STUDIES ON THE WILT COMPLEX DISEASE OF *Capsicum annuum* L.

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THESIS

SUBMITTED TO THE

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2. SHIMLA MIRCH
3. FUNGAL DISEASES
4. PLANT PATHOLOGY
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Certificate - I

This is to certify that the thesis entitled **"Studies on the wilt complex disease of *Capsicum annuum* L."** submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Agriculture (Plant Pathology) to the Faculty of Post-Graduate Studies, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu is a record of bonafide research carried out by **Tariq Rasool Rather,** Registration No. ***J-01-Ph.D.-04*** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma. It is further certified that help and assistance received during the course of thesis investigation have been duly acknowledged.

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Date : 25.11.2005

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Date: 25-11-2005

— Tariq Rasool Rather

CONTENTS

LIST OF TABLES

CONTENTS

LIST OF PLATES

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ABSTRACT

Studies on wilt complex in chilli and bell pepper were carried out during 2001-2004 with the objectives to know the status of the disease, causal agents involved with it and to arrive at the effective management strategies. The wilt disease was found to prevail in all the areas surveyed with average wilt incidence of 54.56 and 48.96 per cent in the year 2001 and 2002, respectively. The maximum disease incidence of 90.53 per cent was recorded at Jathi in district Doda in the year 2001 and the minimum of 30.23 per cent at Thandapani in Rajouri district in the year 2002. The pathogenicity tests of the micro-organisms isolated from diseased plants indicated that *Fusarium oxysporum, Phytophthora capsici, Rhizoctonia solani* and *Sclerotium rolfsii* were the causal organisms associated with the wilt disease of chilli and bell pepper crops, causing the disease independently and also in association with each other.

The studies revealed that soil moisture and minimum temperature were significantly and positively correlated with the wilt incidence, however, maximum temperature had non-significant effect. The maximum infection rate was observed when soil temperature in the range of 20-30^{0}C with soil moisture around 37 per cent prevailed in the field. Field study indicated that *F. oxysporum* was prevalent throughout the cropping season, whereas, *P. capsici* infection started when high soil moisture prevailed and *R. solani* was more prevalent during initial stages of crop growth.

Evaluation of 38 genotypes/varieties against wilt disease revealed that none was resistant, however, two genotypes SC-108 (01) and SC-105 and one variety Suraj Mukhi exhibited moderately resistant reaction under both field and glasshouse conditions.

In cultural management, it was observed that application of irrigation at 11 day intervals recorded significantly less wilt incidence than 5, 7 and 9 day irrigation frequencies, however, the yield at this irrigation interval (11 day) was significantly lower than obtained at 9 and 7 day intervals of irrigation in both, chilli and bell pepper crop. The fertilizer dose of 80:84:42 NPK kg/ha recorded lesser wilt incidence and maximum yield compared to other fertilizer combinations. Ridge planting proved superior to flat-bed planting in reducing wilt incidence and increasing yield in both the crops.

Most of the fungal antagonists tested were found effective against wilt complex pathogen under *in-vitro* conditions. However, *in-vivo* studies revealed that three fungal isolates Th_2 (*Trichoderma harzianum*), Tv_2 (*T. viride*) and Gv_3 (*Trichoderma virens*) were effective in checking wilt complex disease and also increasing seedling emergence under glasshouse studies. Seed + seedling + soil treatment with Gv_3 and Tv_2 recorded lesser wilt incidence of 41.6 per cent each at 100 DAT compared to 100 per cent incidence in check at 40 DAT in chilli crop. With similar methods of applications, Gv_3 and Th_2 recorded only

33.3 and 50.0 per cent wilt incidence in bell pepper at 100 DAT, respectively, compared to 100 per cent in check at 40 DAT.

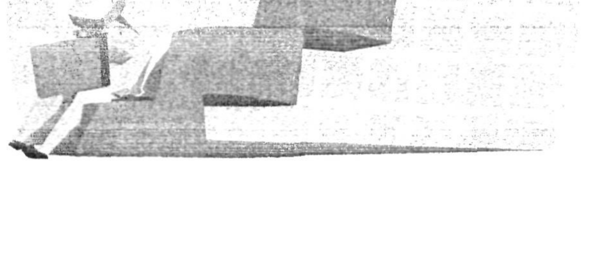
Among the nine fungicides evaluated against four wilt pathogens under *in-vitro* conditions, carbendazim, metalaxyl and carboxin were highly effective against *F. oxysporum*, *P. capsici* and *R. solani*, respectively, at 50 ppm concentration. Captan was highly effective against *P. capsici* and *F. oxysporum* at 500 ppm concentration. Seed treatment with carbendazim + metalaxyl increased 47.7 and 56.5 per cent seedling emergence over check in chillies and bell pepper, respectively. Integration of seed + seedling treatment with carbendazim + metalaxyl and captan + metalaxyl and their subsequent spraying at crown region of plant at 15 day intervals resulted in only 25.0 and 29.1 per cent wilt incidence at 100 DAT in chilli and 25.0 and 33.3 per cent in bell pepper, respectively, compared to 100 per cent wilt incidence in check at 40 DAT.

Chemicals and antagonists found effective under glasshouse conditions were tested for their compatibility and were further evaluated alone and in combinations under glasshouse and field conditions. The integration of Gv_3, Tv_2 and Th_2 with captan + metalaxyl resulted in lesser wilt incidence and higher yield compared to their individual treatments and these treatments were statistically at par with the most effective treatment (carbendazim + metalaxyl), in both the crops.

Signature of the Major Advisor **Signature of the Student**

CHAPTER - 1

Introduction



INTRODUCTION

Chilli and bell pepper are important vegetable crops grown for their unripe-green and ripe-red fruits throughout the world. The powder form of red-ripe chilli fruits is an indispensable condiment, digestive stimulant as well as flavouring and colouring agent in sauces, chutnies, pickles and other forms of food. The increasing interest in cultivation of chilli and bell pepper crop emanates from increasing awareness of its nutritional value, medicinal properties and industrial importance. Besides the source of vitamin A, B_1, B_2, B_3, C and E, and carotenoids, the chilli fruits are known to contain an alkaloid capsicin which has been ascribed to cure more than a dozen ailments including the common cold, headache, toothache and arthritis.

