioagents against *F. oxysporum* f. sp. *pisi and F. solani* f. sp. *pisi*

Bioagents	*Fusarium oxysporum* f. sp. *pisi*		*Fusarium solani* f. sp. *pisi*	
	Mycelial growth (mm)	Mycelial inhibition (%)	Mycelial growth (mm)	Mycelial inhibition (%)
Trichoderma harzianum (SMA-5)	20.3	77.4	21.7	75.9
T. harzianum (JMA-4)	31.7	64.8	34.7	61.4
T. harzianum (Th-M)	29.0	67.8	33.3	63.0
T. koningii (DMA-8)	23.0	74.4	30.0	66.7
T. koningii (JMA-11)	32.0	64.4	43.7	51.4
T. viride	21.0	76.7	24.3	73.0
Control (No bioagent)	90.0	-	90.0	-
CD(P=0.05)	**4.4**	**-**	**4.1**	-

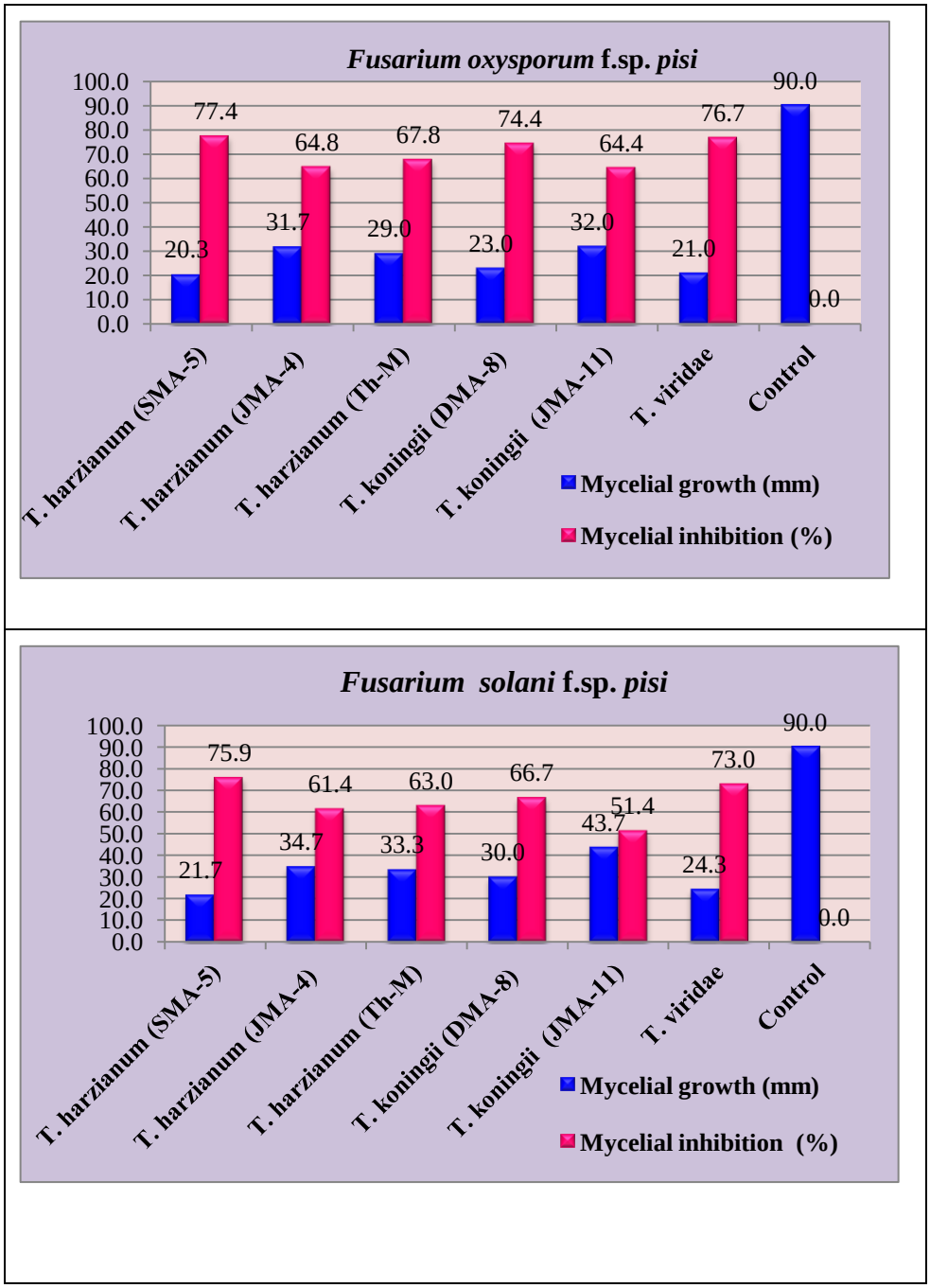


Fig. 3. Mycelial inhibition of *Fusarium oxysporum* f. sp. *pisi* and *Fusarium solani* f. sp. *pisi* by bioagents.

Fusarium oxysporum f. sp. *pisi*

Fusarium solani f. sp. *pisi*

T_5- *Trichoderma harzianum* (SMA-5), **T_4-** *Trichoderma harzianum* (JMA-4), **T_{11}-** *Trichoderma koningii* (JMA-11), **T_8-** *Trichoderma koningii* (DMA-8), **Th-** *Trichoderma harzianum* (Th-M), **Tv-** *Trichoderma viride* and **C -** Control

Plate 4. Mycelial inhibition of *Fusarium oxysporum* f. sp. *pisi* and *Fusarium solani* f. sp. *pisi* by bioagents.

Various workers as Negi et al. (2014), Koli et al. (2014), Hamid et al. (2012) and Kapoor et al. (2005) also reported the antagonistic activities of *T. harzianum, T. viride, G. virens, P. fluorescen*s and *B. subtilis* against *Fusarium* sp.

Though all the test bioagents were proved to inhibit the mycelial growth of both the pathogens but a SMA-5 strain of *T. harzianum* showed the maximum mycelial inhibition against *F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi* and can be used in the management of pea root rots / wilt complex disease.

4.3.3. Evaluation of botanicals

a) Alcoholic extract

The alcoholic leaf extracts of five botanicals namely *Eupatorium adenophorum, Lantana camara, Eucalyptus* sp., *Vitex negundo* and *Melia azedarach* were evaluated at different concentrations of 5, 10, 15, 20 and 25 % for their antifungal properties using Poisoned Food Technique against *F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi* (Table 5 and 6). The data revealed that alcoholic extracts of all botanicals were effective against both pathogens to a varying extent. Antifungal activities of all phytoextracts increased significantly with the increase in the concentration from 5 to 25 %.The pure concentrate (100%) of all phytoextracts resulted in cent percent inhibition of mycelial growth of both *F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi*.

The plant extracts of all botanicals proved to be effective against both the pathogens at 25% concentration resulting >60% inhibition of mycelial growth (Fig. 4). *Eupatorium adenophorum* yielded maximum inhibition of 83.8 %against *F. oxysporum* f. sp. *pisi* and 77.5% against *F. solani* f. sp. *pisi* followed by *Eucalyptus* sp. 83.1 and 76.1% respectively at 25 % concentration and were statistically at par with each other. *L. camera* was found least effective to yield 63.0 and 40.3% inhibition of mycelial growth against both *F. oxysporum* f. sp. *pisi and F. solani* f. sp. *pisi* at 25 % concentration respectively.The results obtained above have also been shown in Fig. 4 and Plate 5 & 6 to depict the mycelial inhibition of the pathogens by the alcoholic extracts of test botanicals.