Chilli terminology is confusing as pepper, chili, chile, chilli, paprika and capsicum are used interchangeably for plants having *Capsicum annuum* L. as the scientific name. The words "chilli" (singular form) or chillies (plural form) are used in Asian countries in connection with pungent forms. However, sweet bell pepper is often called a "capsicum pepper", whereas, a hot or pungent pepper is also called a "chilli pepper". Nowadays most of the people use the word "Bell Pepper" generally to non-punget, bell shaped, sweet chilli pepper types, while "Chilli Pepper" has come to mean the pungent chilli varieties. The modern botanical name used by taxonomists for chilli or bell pepper, is *Capsicum annuum* var. aviculare (Smith *et al.*, 1987). In the present manuscript the term chilli and bell pepper has been used for hot chillies and sweet, bell shaped pepper (locally known as Shimla mirch), respectively.

In the Jammu division of Jammu and Kashmir state, chilli and bell pepper are grown over an area of 760 and 205 ha, with a production of 6380 and 1535 metric tons

tons of fresh chilli and bell pepper fruits, respectively (Anonymous, 2004). In spite of favourable edaphic and environmental conditions for chilli and bell pepper cultivation available in Jammu and Kashmir, the yields have not been so encouraging. Of the many bottlenecks in increasing cultivation area and fruit production, the occurrence of diseases such as anthracnose and die back (*Colletotrichum capsici*), leaf spots (*Alternaria solani*, *Cercospora capsici*) and wilt (*Fusarium* spp., *Rhizoctonia solani, Phytophthora capsici*) are noteworthy (Anonymous, 1993).

The wilt complex has become an important disease of *Capsicum annuum* cultivars in Jammu and Kashmir during the past few years occurring in epiphytotic form in several chilli and bell pepper growing areas causing 30 to 40 per cent losses in fruit yield (Anonymous, 1989). The wilt disease, incited by a number of pathogens, is the devastating soil-borne disease and hence difficult to manage. The repeated cultivation of chilli and bell pepper results in a build-up of inoculum in the soil. The plants can be infected by the pathogens in all stages of growth when environmental conditions are favourable. The disease is characterized by withering and chlorosis of lower leaves followed by the younger leaves, petioles and stem, leading to outright killing of the whole plant within a few days (Wani, 1994). The disease has been reported to be caused by *Fusarium pallidoroseum* Cooke and *Rhizoctonia solani* Kuhn (Wani, 1994), *Phytophthora capsici* and *Fusarium solani* (Shali, 2000). The practice of mono-culture with wilt-susceptible cultivars of chilli and other solanaceous vegetables (Dar and Mir, 1995a) together with excessive use of nitrogenous fertilizers and such predisposing factors as frequent irrigation (Dar and Mir, 1995a; Verma and Sharma, 1995) seems to have given fillip to the development and spread of the disease in the region during the past several years.

Reports on different aspects of wilt disease of *Capsicum annuum* in other parts of the country and abroad are available. However, little information is available on the disease from Jammu division which has varied agroclimatic conditions, congenial for the disease development, thus resulting in the heavy toll of the crop yield. Because of this the production has not been setting pace with the increasing demand. There is considerable potential of augmenting the yield of chilli and bell pepper by minimizing the losses inflicted by the biotic factors such as wilt complex.

Therefore, keeping in view the increasing incidence of chilli and bell pepper wilt complex disease and exhorbitant losses and lack of information regarding cultural, biological, chemical and integrated management of the disease, the present studies were planned with the following objectives :-

(i) Status of wilt complex of *Capsicum annuum* and causal agents involved with it.

(ii) Search for effective management strategies.

CHAPTER - 2

Review of Literature

REVIEW OF LITERATURE

The wilt of *Capsicum annuum* is a complex syndrome known to be caused by different fungal pathogens, reported from different parts of the world. Different strategies for management of the disease have, therefore, been suggested by various workers. The literature pertaining to the etiology and management of the disease is reviewed under the following heads.

2.1 Status of disease

The wilt disease of *C. annuum*, caused by fungi and bacteria is common and often results in serious losses. The disease was first reported in New Mexico in the year 1908 (Chupp and Sherf, 1960). Since then it has been known to cause exhorbitant losses around the globe and has been reported from Peru and Arizona (Brown and Gibson, 1926), West Indies (Ciferri, 1926), India (McRae, 1932), Spain (Benlloch and Dominguez, 1934), Argentin a (Marchionatto, 1935), Uganda (Hansford, 1940), Brazil (Chaves, 1947), Turkey (Copcu and Saydam, 1974), Chile (Fernandez, 1983), Iraq (Sarhan and Sharif, 1986), Cuba (Camino *et al.*, 1987), Tunisia (Moens and Benaicha, 1990) etc.

In India, chilli wilt has been reported in alarming proportions from Karnataka (Khan *et al.*, 1979), Tamil Nadu (Vidhyasakaran and Thiagarajan, 1981), Haryana (Srivastava and Diwakar, 1987), Kerala (Jyothi *et al.*, 1993), Punjab (Kaur, 1993), Kashmir (Dar and Mir, 1995a), West Bengal (Chatterjee *et al.*, 1997) and Himachal Pradesh (Singh and Singh, 1998). Chilli plants showing severe wilt at fruiting stage destroyed the crop before fruit ripening (McRae, 1932). Thomas (1938) recorded considerable damage to chilli pepper (*Capsicum annuum*) after flowering stage due to the wilt disease. Early infection of chilli by wilt pathogens prevented fruiting and caused complete destruction of the crop (Pontis, 1940). Severe incidence of the disease in some genotypes in Punjab caused upto 100 per cent crop loss (Thind and Jhooty, 1985; Kaur, 1993). During a survey in Haryana conducted during August and September, 1985, it was observed that stem rot and wilt disease of chilli was prevalent in severe form in most of the areas and disease incidence in general ranged from 20 to 60 per cent and in heavily infested fields from 60 to 80 per cent (Anonymous, 1987). The disease assumed devastating proportion in Kashmir valley exhibiting wilt incidence of 58.8 to 81.0 per cent in district Srinagar alone, causing 26 to 54 per cent crop losses (Wani, 1994; Dar and Mir, 1995a). In Jammu division of the state of Jammu and Kashmir, 8.3 to 80.0 per cent disease incidence was reported by Shali (2000).

2.2 Etiology

2.2.1 Causal organism

Bacteria : Bacterial wilt of *Capsicum annuum* has been reported from different parts of the world. In USA, bacterial wilt caused by *Pseudomonas solanacearum* has been reported to be common on peppers. The pathogen was also found to be infecting tomato, potato, eggplant and a number of other cultivated as well as wild plants (Doolittle, 1953). In India, Das and Chattopadhyay (1955) reported that chilli could be one of the hosts for the strains of *P. solanacearum* isolated from potato and eggplants. Jyothi *et al.* (1993) reported *Ralstonia solanacearum* causing chilli wilt as one of the most important constraints in chilli production in Kerala. Chatterjee *et al.* (1997)

observed bacterial wilt caused by *R. solanacearum* in tomato, chilli, tobacco, banana, brinjal, marigold, jute and ginger in West Bengal.

Fungi : A number of fungal pathogens have been found associated with the wilt of chilli in different parts of the world. Different workers ascribed the wilt to different species of *Fusarium* such as *F. annuum* (Crawford, 1934), *F. oxysporum* Schl. (Garofalo, 1957), *F. solani* and *F. equisti* (Moens and Benaicha, 1990; Koleva and Vitanov, 1990), *F. moniliformae, F. oxysporum* and *F. solani* (Hashmi, 1989) and *F. pallidoroseum* (Thind and Jhooty, 1985; Kaur, 1993; Wani, 1994).

Leonian (1922) reported and named *Phytophthora capsici* as the causal agent of stem and fruit blight disease of peppers from New Mexico. *P. capsici* as causal agent of wilt of peppers was also reported from Chile (Fernandez, 1983), France (Palloix, 1986), China (Jia, 1992), Taiwan (Hartman and Hwang, 1993), Korea (Hwang and Kim, 1995), Netherlands (Xie *et al.*, 1999) and many other countries.

Alavi *et al.* (1986) reported *Rhizoctonia solani* causing crown and root rot of capsicum characterized by defoliation and wilting, resulting in the death of plants in Central Iran. *R. solani* was also one of the predominant fungi isolated from roots and stem of infected plants of bell pepper showing symptoms of wilting in Pakistan (Mushtaq and Hashmi, 1997). Wanghiliar *et al.* (1988) observed *Sclerotium rolfsii* causing collar/root rot as a menace to chilli in Vidharbha area of Maharashtra. The fungus was also reported as a threat to chilli in Rajasthan by Mathur and Gurjar (2001). Verticillium wilt of capsicum has been reported from Canada (Woolliams *et al.*, 1962), Turkey (Copcu and Saydam, 1974), China (Lu *et al.*, 1984) and USA (Gonzalez-Salan and Bosland, 1993).

2.2.2 Symptomology

Slight variation in the development and expression of wilt in chilli by different pathogens has been observed by different workers world over. Crawford (1934) reported that *Fusarium annuum* infected the base of chilli stem and caused more or less sudden wilting of lower leaves followed by death of the whole plant within a short period of time, given the favourable temperature and moisture conditions. It has been reported that the older leaves of *Fusarium* infected chilli plants turned yellow first followed by younger leaves, petioles and stem; the leaves became chlorotic and desiccated and the whole plant withered and died slowly (Dimond, 1970). Luckas and Sjarka (1988) found *F. oxysporum* and *F. solani* causing stem browning, peeling off the epidermis and vascular browning. *F. oxysporum* was found in all parts of the inoculated plant, whereas, *F. solani* occurred mostly in roots and lower stem. They further mentioned that *F. solani* spread in plants more slowly than *F. oxysporum*, and seedlings were mostly killed by *F. oxysporum*. Wani (1994) reported sudden wilting of leaves with loss of green colour, vein clearing and epinasty of older leaves often at flowering stage due to root infection with *F. pallidoroseum*. He further reported that the infected roots were brown from within and wilting started in the lower plant parts and spread upwards.

Leonian (1922) described that stem and fruit blight disease of pepper, caused by *Phytophythora capsici*, appeared as blight on branches and on fruit as dry lesions of various sizes. The seeds also became infected, turned brown shrivelled and were killed in severe infection. Most frequently the branches became infected directly at their basis, resulting into a ring of blighted tissue and the parts above it wilted, when the primary infection was on the main stem, the entire plant was killed. Tomkins and Tucker (1942) reported that *P. capsici* caused stem girdling at collar region, rapid and permanent wilting of leaves without noticeable change in colour. Hwang and Kim (1995) found that infection of pepper plants by *P. capsici* was characterized by sudden wilting of entire plant which was caused by rotting of the stem near the soil surface. They observed that *P. capsici* infection occurred in the aerial parts of pepper plants also when zoospores splash from the soil surface during rainfall and leaves, petioles, fruits, stems and branches became locally rotted, starting with small water soaked lesions. Leaf lesions expand rapidly to form round irregular shaped, dark green, water soaked areas that latter dry and turn light tan, eventually infected leaves absicise from the plants. The light brown lesions at the stem base also extend rapidly into the upper part of the stem and branches. The lower tap roots and root hairs became brown and rotten. Whitish grey mycelial growth with abundant zoosporangia often developed on the surface of infected stem under suitable moisture conditions.

2.2.3 Predisposition

The disease is known to be favoured by various environmental conditions. Leonian (1922) described that the wilt disease of *Capsicum annuum* in USA generally appeared anytime after May when warm and rainy season started. Crawford (1934) reported that chilli wilt (*Fuarium annuum*) became severe in low lying and undrained fields. Luckas and Sjarka (1988) observed that the infection of capsicum plants by *F. oxysporum* and *F. solani* occurred only when the plants were weakened by unfavourable weather conditions. Most of *Fusarium* spp. responsible for wilts in solanaceous and other crops remained confined to acidic soils (Nirwanto and Djajati, 1994). Application of higher levels of nitrogenous fertilizers have also been found to predispose the hosts to the infection by *Fusarium* spp. (Huber and Watson, 1974; Alois and Mace, 1981; Huber, 1981).

Elenkov and Khrelkova (1977) found that abundant rainfall and warm weather in August favoured the development of disease, while as rain and run-off water appeared to be the main means of spread. Phytophthora blight of *Capsicum annuum* occurred in wet soils but not in dry soils (Shin and Tezuka, 1992). The repeated cultivation of pepper resulted in buildup of inoculum in the soil and the disease was favoured by prolonged periods of heavy rainfall accompanied by strong winds. Stems of pepper plants were readily damaged by splitting, breaking and lodging thus accelerating development of Phytophthora blight (Hwang and Kim, 1995).