Table 5. *In vitro* evaluation of alcoholic extracts of botanicals against *Fusarium oxysporum* f. sp. *pisi*

Botanicals	Mycelial growth (mm) at different concentrations (%)					Mycelial inhibition (%) at different concentrations (%)				
	5	10	15	20	25	5	10	15	20	25
Vitex negundo	26.0	25.3	22.7	21.7	19.7	71.1	71.9	74.8	75.9	78.1
Lantana camara	43.7	40.7	38.7	35.7	33.3	51.4	54.8	57.0	60.3	63.0
Eupatorium adenophorum	30.3	25.0	20.7	17.7	14.6	66.3	72.2	77.0	80.3	83.8
Eucalyptus sp.	27.7	22.7	19.0	16.0	15.2	69.2	74.8	78.9	82.2	83.1
Melia azedarach	54.7	52.0	48.3	40.0	30.7	39.2	42.2	46.3	55.6	65.9
Control (No treatment)	90.0	90.0	90.0	90.0	90.0					
CD (P=0.05)	**1.3**	**1.6**	**1.1**	**1.3**	**0.9**					

Table 6. *In vitro* evaluation of alcoholic extracts of botanicals against *Fusarium solani* f. sp. *pisi*

Botanicals	Mycelial growth (mm) at different concentrations (%)					Mycelial inhibition (%) at different concentrations (%)				
	5	10	15	20	25	5	10	15	20	25
Vitex negundo	45.7	42.7	38.7	35.7	30.7	49.2	52.6	57.0	60.3	65.9
Lantana camara	63.7	60.7	57.7	55.7	53.7	29.2	32.6	35.9	38.1	40.3
Eupatorium adenophorum	60.7	50.0	35.3	22.1	20.2	32.6	44.4	60.8	75.4	77.5
Eucalyptus sp.	45.3	32.3	25.7	21.6	21.5	49.7	64.1	71.4	74.9	76.1
Melia azedarach	60.3	56.7	51.0	49.0	47.0	33.0	37.0	43.3	45.6	47.8
Control (No treatment)	90.0	90.0	90.0	90.0	90.0					
CD (P=0.05)	**1.7**	**1.3**	**1.5**	**1.2**	**1.0**					

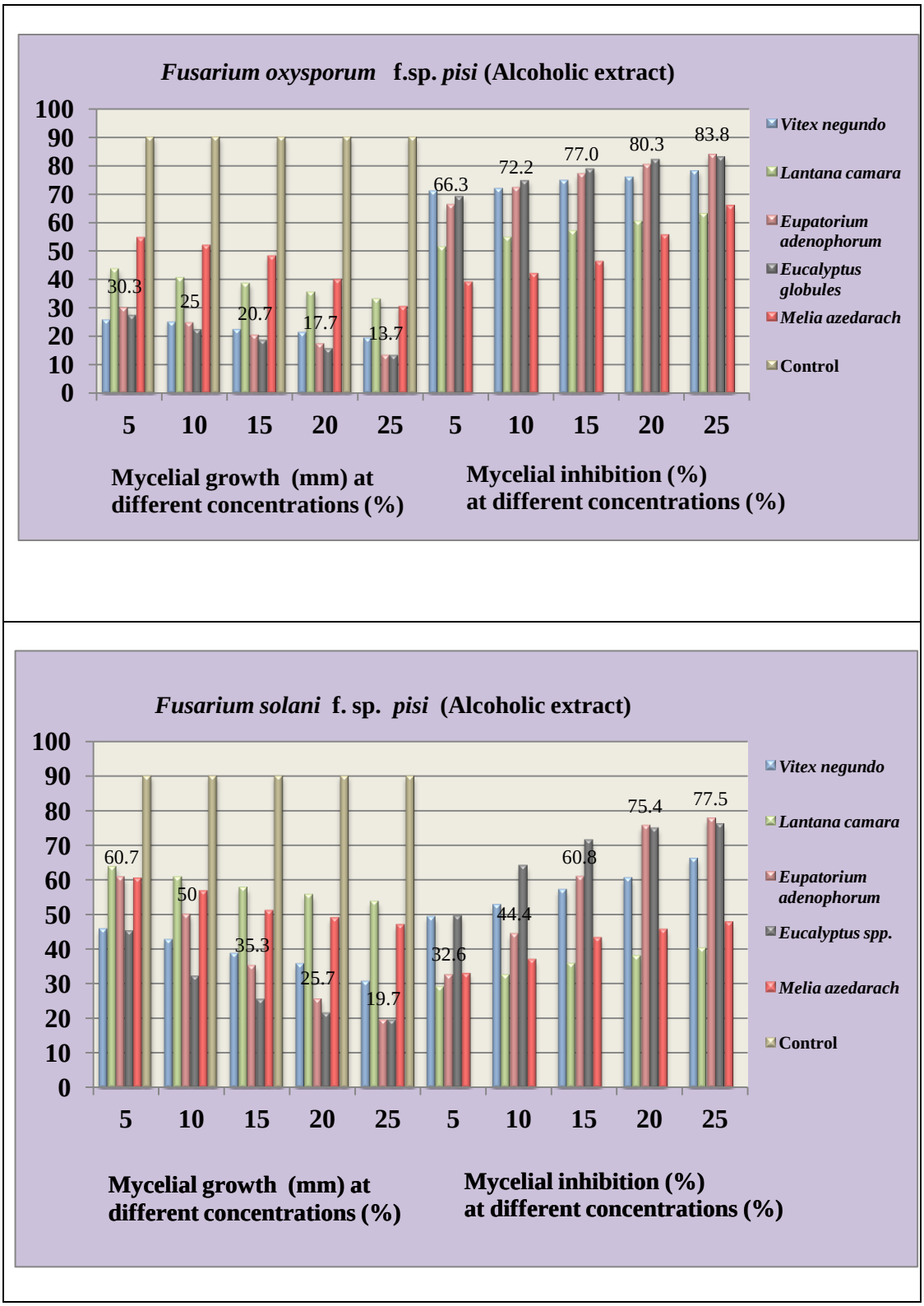


Fig. 4 & 5. *In vitro* evaluation of alcoholic extracts of botanicals against *Fusarium oxysporum* f. sp. *pisi* and *Fusarium solani* f. sp. *pisi.*

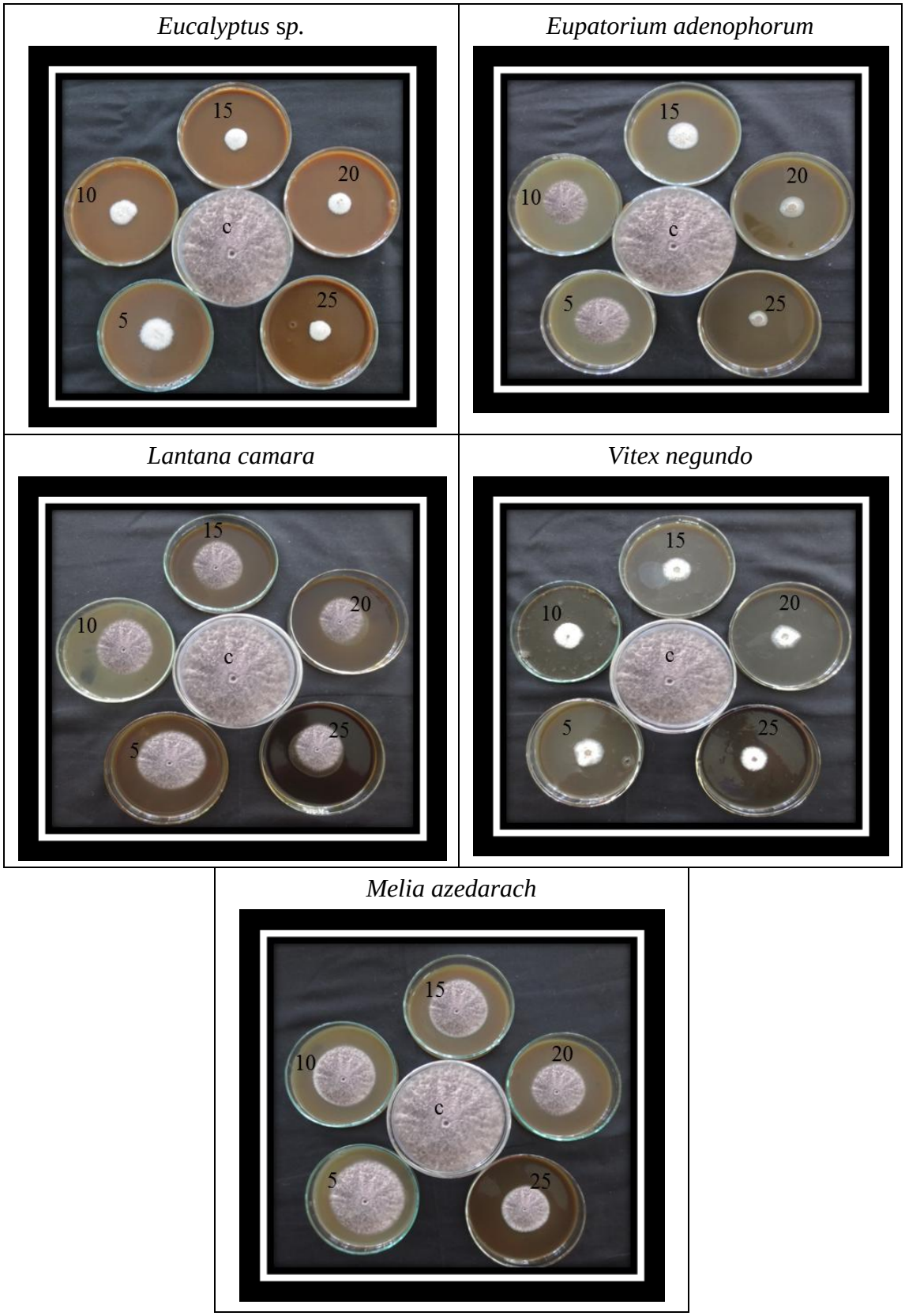


Plate 5. *In vitro* evaluation of alcoholic extracts of botanicals against *Fusarium oxysporum* f. sp. *pisi.*