Rhizoctonia root rot was most severe on chilli grown in clay soils, the disease became more severe as the crop was planted in the same field for several consecutive years (Shannon and Cotter, 1986). Abiotic factors such as frequent rains during crop growth, heavy soils coupled with poor drainage and monoculture aggravated the disease (Dar and Mir, 1995a). Significant reduction in Fusarium wilt of chilli by combination of drainage with planting on ridges has been reported by Verma and Sharma (1995). They reported that flood irrigation resulted in heavy losses and that the disease appeared in patches at fruit formation stage before the onset of rains and assumed serious proportion after heavy rainfall followed by hot dry days in poorly drained conditions.

2.2.4 Perpetuation of pathogens

Seed and soil-borne nature of wilt causing pathogens have been reported by many workers. Babayan and Shakhnubaryan (1969) frequently isolated *F. oxysporum* from chilli seeds, and reported that the infection reduced seed germination, growth rate and fruit yield and induced wilting in transplanted crop. Vidhyasakaran and Thiagrajan (1981) isolated *F. oxysporum* from wilted chilli plants raised from infected seeds. The *Fusarium* spp., isolated from *Capsicum annuum* seeds collected from 30 different countries included, *F. semiticum, F. solani, F. equisiti, F. oxysporum* and *F. moniliforme*, of which *F. moniliforme, F. solani* and *F. oxysporum* were found to cause root rot and wilt of capsicum seedlings (Hashmi, 1989).

Hwang and Kim (1995) reported that the oospores of *Phytophthora capsici* produced in diseased pepper plants served as survival structures, over-wintering in infected roots or in the soil. *R. solani* has also been reported to perpetuate in the seed and soil (Muhyi and Bosland, 1995; Mushtaq and Hashmi, 1997).

2.3 Disease management

2.3.1 Host resistance

The cultivation of resistant varieties is by far the most effective, economical and environmentally safe method for controlling plant diseases. Because of the soil borne nature of wilt pathogens, cultivation of resistant genotypes, if any, is best way of managing the problem. Dukes and Fery (1984) reported that pepper lines with highest level of resistance against *Sclerotium rolfsii* included *Capsicum chinensis* cv. PI 224428, *C. fruitescens* cvs. Greenleaf Tabasco and Mcllhenny Tabasco, *C. annuum* cvs. Golden California Wonder, Santanka and PI 1613192. They also reported that only

10-15 sclerotia per plant were needed to evaluate a candidate pepper line for southern blight reaction. Camino *et al.* (1987) identified Keystone Resistant Giant, Mild Calfornia Wonder and Export as susceptible to *Fusarium solani* and Bell Boy, Citrina, New Ace, Regalode Moldavia, True Heart and Visna as susceptible to *F. oxysporum* f. sp. *lycospersici*, whereas, Hungarian sweet wax as susceptible to both the pathogens.

Hartman and Hwang (1992) reported that when varieties of pepper were inoculated with 105 zoospores/ml of *Phytophthora capsici,* no symptoms were observed on PI 201234, some wilting was observed for Szechwan while all Blue star plants died. When inoculated at different plant ages, PI 201234 did not wilt, but Blue star wilted and died at all the stages tested. Younger and older plants of Szechwan had less disease than plants of intermediate age.

Ahmad *et al.* (1994) identified 16 lines *viz.*, SC-114, SC-158, SC-191, SC-101, SC-108, SC-185, SC-161, SC-126, SC-125, SC-152, SC-137, SC-166, SC-118, SC-122, SC-111, SC-102 and SC-143 resistant out of 142 advanced lines of chilli. They also identified two cultivars of sweet pepper *viz.*, Okash and Verdale resistant against the same pathogen *Fusarium pallidoroseum* under field and controlled conditions. Muhyi and Bosland (1995) identified *Capsicum annuum* accessions Long Chilli (a Korean hybrid) and PI 167061 resistant against *Rhizoctonia solani.* Nayeema *et al.* (1995) identified Masalwadi cultivar of hot pepper immune to *F. pallidoroseum* under field and controlled conditions, whereas, the lines SC-120, Phule C-5, SC-335, SC-502, SC-415, SC-107, SC-348, SC-108, LACA-304, Arkalohit, SC-101, SC-371, SC-137, SC-419, SC-451, SC-31, LCA-248, Pusa Jawala, Pant C-8, and Jawahar 218 were moderately to highly resistant. Singh and Singh (1998) reported that out of 30 germplasm evaluated against Fusarium wilt only nine *viz.*, Punjab Lal, Solan Red, Pacchad Yellow, Pant C-1, Sweet Banana, IC-4, IC-8 and IC-21 were found moderately resistant and the remaining 21 were either susceptible or highly susceptible, whereas, none of the germplasm tested was highly resistant. Alegbejo and Ernile (2000) screened six pepper lines for resistance to *Phytophthora capsici* in glasshouse trials, only one line 2230 was found resistant and four lines 2298, 2284, 3289 and 2227 were moderately resistant.

2.3.2 Cultural management

Cultural control offers an opportunity to alter the environment, the condition of the host, and the behaviour of pathogenic organisms in ways that adequately control a particular disease. Garcia (1933) recorded only seven per cent wilt of chilli by planting on ridges compared to 42 per cent observed in leveled plantation. Pontis (1940) and Beattie *et al.* (1944) also reported successful management of Fusarium wilt of chilli by sowing plants on ridges and avoiding excessive irrigation. Irrigating the alternate furrows at longer intervals helped to reduce Phytophthora root rot of pepper (Duniway, 1975). Ahmad *et al.* (1989) observed that the prevalence and progress of Phytophthora blight of chilli was influenced indirectly by wet season and directly by rainfall. Planting at a ridge height of 20-40 cm, helped to reduce *Phytophthora capsici* infection of chilli plants compared to 10 cm ridge height (Vitanov, 1989). Periodic flooding also increased mortality (*P. capsici*) of early California Wonder pepper (*Capsicum annuum*) by 20 to 100 per cent depending upon flooding period (Bowers and Mitchell, 1990). Restricted irrigation and planting on raised beds or ridges have been found to reduce the incidence of wilts and root/collar rots (Bowers and Mitchell, 1990; Ristaino, 1991;

Dar and Mir, 1995b). Pepper plants were more adapted to inadequate rainfall than to rainy weather, consequently, appropriate drainage with high ridges was recommended to Korean farmers for successful cultivation of pepper (Hwang and Kim, 1995).

Soil moisture levels have been found influencing the severity of wilts and root/collar rots. Wet soils were found to favour Fusarium wilt (*F. oxysporum* f.sp. *lycopersici*) of tomato (Strong, 1946). Hot weather of 30^0C and soil moisture of 40 per cent proved conducive for the disease development (Nelson, 1981). Kanniayan and Prasad (1975) reported 60 to 75 per cent moisture level as optimum for survival of *F. oxysporum* f.sp. *melonis*.

The role of nitrogen, phosphorus and potassium in disease development depends upon the nature of the pathogen and host interaction on one hand, and the quality and quantity of the fertilizers on the other. Nitrogen is known to exhibit significant influence on disease development especially the ones caused by soil-borne fungi (Kaufman and Williams, 1964). The disease severity has in general been found to increase as the rate of nitrogen application was increased. Higher levels of nitrogen generally decreased resistance of tomato and cotton to *Fusarium* (Woltz and Engelhard, 1973; Woltz and Jones, 1981), whereas, the balanced doses at minimum rates enhanced resistance of pea to *F. oxysporium* f.sp. *pisi* (Alois and Mace, 1981). Kiraly (1976) also reported reduced severity of wilts and root rots caused by *Fusarium* spp. Application of ammonium nitrate along with organic amendments helped control root rot (*R. solani*) of bean (Davey and Papavizas, 1960). Sharma and Sohi (1983) reported that Phytophthora blight of pepper was enhanced with the application of higher doses of nitrogen. However, Sarhan *et al.* (1982) recorded lesser incidence of tomato wilt (*F.*

oxysporium f.sp. *lycopersici* race 1) by applying high doses of nitrate nitrogen to the infested soil, indicating thereby that the influence of nitrogen could vary depending upon the nature of host / or pathogen. Dry root rot (*Rhizoctonia bataticola*) of chickpea was also enhanced by increased levels of nitrogenous fertilizer (Taya *et al.*, 1988).

Phosphorus, the second most important element applied to soil as fertilizer, is essentially required for merismatic tissue and root proliferation. The root growth promoted by adequate phosphorus application helps plants bear the damage caused by root pathogens (Huber, 1980). Woltz and Jones (1981) reported that a high level of phosphorus increased the severity of Fusarium wilt of tomato in glasshouse and field experiments and that the combination of high lime with low phosphorus greatly curtailed it. They further observed that supplemental application of superphosphate above the amount required for growth of tomato greatly increased the occurrence of wilt in soils of pH 6.0. At pH 7.0 or 7.5, supplemental application did not increase wilt occurrence because at high pH values, phosphorus becomes sparingly available being pH dependant. Woltz and Jones (1984) observed that in combination with nitrogen, phosphorus synergistically decreased resistance of tomato to *Fusarium oxysporum* f.sp. *lycopersici*.

Potassium is the third major nutrient supplement in soils for plant growth. Besides regulating enzyme activity in most cellular functions such as photosynthesis, phosphorylation, protein synthesis and reproduction it induces formation of thicker cuticular and epidermal cell wall (Huber, 1980) and modifies disease reaction in plants both directly or indirectly. The direct effects involve formation of adequate structural barriers and to reduce penetration, multiplication, survivability and aggressiveness of invading pathogen. Whereas, indirectly, the delayed initiation of senescence by potassium avoids infection by facultative parasites (Kiraly, 1976). An increase in potassium from deficiency level causes crop growth and yield with simultaneous reduction in disease susceptibility. The host resistance to pathogen, however, remains unchanged if K_2O level is enhanced beyond certain optimum dose. The excess K_2O level is known to inhibit uptake of other cations like Ca^{++}, Mg^{++} and Mo^{+++} essential for plant growth (Balaji and Vaitheswaran, 1988). It is believed that the synthesis of high molecular weight compounds, like proteins, starch and cellulose in K-deficient plants gets impaired and low molecular weight compounds accumulated which increase susceptibility to pathogen infection (Huber, 1980).

Ramasamy and Prasad (1975a and b) observed considerable reduction of *F. oxysporum* propagules in inoculated melon plants given potassium fertilization, indicating that secondary colonization is reduced with increase in resistance. However, very little effect of potassium on Phytophthora blight of pepper has been observed (Sharma and Sohi, 1983).

The effect of nitrogen, phosphorus and potassium fertilizers in combination may or may not modify their individual influence on disease development. Zakharova (1971) reported reduced incidence of wheat hollow ear (*F. oxysporum, F. equisti* and *F. tracheomycosis*) by using P-K fertilizers. Higher levels of N and K in soils were found to reduce susceptibility of pepper plants to Fusarium wilt toxin (Sarhan and Hegazi, 1986). Similarly, the adverse effects of increased chickpea dry root rot (*Rhizoctonia bataticola*) were significantly reduced by simultaneous application of nitrogen and phosphorus fertilizers (Taya *et al.*, 1988). Application of higher levels of phosphorus and potassium with varying levels of nitrogen significantly reduced leaf and fruit rot (*Alternaria alternata*) of brinjal (Singh, 1989). Gandhi *et al.* (1993) recorded a moderate increase of onion purple blotch (*A. porii*) at recommended doses (120:50:25) of NPK compared to an enhanced disease progress separately at 60-80 kg ha^{-1} N and decreased disease progress at 30-70 kg ha^{-1} P_2O_5 and 10-40 kg ha^{-1} K_2O.

2.4 Biological management

The biological management of plant pathogens is assuming significance on account of ill-effects of conventional measures of disease control by chemical fungicides, and has become quite popular strategy to manage especially those diseases which are soil borne in nature and, hence, difficult to manage chemically. Sanford (1926) working on potato scab caused by the actinomycete *Streptomyces scabies*, realised that other soil microorganisms must exert a natural biological control even on root disease pathogens. In 1932, Weindling showed that *Trichoderma* sp. a common saprophytic fungus was able to parasitize the mycelium of other fungi and the lethal action of *T. viride* was due to the secretion of an antibiotic substance which he called "gliotoxin". Brain and McGowan (1945) isolated another antibiotic substance from *T. viride* which they named as "viridin". These discoveries raised hopes of controlling plant diseases by biological means and subsequently a number of workers across the world took interest in exploring the different aspect of biological control method.