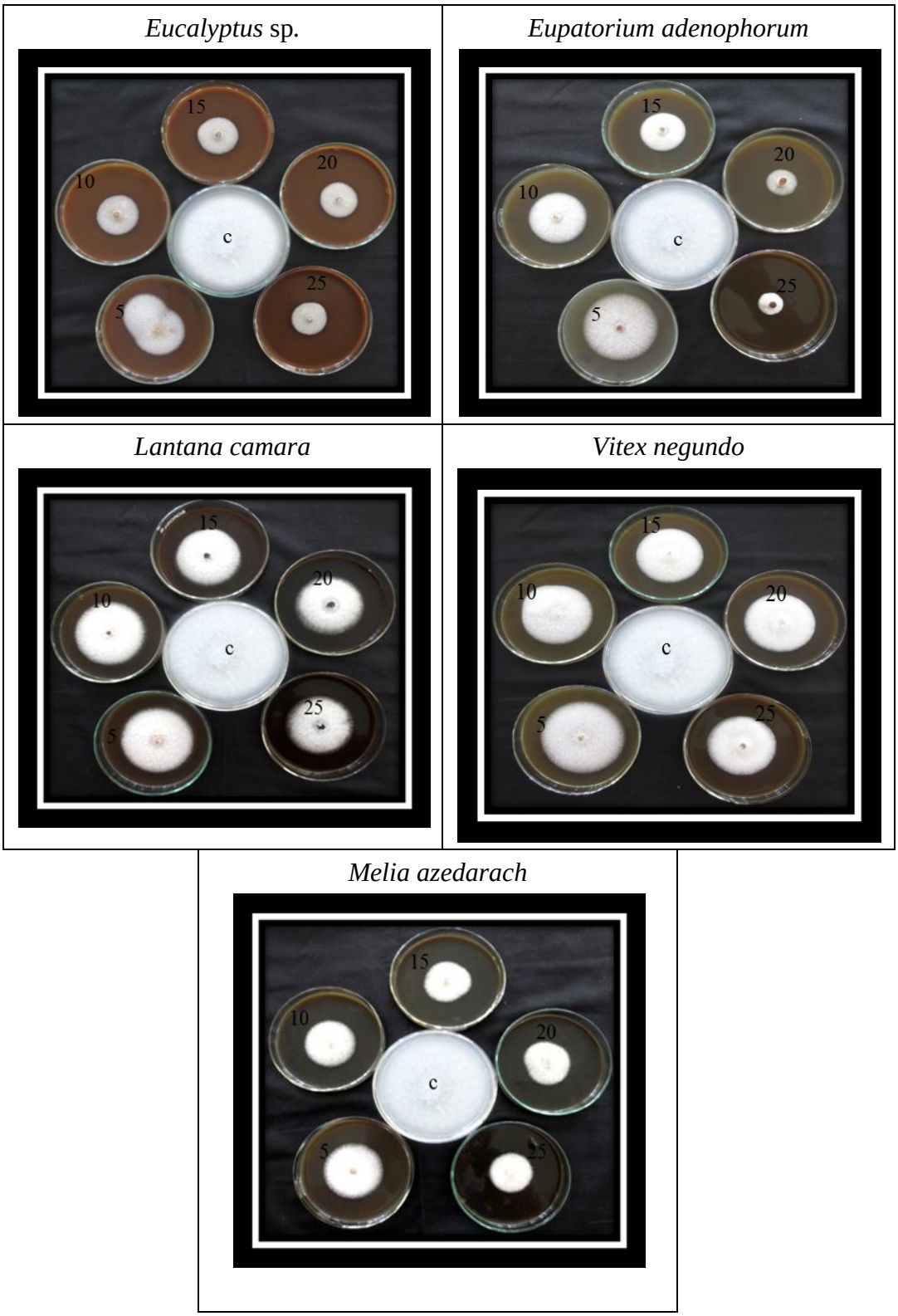


Plate 6. *In vitro* evaluation of alcoholic extracts of botanicals against *Fusarium solani* f. sp. *pisi*.

b) Aqueous extract

Data on antifungal potential of aqueous extracts of botanicals (1:1 in w/v) *viz*., *Eupatorium adenophorum*, *Lantana camara*, *Eucalyptus* sp., *Vitex negundo* and *Melia azedarach* with antifungal properties were evaluated at 5, 10, 15, 20 and 25 % concentrations against *F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi* using Poisoned Food Technique (Table 7 & 8). The pure concentrate (100%) of all phytoextracts resulted in cent percent inhibition of mycelial growth of both *F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi*. At 25 % concentrations, *Eucalyptus*sp. yielded maximum mycelial inhibition of 25.2% against *F. oxysporum* f. sp. *pisi* followed by *E. adenophorum* with 24.1% and were statistically at par with each other. At 25 % concentrations, *E. adenophorum* yielded maximum inhibition of 37.8 % followed by *Eucalyptus* sp. with 31.9% mycelial inhibition against *F. Solani* f. sp. *pisi* and were not statistically at par with each other. *Melia azedarach* was found least effective against both the pathogens even at 25 % concentrations.The results obtained above have also been shown in Fig. 6 & 7 and captured in Plate 7 & 8 to depict the mycelial inhibition of the pathogens by aqueous extracts of test botanicals.

The antifungal potential of aqueous and crude extracts of botanicals against *F. solani, F. oxysporum, R. solani* and *S. sclerotiorum* have also been reported by Kumar and Tripathi (1991) and Meena and Paul (2005).

Though the pure concentrate of all the test botanicals (alcoholic as well as aqueous) resulted in cent per cent inhibition of mycelial growth of both *F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi* causing pea root rots/wilt complex disease but alcoholic extract of *E. adenophorum* and *Eucalyptus* sp. at 25%test concentration were proved significant in mycelial inhibition of *F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi*. Hence, alcoholic extract of *E. adenophorum* or *Eucalyptus* sp. at 25% test concentration can be used in the management of the disease.

Table 7. *In vitro* evaluation of aqueous extracts of botanicals against *Fusarium oxysporum* f. sp. *pisi*

Botanicals	Mycelial growth (mm) at different concentrations (%)					Mycelial inhibition (%) at different concentrations (%)				
	5	10	15	20	25	5	10	15	20	25
Vitex negundo	81.0	79.0	77.0	74.0	70.0	10.0	12.2	14.4	17.8	22.2
Lantana camara	78.0	77.3	75.0	73.7	69.7	13.3	14.1	16.7	18.1	22.6
Eupatorium adenophorum	81.0	79.0	77.0	71.0	68.3	10.0	12.2	14.4	21.1	24.1
*Eucalyptus*sp.	78.3	74.7	72.7	70.0	67.3	13.0	17.0	19.2	22.2	25.2
Melia azedarach	81.3	78.7	76.7	74.7	72.0	9.7	12.6	14.8	17.0	20.0
Control	90.0	90.0	90.0	90.0	90.0					
CD (P=0.05)	**1.4**	**1.3**	**1.2**	**1.9**	**2.4**					

Table 8. *In vitro* evaluation of aqueous extracts of botanicals against *Fusarium solani* f. sp. *pisi*

Botanicals	Mycelial growth (mm) at different concentrations (%)					Mycelial inhibition (%) at different concentrations (%)				
	5	10	15	20	25	5	10	15	20	25
Vitex negundo	77.0	72.7	71.3	69.7	65.3	14.4	19.2	20.8	22.6	27.4
Lantana camara	78.7	72.7	70.3	68.3	66.3	12.6	19.2	21.9	24.1	26.3
Eupatorium adenophorum	66.7	63.0	62.3	60.3	56.0	25.9	30.0	30.8	33.0	37.8
Eucalyptus sp.	69.3	66.7	65.3	63.3	61.3	23.0	25.9	27.4	29.7	31.9
Melia azedarach	82.0	84.7	78.7	74.0	67.0	8.9	5.9	12.6	17.8	25.6
Control	90.0	90.0	90.0	90.0	90.0					
CD (P=0.05)	**1.8**	**3.1**	**1.7**	**1.5**	**1.8**					

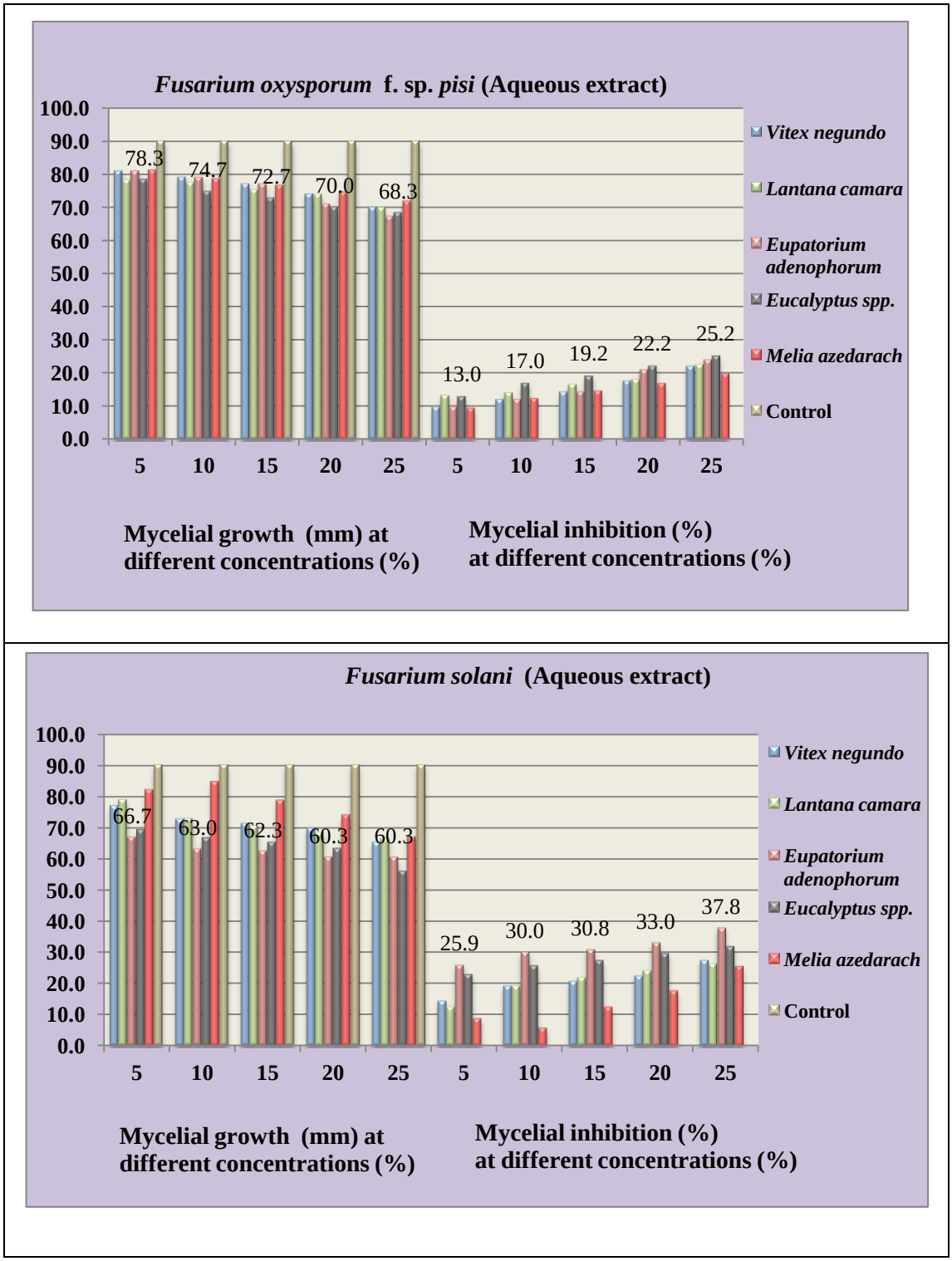


Fig. 6&7. *In vitro* evaluation of aqueous extracts of botanicals against *Fusarium oxysporum* f. sp. *pisi* and *Fusarium solani* f. sp. *pisi.*

Plate 7. *In vitro* evaluation of aqueous extracts of botanicals against *Fusarium oxysporum* f. sp. *pisi.*

Plate 8. *In vitro* evaluation of Aqueous extracts of botanicals against *Fusarium solani* f. sp. *pisi*.

4.3.4. Evaluations of fungicides

Six fungicides *viz.,* Bavistin (carbendazim 50 WP), Tilt (propiconazole 25 EC), Raxil (tebuconazole 2 DS), Thiram 75 DS, Vitavax power (carboxin 37.5% + thiram 37.5%) and Vitavax (carboxin 75 WP), were tested against both *F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi* at different concentrations i. e. 50, 100, 250, 500. 750, 1000, 1500, 2000 and 2500 ppm *in vitro* conditions using the Poisoned Food Technique (Table 9 & 10). The perusal of data depicted that all the test fungicides were found effective even at 50 ppm with >70 % inhibition of mycelial growth against *Fusarium oxysporum* f. sp. *pisi* except Vitavax (carboxin 75 WP). All the test fungicides obtained cent per cent mycelial inhibition at 1000 ppm except Vitavax (carboxin 75 WP). Vitavax power (carboxin 37.5% + thiram 37.5%) and Bavistin (carbendazim 50 WP) yielded cent per cent mycelial inhibition even at 500 ppm against *F. oxysporum* f. sp. *pisi* followed by Tilt (propiconazole 25 EC) and Raxil (tebuconazole 2 DS) with 93.3 and 90.4 % respectively. In case of *F. solani* f. sp. *pisi,* Bavistin (carbendazim 50 WP), Raxil (tebuconazole 2 DS) and Vitavax power (carboxin 37.5% + thiram 37.5%) yielded cent per cent mycelial inhibition at 1000 ppm. Bavistin (carbendazim 50 WP) alone yielded cent per cent mycelial inhibition even at 500 ppm and >85% at 50 ppm. All the test fungicides obtained cent per cent mycelial inhibition at 1500 ppm except Vitavax (carboxin 75 WP). The results obtained have also been shown in Fig. 8 & 9 and Plate 9 & 10.

Many workers (Maheshwari and Jhooti 1987; Gupta et al. 1988; Harvey et al. 1992; Kumar et al. 2011; Koli et al. 2014) have also reported Bavistin, Thiram and Vitavax effective against *F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi.*

Hence, Bavistin (carbendazim 50 WP) was found the best one among all the test fungicides followed by Vitavax power (carboxin 37.5% + thiram 37.5%), Raxil (tebuconazole 2 DS) and Tilt (propiconazole 25 EC) against both the pathogens *F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi* causing pea root rots/wilt complex disease.