Various soil borne plant pathogens are known to be antagonized by one or other antagonist. *Gliocladium virens* was reported to have significantly inhibited the mycelial growth and sclerotial production of *Thanetephorus cucumeris*, the causal organism of web blight of horse gram, *G. virens* being more effective than *Trichoderma* spp.

(Dubey, 1998). *Trichoderma harzianum* and *T. viride* reduced the *in-vitro* mycelial growth and sclerotial germination of *Rhizoctonia solani*, the incitant of French bean root rot (Hazarika and Das, 1998). Singh (1998) reported that the culture filterate of *T. viride* proved more potent in inhibiting the growth of *Sclerotinia sclerotiorum*, the incitant of rapeseed and mustard root rot disease. Prasad *et al.* (1999) reported that *Trichoderma* and *Gliocladium* species showed more than 30 per cent inhibition of mycelial growth of *Sclerotium rolfsii*, the causal organism of root/collar rot of sunflower. Damping off of chilli caused by *Pythium aphanidermatum* was reduced by the application of talc based formulation of *T. viride* and *Pseudomonas flourescens* in nursery beds before sowing (Manoranjitham *et al.*, 2000). Prasad *et al.* (2002) found *T. harzianum* isolate superior than *T. viride* isolate in reducing colony diameter of *S. rolfsii*.

Fungal antagonists not only inhibit the mycelial growth of the fungal pathogens, the spore production and their germination is also impaired. *T. harzianum* and *Bacillus subtilis* were reported to produce a wide zone of inhibition against *Fusarium udum*, the incitant of pigeonpea wilt, and also completely inhibited spore germination (Sumitha and Gaikward, 1995). Pratap *et al.* (1996) reported that *Trichoderma* isolates caused 60 and 67 per cent inhibition of spore production and germination, respectively, of *Cercospora moricola*, the pathogen causing leaf spot of mulberry.

Managing the disease caused by sclerotia forming fungi are awfully difficult, attempts have been made to manage such diseases by the applications of biocontrol agents in the soil. Mihutta and Rowe (1986) demonstrated that some isolates of *Trichoderma* obtained from organic soils provided better control of Rhizoctonia damping off than even PCNB applied at 5.3 kg a.i. ha^{-1}. The soil application of *T. harzianum* and *T. viride* was found to be more effective than seed treatment in reducing wilt and wet root rot of chickpea (Prasad *et al.*, 2002). The authors also reported positive effect of bioagents on plant growth.

Fusarium spp. are the most important soil and seed borne pathogens which cause wilt, various biocontrol agents have been tried against these pathogens with considerable success. Soil Guard and Root Shield, two commercially available biocontrol products containing *G. virens* and *T. harzianum*, respectively, exhibited 62 to 68 per cent control of tomato wilt when incorporated in potting medium at the rate of 0.2% w/v (Larkin and Fravel, 1998). Parveen *et al.* (1998), reported a considerable reduction in the infection of *F. solani* and *F. oxysporum* on pumpkin, guar, chilli and watermelon by soil application of *Paecilomyces lilacinus* and/or *Paecilomyces aeruginosa*. Application of *Trichoderma hamatum* reduced the aubergine wilt to 38 per cent followed by *T. viride* which exhibited only 46 per cent wilt incidence compared to 74 per cent observed in untreated check (Sheela *et al.*, 1995).

2.5 Chemical management

Chemical management is often the most feasible means of tackling a plant disease problem. It is often more economical and effective than any other measures. Pathogens which are mainly soil and / or seed borne, disinfection of seeds and soil with chemicals / fungicides has yielded encouraging results. Some gaseous fumigants such as methyle bromide and chloropicrin were the only commercially feasible measures of vascular wilt control prior to 1970. Soil treatment with formalin, copper sulphate, as well as burning of bush wood were most effective in nursery against *Fusarium* *oxysporium* (Kozlowska, 1964). Pepper wilt complex (*Fusarium solani, Rhizoctonia solani, Phytophthora capsici*) was also controlled by methane-Na or diazomet or metalaxyl (Moens and Benaicha, 1990; Ahmad *et al.*, 2000).

Effective control of Phytophthora blight and wilt of pepper depends mainly on the application of fungicides. Several fungicides such as metalaxyl, oxadixyl, propamocarb, copper oxychloride, chlorothalonil and dithianon have been applied for Phytophthora blight and wilt of peppers in Korea (Hwang and Kim, 1995). Among the fungicides the mixture of metalaxyl-copper oxychloride, metalaxyl-dithianon and oxadixyl-chlorothalonil have been most frequently employed and found effective in reducing wilt and increasing in pepper production (Sung and Hwang, 1988).

Laboratory evaluations of some fungicides against wilt pathogens have yielded encouraging results. Behera *et al.* (1989) and Singh *et al.* (1995) reported that carbendazim and benomyl were the most effective *in-vitro* fungitoxicants against *Fusarium* spp. compared to captafol, thiram, thiophanate methyl and captan. Chowdhary *et al.* (1998) found chestnut compound and captan superior than thiram and mancozeb although all were completely inhibitory to the growth of the fungus at 500 ppm. Among systemic fungicides hexacanozole was significantly superior than triadimafox, propic onazole and bitertinol in controlling *Sclerotium rolfsii* causing wilt of bell pepper (Chowdhary *et al.*, 1998). Babadoost and Islam (2003) reported that metalaxyl and mefenoxam at concentrations ≥ 0.5 μg a.i./ml significantly reduced colony growth of five isolates of *Phytophythora capsici*. They also found that mefenoxam strongly inhibited sporangial germination at concentrations of ≥ 100 μg a.i./ml and zoospore germination was inhibited by mefenoxam at 125 μg a.i./ml of culture medium.