Table 9. *In vitro* evaluation of chemicals against *Fusarium oxysporum* f. sp. *pisi*

Fungicides	Mycelial growth (mm) at different concentrations (ppm)									Mycelial inhibition (%) at different concentrations (ppm)								
	50	100	250	500	750	1000	1500	2000	2500	50	100	250	500	750	1000	1500	2000	2500
Carboxin 37.5% + Thiram 37.5% (Vitavax power)	44.3 (6.7)	39.0 (6.3)	34.7 (6.0)	21.0 (4.7)	10.7 (3.4)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	50.7	56.7	61.5	76.7	88.1	100.0	100.0	100.0	100.0
Carboxin 75 WP (Vitavax)	74.0 (8.7)	72.0 (8.5)	66.3 (8.2)	64.0 (8.1)	60.7 (7.9)	59.0 (7.7)	41.0 (6.5)	26.0 (5.2)	20.7 (4.7)	17.8	20.0	26.3	28.9	32.6	34.4	54.4	71.1	77.0
Tebuconazole 2 DS (Raxil)	35.7 (6.1)	30.0 (5.6)	10.7 (3.4)	9.7 (3.3)	6.3 (2.7)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	60.4	66.7	88.1	89.3	93.0	100.0	100.0	100.0	100.0
Thiram 75 DS	46.7 (6.9)	39.7 (6.4)	40.3 (6.4)	26.0 (5.2)	18.0 (4.4)	12.0 (3.6)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	48.1	55.9	55.2	71.1	80.0	86.7	100.0	100.0	100.0
Carbendazim 50 WP (Bavistin)	13.3 (3.8)	11.0 (3.5)	6.7 (2.8)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	85.2	87.8	92.6	100.0	100.0	100.0	100.0	100.0	100.0
Propiconazole 25 EC (Tilt)	27.7 (5.4)	23.3 (4.9)	17.3 (4.3)	7.3 (2.9)	6.3 (2.7)	6.0 (2.6)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	69.3	74.1	80.7	91.9	93.0	93.3	100.0	100.0	100.0
Control	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	-	-	-	-	-	-	-		
CD (P=0.05)	**0.3**	**0.2**	**0.2**	**0.3**	**0.3**	**0.2**	**0.1**	**0.1**	**0.1**									

The figures in parentheses are square root transformed values

Table 10. *In vitro* evaluation of chemicals against *Fusarium solani* f. sp. *pisi*

	Mycelial growth (mm) at different concentrations (ppm)									Mycelial inhibition (%) at different concentrations (ppm)								
	50	100	250	500	750	1000	1500	2000	2500	50	100	250	500	750	1000	1500	2000	2500
Carboxin 37.5% +Thiram 37.5% (Vitavax power)	19.7 (4.5)	17.3 (4.3)	10.7 (3.4)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	78.1	80.7	88.1	100.0	100.0	100.0	100.0	100.0	100.0
Carboxin 75 WP (Vitavax)	78.0 (8.9)	74.0 (8.7)	67.3 (8.3)	54.0 (7.4)	44.0 (6.7)	30.3 (5.6)	9.0 (3.2)	3.7 (2.2)	2.3 (1.8)	13.3	17.8	25.2	40.0	51.1	66.3	90.0	95.9	97.4
Tebuconazole 2 DS (Raxil)	20.7 (4.7)	19.0 (4.5)	13.0 (3.7)	8.7 (3.1)	7.0 (2.8)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	77.0	78.9	85.6	90.4	92.2	100.0	100.0	100.0	100.0
Thiram 75 DS	26.0 (5.2)	21.0 (4.7)	16.0 (4.1)	13.0 (3.7)	12.7 (3.7)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	71.1	76.7	82.2	85.6	85.9	100.0	100.0	100.0	100.0
Carbendazim 50 WP (Bavistin)	15.0 (4.0)	11.0 (3.5)	8.3 (3.1)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	83.3	87.8	90.7	100.0	100.0	100.0	100.0	100.0	100.0
Propiconazole 25 EC (Tilt)	21.3 (4.7)	13.3 (3.8)	9.7 (3.3)	6.0 (2.6)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	76.3	85.2	89.3	93.3	100.0	100.0	100.0	100.0	100.0
Control	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	-	-	-	-	-	-	-	-	-
CD (P=0.05)	**0.2**	**0.2**	**0.3**	**0.1**	**0.2**	**0.1**	**0.1**	**0.1**	**0.5**									

The figures in parentheses are square root transformed values

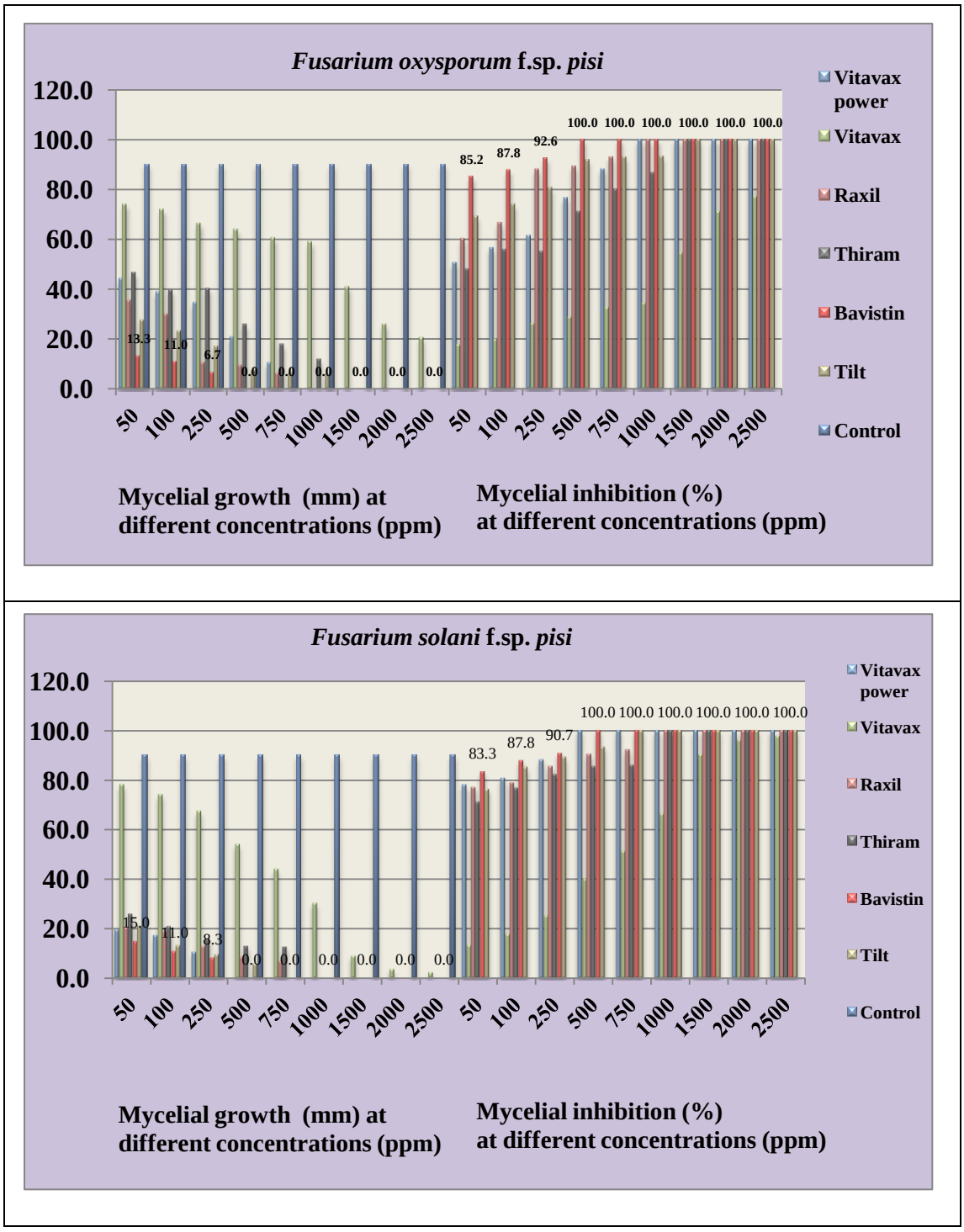


Fig. 8 & 9. *In vitro* evaluation fungicides against *Fusarium oxysporum* f. sp. *pisi* and *Fusarium solani* f. sp. *pisi***.**

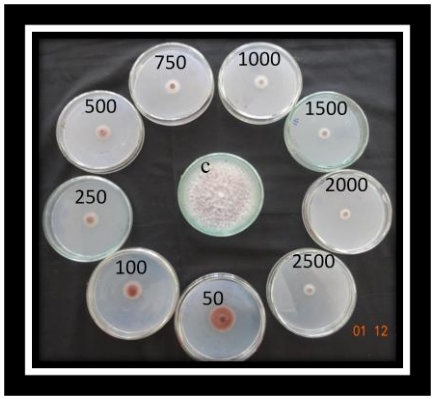
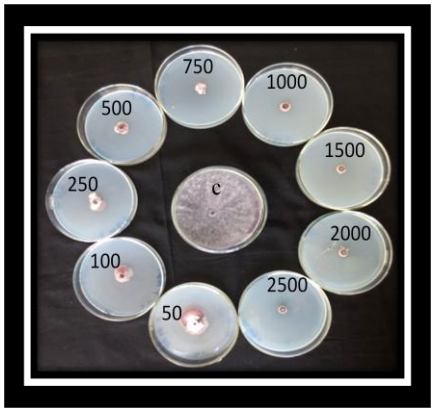
Bavistin	Vitavax Power	Vitavax
		
Raxil	Thiram	Tilt
		

Plate 9. *In vitro* evaluation of fungicides against *Fusarium oxysporum* f. sp. *pisi* .

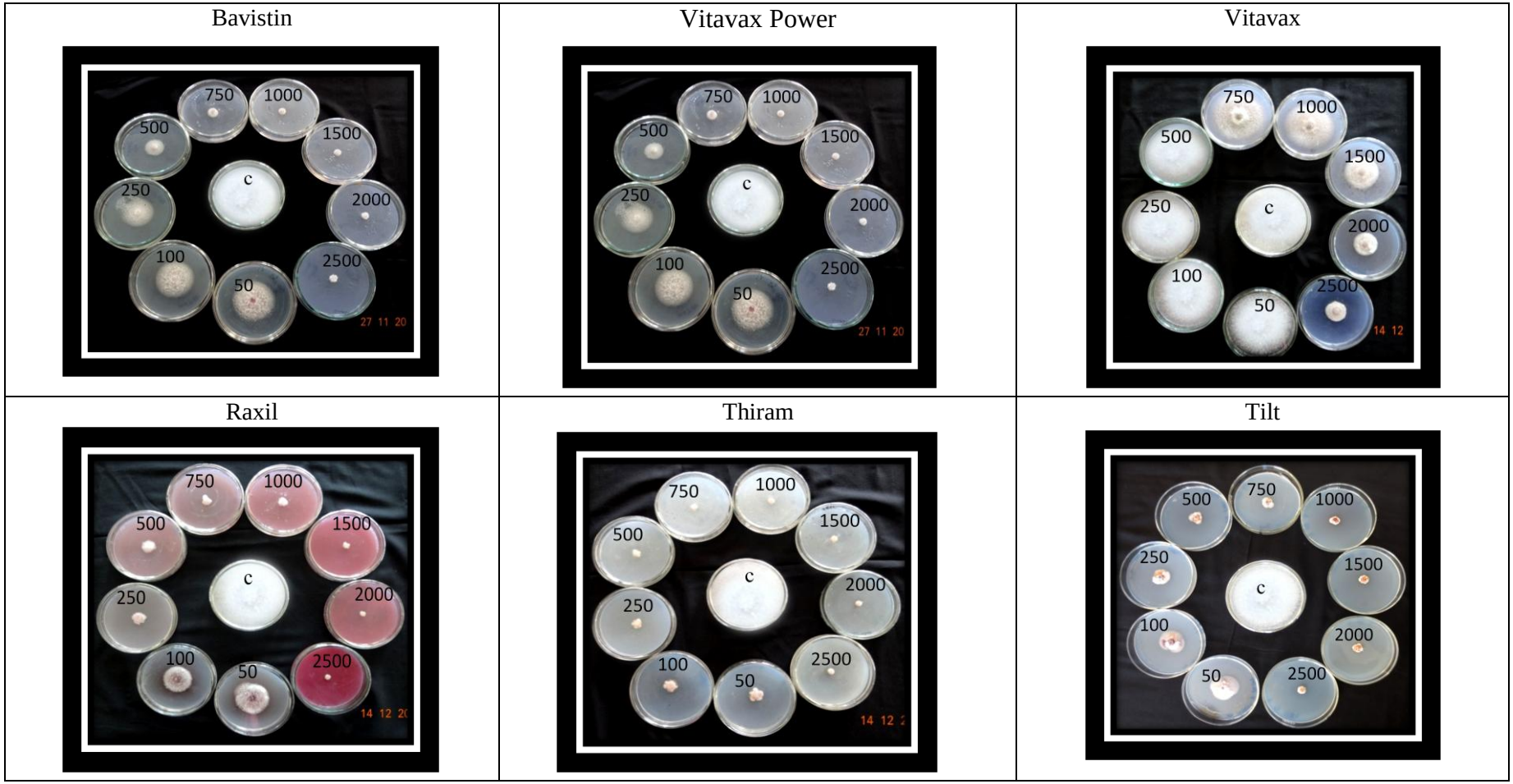


Plate 10. *In vitro* evaluation of fungicides against *Fusarium solani* f. sp. *pisi.*

4.3.5. Evaluation of germplasm

One hundred and thirteen elite pea lines, procured from the Department of Plant Pathology and Department of Vegetable and Floriculture, were screened against pea root rot /wilt complex pathogens (*F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi*) to locate host resistance and disease reactions were given in the table 11. No pea lines fell under the disease score of 0 to show highly resistant (HR) reactions. Five pea genotypes *viz.,* EC-329570, EC-329573, DPP-127-R, DPP-100, KS-268 were remained resistant under disease score of 1 whereas, twenty three pea lines were remained moderately resistant with disease score of 2 *viz.,* EC-322748, EC-328753, EC-329577, EC-328786, IC-208378, IC-395309, EC-548811, LFP-540, IPFD-99-13, EC-381860, VRP-16, DPP-62, DPP-80, DPP-102-T, P-1297-22, P-111, P-263, P-1297-84, P-1778, P-206 , PG-3, JM-1, KTP-8. Thirty one pea lines C-400, JP-15-1, DMR-49, Pb-89, IC-208395, CHP-2, DGP-4, C-96, DARL-104, PMR-4, JP-85, SL-82, DM-1731, HPPC-63, FP-216, NIC-11183, KMNR-896, MA-6, P-1440-20, P-1610-3, Line-13, LFP-573, P-117-1, LFP-574, KDMR-675, KMNR-894, DPP-9411, EC-342007, JP-Ajjila, DPFPP-1, NDVP-24 fell under the disease score of 3 and were rated as moderately susceptible (tolerant) whereas, thirty three pea lines DPP-13T, DPP-25G, DPP-13, HFP-4, NPVP-104, JP-823, DPP-107, JI-1559, Kukumseri Selection-6, KS-245, Line-11, P-212B, KPMR-400, HUDP-15, HFP-8909-B, KPMR-523, IPF-P-2-5, DPP-120, JP-501-A/2, F-4-1429-4, EC-328743, LFP-431, VP-8005, CHPMR-1, VRP-22, IC-296678, HMQ-22, FC-2, Matar Ageta, Rachna, Matialla, Lincoln, Bonnevile showed susceptible reactions with disease score of 4 and rest twenty one lines showed susceptible reactions with disease score of 5.

Kapoor et al. (2006)) also reported DPP-54, KS-268, LP-3 and UN-536 lines resistant whereas, KS-221, Azad-P1, EC-381813, EC-381854 and JI-2438 highly susceptible-to root rot / wilt complex. Khadija N (2004) found only one line (G-127) as highly resistant to *Fusarium* sp.

Since the preliminary screening of available germplasm of pea has been done but again confirmation is required to identify the sources of resistance against complex disease on the basis of scoring for different categories.

Table 11. Reactions of pea germplasm against pea root rot/wilt complex disease

Disease score	Pea germplasm	Disease reaction
0	Nil	HR
1	EC-329570, EC-329573, DPP-127-R, DPP-100, KS-268.	R
2	EC-322748, EC-328753, EC-329577, EC-328786, IC-208378, IC-395309, EC-548811, LFP-540 , IPFD-99-13, EC-381860, VRP-16, DPP-62, DPP-80, DPP-102-T, P-1297-22, P-111, P-263, P-1297-84, P-1778, P-206, PG-3, JM-1, KTP-8.	MR
3	C-400, JP-15-1, DMR-49, Pb-89, IC-208395, CHP-2, DGP-4, C-96, DARL-104, PMR-4, JP-85, SL-82, DM-1731, HPPC-63, FP-216, NIC-11183, KMNR-896, MA-6, P-1440-20, P-1610-3, Line-13, LFP-573, P-117-1, LFP-574, KDMR-675, KMNR-894, DPP-9411, EC-342007, JP-Ajjila, DPFPP-1, NDVP-24.	MS
4	DPP-13T, DPP-25G, DPP-13, HFP-4, NPVP-104, JP-823, DPP-107, JI-1559, Kukumseri Selection-6, KS-245, Line-11, P-212B, KPMR-400, HUDP-15, HFP-8909-B, KPMR-523, IPF-P-2-5, DPP-120, JP-501-A/2, F-4-1429-4, EC-328743, LFP-431, VP-8005, CHPMR-1, VRP-22, IC-296678, HMQ-22, FC-2, Matar Ageta, Rachna, Matialla, Lincoln, Bonnevile.	S
5	HPPC-75, DPP-1542, DPP-3, JPP Lufela, KS-146, DP-9414, JP-15, VRPMR-9, VP-106, Tritoa-RI 497, KP-1, VL-3, CHP-1, VP-223, P-9297-1, DPP-139-3, KS-146, NDVP-9, CHPM-2, JP-20, Azad-P1.	HS

4.4. Disease management

The pot and field experiments were conducted with nine treatments in best combinations to formulate management strategies against pea root rot/wilt complex disease. The results obtained were presented in the tables 12 and 13.