Seed treatment with fungicides is regarded as the most economical and convenient method of chemical control of a particular plant disease. Treatment of tomato seeds with either carbendazim or captafol at 1 g kg^{-1} seed controlled *Fusarium semitectum* infection, and the effectivity of captan, thiram and benomyl used in soaking or slurry seed treatment was enhanced by storing the treated seeds for atleast 24 hours (Nedumaran and Vidhyasakaran, 1981). *Fusarium oxysporium* was eradicated from chilli seeds with corresponding improvement in seed germination and fruit yield and reduced wilting by seed treatment with carbendazim or carboxin (Vidhyasakaran and Thiagrajan, 1981). Groundnut seed treatment with a mixture of carbendazim and thiram eliminated *Fusarium pallidoroseum* infection from seeds with concomitant increase in yields (Behera *et al.*, 1989; Narain *et al.*, 1989).

The sudden appearance of wilts / root rots / blights in standing crops in absence of any history of the disease in the field necessitates the application of such chemicals in soil which are safe to the standing crop, while at the same time have inherent ability to either kill or atleast reduce the population of causal pathogens. Applying fungicides as a drench around the stem of plants was more effective than using foliar sprays. In a field trial, three soil drenches of metalaxyl suppressed incidence of Phytophthora blight to below 3 per cent compared to 20 and 31 per cent in foliar sprays and the untreated control, respectively (Kim *et al.*, 1982). Simons *et al.* (1990) reported that spraying metalaxyl directly at the lower stem of bell pepper plants gave effective control of root rot disease caused by *Phytophthora capsici*. They also found that metalaxyl spray was highly effective in limiting the spread of disease while the benomyl sprays were only marginally effective.

Kapoor and Thakur (1987) reported seed treatment with hot water and rhizolex and its subsequent application as soil drench and spray was most effective treatment in controlling losses due to *Pythium debaryanum, P. capsici, Rhizoctonia solani* and *Verticillium* sp. Kapoor and Sharma (1988) obtained the lowest rate of wilting (*F. solani*) eggplants cv. Pusa purple long with chlorothalonil root dip at transplanting and four fortnightly soil drenches.

2.6 Integrated disease management

The four basic requirement for management of plant diseases are clean and healthy seed, clean field or pathogen-free soil, prevention of entry of and infection of a pathogen in a standing crop and precaution during harvesting and storage of the produce. An ideal schedule for controlling a disease is to integrate measures covering these four requirements. Integrated disease management attempts to use all the known suitable techniques of control to maintain the particular pest population at a level below that which causes economically important losses to the crop.

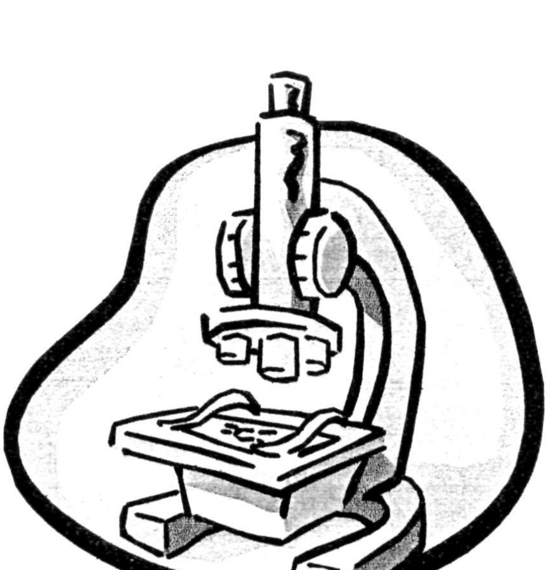
Dar and Mir (1995b) reported that pre-transplanting dip of chilli seedlings with Bavistin (0.05%), benlate (0.05%) or captan (0.2%) and post-transplanting drench with Bavistin (0.1%) or captan (0.3%) controlled early wilt of chilli caused by *Fusarium pallidoroseum* to a great extent. However, these chemicals failed to control the wilt at late stages. They further pointed out that the application of fungicides and soil amendments with decomposing poultry litter failed to control the disease under wet conditions. However, transplanting of seedlings on raised bed with light irrigation in mid and high altitude areas was found beneficial in managing the disease. Hwang and Kim (1995) concluded that resistant *Capsicum annuum* with high fruit quality need to be developed and that integrated disease management could be achieved by using metalaxyl together with resistant cultivars. They suggested that cultural control method such as drainage with high ridges, crop rotation and mixed cropping should be integrated into overall disease control programme.

Bunker and Mathur (2001) evaluated biocontrol agents individually and in combinations and in integration with Bavistin seed treatment in pathogen infested soil in pots, for suppression of dry root rot pathogen *Rhizoctonia solani* in bell pepper cv. California Wonder. They found seed treatment with the biocontrol agent as effective as Bavistin seed treatment. They also reported that seed and soil application of individual biocontrol agents resulted in higher germination and reduced mortality. Combination of two biocontrol agents, particularly of *Trichoderma harzianum* and *T. aureoviride* was better than the individual one. Dubey (2002) reported seed treatment of Vitavax + *Trichoderma viride* resulted in maximum seed germination, minimum disease incidence in frenchbean with highest pod yield followed by seed treatment with thiram + *T. viride* and captaf + *T. viride*. Seeds treated with *T. viride* alone showed superiority over fungicides alone in all respects. The seeds treated with captan (1 g/kg) + *T. harzianum* (10^6 spores/ml/10 g seed) gave good germination, least disease incidence along with highest green pod yield of pea, which was statistically similar to seed treated with *T. harzianum* alone, thiram + *T. harzianum*, carboxin + *Gliocladium virens* and *G. virens* alone (Kumar and Dubey, 2001). Integration of soil application of antagonists with fungicidal rhizome treatment (Bavistin + Ridomil MZ.) increased the efficiency of disease control as compared to their individual treatments (Ram *et al.*, 2000).