In pot conditions

The perusal of data obtained from pot experiment (Table 12) revealed that the combination of soil amendment with Vermicompost : FYM (1:1) @ 15 t/ha carrying *Trichoderma* @ 2.5 kg/t and seed treatment with *E. adenophorum* @ 5.0 ml/kg seed was found best against pea root rot /wilt complex pathogens (*F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi*) to yield the per cent disease control of 70.0 % and was also statistically at par with the check (seed treatment with Bavistin @ 2.5 g/kg seed) followed by the combination of soil amendment with Vermicompost : FYM (1:1) carrying *Trichoderma* @ 2.5 kg /t and seed treatment with *Trichoderma* @ 5.0 g/kg seed. Soil amendment with Vermicompost : FYM (1:1) mixed with *Trichoderma* @ 2.5 kg/t or seed treatment with *E. adenophorum* @ 5.0 ml/kg seed alone also yielded the results upto satisfaction i.e. > 55.0 % disease control and were found statistically at par with each other. But the combination of both i.e. soil amendment with Vermicompost : FYM (1:1) carrying *Trichoderma* @ 2.5 kg/t and seed treatment with *E. adenophorum* @ 5.0 ml/kg seed or *Trichoderma* @ 5.0 g/kg seed improved the germination and crop stand of peas.

In field conditions

Similar results were also obtained in the field conditions with the significant per cent increase in yield (Table 13). The perusal of data revealed that the combination of soil amendment with Vermicompost : FYM (1:1) @ 15 t/ha carrying *Trichoderma* @ 2.5 kg/t and seed treatment with *E. adenophorum* @ 5.0 ml/kg seed was found best one among all the combinations in the management strategies against pea root rot /wilt complex pathogens to yield the maximum germination and crop stand of 69.7 and 86.0 % respectively with 80.7 per cent increase in yield followed by the combination of soil amendment with Vermicompost : FYM (1:1) carrying *Trichoderma* @ 2.5 kg/t and seed treatment with *Trichoderma* @ 5.0 g/kg seed with

78.3 per cent increase in yield and remained statistically at par with the check (Seed treatment with Bavistin @ 2.5g/kg seed).

Table 12. Disease management of pea root rot/wilt complex in pot

	Treatments	Per cent Germination	Per cent Mortality	Per cent disease control
T_1	Soil amendment with Vermicompost : FYM (1:1) @ 15t/ha	46.7 (43.0)	28.6 (32.3)	14.1
T_2	Soil amendment with Vermicompost : FYM (1:1) mixed with *Trichoderma* @ 2.5 kg/t	60.0 (50.9)	14.8 (22.3)	55.6
T_3	Seed treatment with *Trichoderma* @ 5.0 g/kg seed	48.9 (44.4)	22.7 (28.2)	31.8
T_4	Seed treatment with *E. adenophorum*@ 5.0 ml/kg seed	53.3 (46.9)	16.7 (23.8)	49.8
T_5	$T_1 + T_3$	55.6 (48.2)	16.0 (23.3)	52.0
T_6	$T_1 + T_4$	57.8 (49.5)	15.4 (22.8)	53.8
T_7	$T_2 + T_3$	62.2 (52.1)	14.3 (21.9)	57.1
T_8	$T_2 + T_4$	66.7 (54.8)	10.0 (18.4)	70.0
T_9	Seed treatment with Bavistin @ 2.5g/kg seed (check)	71.1 (57.5)	9.4 (17.8)	71.8
T_{10}	Control (No treatment)	40.0 (39.2)	33.3 (35.2)	-
	CD (P=0.05)	**8.7**	**6.9**	**-**

The figures in parentheses are arc sin transformed values

Table 13. Disease management of pea root rot/wilt complex under field conditions

	Treatments	Per cent germination	Per cent Mortality	Per cent disease control	Yield (q/ha)	Per cent increase in yield
T_1	Soil amendment with Vermicompost : FYM (1:1) @ 15t/ha	56.5 (48.7)	32.4 (34.6)	51.1	46.3	20.9
T_2	Soil amendment with Vermicompost : FYM (1:1) mixed with *Trichoderma* @ 2.5 kg/t	64.5 (53.4)	15.2 (22.9)	77.0	65.4	70.8
T_3	Seed treatment with *Trichoderma* @ 5.0 g/kg seed	60.5 (51.0)	24.2 (29.4)	63.4	51.7	35.0
T_4	Seed treatment with *E. adenophorum*@ 5.0 ml/kg seed	62.3 (52.1)	19.5 (26.1)	71.0	57.5	50.1
T_5	$T_1 + T_3$	63.0 (52.5)	19.8 (26.4)	70.1	56.7	48.0
T_6	$T_1 + T_4$	64.3 (53.3)	15.5 (23.0)	76.6	64.2	67.6
T_7	$T_2 + T_3$	67.5 (55.2)	12.3 (20.2)	81.4	68.3	78.3
T_8	$T_2 + T_4$	69.7 (56.6)	9.3 (17.5)	86.0	69.2	80.7
T_9	Seed treatment with Bavistin @ 2.5g/kg seed (check)	71.2 (57.5)	7.0 (15.0)	89.4	70.0	82.8
T_{10}	Control (No treatment)	50.8 (45.5)	66.2 (54.5)	-	38.3	-
	CD (P=0.05)	**2.0**	**5.5**		**17.0**	

The figures in parentheses are arc sin transformed values

Soil amendment with Vermicompost : FYM (1:1) carrying *Trichoderma* @ 2.5 kg/t alone also managed the disease with good crop stand 77.0 % with per cent increase in yield of 70.8. Seed treatment with *Trichoderma* @ 5.0 g/kg seed or *E. adenophorum* @ 5.0 ml/kg seed alone could also manage the disease upto satisfaction. But the combination of both i.e. soil amendment with Vermicompost : FYM (1:1) carrying *Trichoderma* @ 2.5 kg/t and Seed treatment with *E. adenophorum* @ 5.0 ml/kg seed or *Trichoderma* @ 5.0 g/kg seed improved the germination and crop stand of peas along with yield. Though all the treatments were found satisfactory with > 50 % disease control over control (No treatment) but Soil amendment with Vermicompost : FYM (1:1) mixed with *Trichoderma* @ 2.5 kg/t improved the germination and crop stand of peas along with yield.

Many workers [Chattopadhyay et al. 1996; Paul and Rathour 1997; Dohroo et al. 1998; Kumar and Dubey 2001 and Kapoor et al. 2006] also suggested the integration of chemical, cultural and biological control along with host resistance to combat the disease.

Hence, the combination of soil amendment with Vermicompost : FYM (1:1) @ 15 t/ha carrying *Trichoderma* @ 2.5 kg/t and seed treatment with *E. adenophorum* @ 5.0 ml/kg seed was found best one among all the combinations in the management strategies against pea root rot /wilt complex pathogens to yield the maximum germination and crop stand of 69.7 and 86.0 % respectively with 80.7 per cent increase in yield.

Hence, the pot and field experiments studies for disease management reveals that the combination of soil amendment with Vermicompost : FYM (1:1) carrying *Trichoderma* @ 2.5 kg/t and seed treatment with *E. adenophorum* @ 5.0 ml/kg seed was found best one among all the combinations in the management strategies against pea root rot /wilt complex pathogens to yield the maximum germination and crop stand.

5. SUMMARY AND CONCLUSIONS

The present investigation entitled **"Studies on Pea root rot /wilt complex disease"** was conducted in the Department of Plant Pathology, CSKHPKV, Palampur to achieve set objectives which are summarized and concluded as below:

An extensive survey of different agro climatic zones of pea growing areas of Himachal Pradesh were undertaken during crop growing seasons in respective regions. Pea root rot /wilt complex had been noticed as an emerging problem in pea growing regions of Himachal Pradesh. The disease had been occurring with different disease intensity levels in different pea growing areas of the state. In Zone IV, the highest disease incidence of 54.7 % was recorded at HAREC, Kukumseri followed by Dalang (54.3%), Kishori (46.0%), Sissoo (32.0%) and Karpat (24%). In Zone III, the disease incidence varies from 17.7 (Bajaura) to 19.7% (Nagwain). In Zone II, the highest disease incidence of 35.3% was recorded at Departmental Farm of CSK HPKV, Palampur followed by Kachhiyari (30.7 %) and Sagoor (22.0 %).

The two types of isolates were obtained from isolations taken from diseased seedlings of peas collected during surveys. The two species of *Fusarium* viz., *Fusarium solani* f. sp. *pisi* and *Fusarium oxysporum* f. sp. *pisi* were found to be associated with pea root rot/wilt complex disease in Himachal Pradesh. Both species of *Fusarium* produced two distinct types of symptoms in pathogenicity tests. *F. solani* f. sp. *pisi* was solely responsible to cause root rots of peas with necrosis and maceration of pea roots resulting in yellowing of leaves from basal leaf to upward whereas, *F. oxysporum* f. sp. *pisi* was responsible to cause wilting without root rots with clogging of xylem vessels.

For the management of disease different components *viz*., composts, bioagents, botanicals, chemicals and host resistance were evaluated to integrate disease management modules. In the composts, Vermicompost showed the maximum mycelial inhibition of 39.7% against *F. oxysporum* f. sp. *pisi* and 36.3% against *F. solani* f. sp. *pisi* followed by Farm Yard Manure with 29.7 and 30.0% respectively. In the bioagents, SMA-5 strain of *Trichoderma harzianum* showed the maximum

mycelial inhibition of 77.4 and 75.9 % against *F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi* respectively. In the botanicals, the plant extracts of all botanicals proved to be effective against both the pathogens at 25% concentration resulting in >60% inhibition of mycelial growth. However, *Eupatorium adenophorum* yielded maximum inhibition of 83.8 % against *F. oxysporum* f. sp. *pisi* and 77.5% against *F. solani* f. sp. *pisi* followed by *Eucalyptus* sp. 83.1 and 76.1% respectively at 25 % concentration.The alcoholic extracts of *E. adenophorum* or *Eucalyptus* sp. at 25% test concentration can be used in the management of the disease.

In the chemicals, all the test fungicides were found effective even at 50 ppm with >70 % inhibition of mycelial growth against *F. oxysporum* f. sp. *pisi* except Vitavax (carboxin 75 WP). In case of against *F. oxysporum* f. sp. *pisi*, Vitavax power (carboxin 37.5% + thiram 37.5%) and Bavistin (carbendazim 50 WP) yielded cent per cent mycelial inhibition even at 500 ppm followed by Tilt (propiconazole 25 EC) and Raxil (tebuconazole 2 DS) with 93.3 and 90.4 % respectively. In case of *F. solani* f. sp. *pisi*, Bavistin (carbendazim 50 WP), Raxil (tebuconazole 2 DS) and Vitavax power (carboxin 37.5% + thiram 37.5%) yielded cent per cent mycelial inhibition at 1000 ppm. Hence,Vitavax power (carboxin37.5%+ thiram 37.5%), Raxil (tebuconazole 2 DS) and Tilt (propiconazole 25 EC) can be used along with Bavistin (carbendazim 50 WP) in the management of the disease.

In the host resistance, out of 113 elite pea lines, five pea genotypes *viz.*, EC-329570, EC-329573, DPP-127-R, DPP-100, KS-268 were found resistant against root rot/wilt complex of pea.

Soil amendment with Vermicompost : FYM (1:1) @ 15 t/ha carrying *Trichoderma* @ 2.5 kg/t alone also managed the disease with good crop stand of 77.0 % with per cent increase in yield of 70.8. Seed treatment with *Trichoderma* @ 5.0 g/kg seed or *E. adenophorum* @ 5.0 ml/kg seed alone could manage the disease upto satisfaction. But the combination of both i.e. soil amendment with Vermicompost : FYM (1:1) carrying *Trichoderma* @ 2.5 kg/t and seed treatment with *E. adenophorum* @ 5.0 ml/kg seed or *Trichoderma* @ 5.0 g/kg seed improved the germination and crop stand of peas along with yield. For the better management of disease, the combination of soil amendment with Vermicompost : FYM (1:1) carrying *Trichoderma* @ 2.5 kg/t and seed treatment with *E. adenophorum* @ 5.0 ml/kg seed

was found best one among all the combinations in the management strategies against pea root rot /wilt complex pathogens to yield the maximum germination and crop stand of 69.7 and 86.0 % respectively with 80.7 per cent increase in yield.

Hence, the pot and field experiments studies for disease management reveals that the combination of soil amendment with Vermicompost : FYM (1:1) carrying *Trichoderma* @ 2.5 kg/t and seed treatment with *E. adenophorum* @ 5.0 ml/kg seed was found best one among all the combinations in the management strategies against pea root rot /wilt complex pathogens to yield the maximum germination and crop stand. The studies on pea root rot/wilt complex disease has been concluded as below:

- Pea root rot /wilt complex is as an emerging problem in pea growing regions of Himachal Pradesh.
- The disease incidence of 54.7 % was recorded at HAREC, Kukumseri.
- The two species of *Fusarium* viz., *Fusarium solani* f. sp. *pisi* and *Fusarium oxysporum* f. sp. *pisi* were found to be associated with pea root rot/wilt complex disease in Himachal Pradesh.
- Vermicompost, SMA-5 strain of *T. harzianu*m and the alcoholic extracts of *Eupatorium adenophorum* or *Eucalyptus* sp. at 25% test concentration showed the maximum mycelial inhibition against *F. oxysporum* f. sp. *pisi* and *F. solani* f. sp. *pisi*
- Vitavax power (carboxin 37.5% + thiram 37.5%) or Raxil (tebuconazole 2 DS) or Tilt (propiconazole 25 EC) can be used along with Bavistin (carbendazim 50 WP) in the management of the disease since all these fungicides are almost statistically at par.
- Five pea genotypes *viz.*, EC-329570, EC-329573, DPP-127-R, DPP-100, KS-268 remained resistant against root rot/wilt complex of pea and were further required screening to confirm the sources of resistance.
- For the better management of disease, the combination of soil amendment with Vermicompost : FYM (1:1) carrying *Trichoderma* @ 2.5 kg/t and seed treatment with *E. adenophorum* @ 5.0 ml/kg seed was found best one among all the combinations in the management strategies against pea root rot /wilt complex pathogens to yield the maximum germination and crop stand of 69.7 and 86.0 % respectively with 80.7 per cent increase in yield.

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APPENDIX

Composition of media used

Potato Dextrose Agar (PDA)

Peeled Potato	200.0 g
Dextrose	20.0 g
Agar	20.0 g
Streptomycin sulphate	200 ppm
Distilled Water	1000.0 ml

Hoagland solution of Half Strength

1M KH_2PO_4 (1.36 g in 10 ml)	1.0 ml
1M KNO_3 (1.00 g in 10 ml)	5.0 ml
Ca $(NO_3)_2$. $4H_2O$ (2.36 g in 10 ml)	5.0 ml
$MgSO_4$. $7H_2O$ (2.46 g in 10 ml)	2.0 ml
* Fe tarterate (0.5%)	1.0 ml
** Microelement stock solution	1.0 ml
Distilled water	2000.0 ml

*** Instead of Fe tarterate (0.5%), we can use solution (autoclaved) given below :**

EDTA	10.4 g
$FeSO_4.7H_2O$	7.8 g
KOH	66.1 g
Distilled water	1000.0 ml

**** Microelement stock solution**

H_3Bo_3	0.286 g
$MnCl_2.\ 4H_2O$	0.181 g
$ZnSo_4.\ 7H_2o$	0.022 g
$CuSO_4.\ 5H_2O$	0.008 g
$H_2MoO_4.\ H_2O$	0.002 g
Distilled Water	100.0 ml

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