Upmanyu *et al.* (2002) observed that soil amendment (cotton cake) + *Trichoderma virens* and carboxin (seed treatment), mustard cake + *T. virens* and carbendazim (seed treatment), seed treatment with combination of *T. viride* and carboxin, *T. harzianum* + tebuconazole, *T. virens* + tebuconazole, and soil amendment (mustard cake) + carbendazim (seed treatment) were found effective in containing the root rot under glasshouse conditions while soil amendment (mustard cake) + carbendazim (seed treatment) + carbendazim (foliar spray) were found highly effective in reducing pre- and post-emergence root rot while web blight severity was best contained by soil amendment (mustard cake) + carbendazim (seed treatment + foliar spray) followed by tebuconazole + *T. virens* (seed treatment) + carbendazim (foliar spray). Chattopadhay and Sen (1996) used two biocontrol agents *Aspergillus niger* isolate $A27^{-1}$ and *Trichoderma viride* isolate $T4^{-1}$ (both carbendazim tolerant strains) and carbendazim 0.1% as seed treatment for integration with potash 186.7 kg/ha and soil amendment with sawdust (w/w) @ 7%. They found under both glasshouse and field experiment, $T4^{-1}$ (seed treatment) + Bavistin + KCl was most effective in reducing muskmelon wilt caused by *Fusarium oxysporum*. The treatment reduced the pathogen population in soil and root tissue, and increased shoot length and root length.

<u>CHAPTER - 3</u>

Materials and Methods



MATERIALS AND METHODS

The present studies on wilt complex of *Capsicum annuum* were conducted during 2001-2004 at Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu. The details of the methodology adopted is described as under.

3.1 Status of wilt complex in *Capsicum annuum* and the causal agents involved with it

3.1.1 Prevalence and incidence of the disease

Surveys of the major chilli and bell pepper growing areas of Kathua, Jammu, Udhampur, Rajouri and Doda districts of Jammu division were conducted during the years 2001 and 2002 to ascertain the status of wilt disease in the region. The incidence of the disease was recorded at pre-flowering, flowering and fruit set stages. Randomly, three fields were selected at each location and the wilt incidence from 10 random spots, each of 5 m^2 in each field, was recorded using the following formula (Mayee and Datar, 1986).

$$\text{Wilt incidence (\%)} = \frac{\text{Number of wilted plants}}{\text{Total number of plants examined}} \times 100$$

3.1.2 Isolation and identification of pathogens

During surveys, plants showing wilt symptoms were uprooted, bagged separately in perforated polythene envelops and brought to laboratory for further studies.

(a) Preliminary examination : Small bits taken from the infected portion of the diseased plants *viz.* roots, stems, and branches were placed separately and teased on clean glass slides in a drop of distilled water/lactophenol, covered with coverslips and examined under microscope for the presence of mycelial strands, spores, etc. in order to identify the causal organisms.

(b) Isolation of pathogen : Bits of approximately 5 mm size were cut at the junction of diseased and healthy portion of the infected plant with the help of sterilized blade. The bits were then surface sterilized in 0.1 per cent mercuric chloride solution for 20 seconds followed by three consecutive washings in sterilized distilled water and dried on a sterilized blotter paper. The bits were aseptically transferred to petri-plates containing potato dextrose agar (*Appendix-I*), 2 per cent agar and sterilized water, separately and incubated at 25 ± 2^0C. The bits incubated in petri-plates containing sterile water were aseptically dried by using sterile blotting paper and transferred to sterilized petri-plates containing P_{10}VP medium *(Appendix-I)* (Tsao and Gilberto, 1969) for ascertaining the presence of *Phytophthora* sp. from the infected bits.

(c) Purification of culture : The fungal growth obtained from the diseased tissues were purified by the single hyphal tip method. When the fungus inoculated at the centre of petri-plates containing 2 per cent water agar medium grew and spread in the form of thin hyphal strands, the individual hypha was located on plates in inverted position by examining under microscope. The hyphal tips, away from the place of inoculation were marked with a glass marker. The individual hypha was then removed with the help of inoculation needle from the plate along with agar and transferred aseptically on the medium. Pure culture of each fungus thus obtained were subjected to microscopic studies. The observations on radial growth of the colonies were recorded by measuring the colony diameter of the isolates at 24 h interval upto 168 h and the growth rate (mm/h) of each isolate was calculated using the following formula (Verma, 1997).

$$rg = (cd_2 - cd_1)(t_2 - t_1)^{-1}$$

Where,	rg	=	rate of mycelial growth (mm/h)
	cd_2	=	mean diameter of colony at time t_2
	cd_1	=	mean diameter of colony at time t_1
	t_2	=	time when mean diameter of colony was cd_2
	t_1	=	time when mean diameter of colony was cd_1

Morphological examinations and cultural characters of the isolated fungi were recorded and observation compared with standard text (Leonian, 1922; Parmeter and Whitney, 1970; Subramanian, 1971; Domsch *et al.*. 1980; Booth and Sutton, 1984; Brayford, 1993) for establishing their correct identification.

(d) Mass multiplication of pathogens : The pathogens isolated viz., *Fusarium oxysporum, Rhizoctonia solani* and *Sclerotium rolfsii* were mass multiplied on preboiled and sterilized sorghum grains, supplemented with 5 per cent anhydrous dextrose. The Erlenmeyer flasks containing 300 g sorghum grains were autoclaved for 1 hour at 15 lb pressure (per square inch) and inoculated with 5 mm actively growing fungal discs from 7 days old culture of each pathogen. The flasks were incubated at 25 ± 2^0C for 25 days for complete fungal colonization of grains. The flasks were shaken regularly to ensure thorough colonization. After the grains were well colonized, inoculum was air dried in shade, broken apart into individual kernels, placed in plastic bags and stored at 4^0C until used. *Phytophthora capsici* was multiplied on sand carrot mixture. Five hundred gram sieved sand was filled in flasks and moisturised with 150 ml carrot broth. For the preparation of carrot broth, 200 g of fresh carrot was cut into small pieces, its juice extracted and passed through a double-layered muslin cloth to obtain clear carrot broth. Total volume of the juice was made upto 1 litre with distilled water. The sand carrot mixture was autoclaved for one hour at 15 lb pressure (per square inch). After cooling, each flask was inoculated with 5 culture discs, each of 5 mm in diameter from actively grown culture of *P. capsici* and then incubated at 25±2^{0}C for 20-25 days. The flasks were shaken regularly to ensure thorough colonization.

(e) Pathogenicity test : For pathogenicity test, the pot soil was sterilized with 5 per cent formaldehyde solution and then inoculated separately with isolated fungi *viz.*, *Fusarium oxysporum*, *Rhizoctonia solani*, *Sclerotium rolfsii* and *Phytophthora capsici* @ 5 g/kg soil (first three pathogens) and 20 g/kg soil (*P. capsici*), 7 days before transplanting of the seedlings. The pots were watered regularly to maintain optimum soil moisture. Three healthy seedlings, each of chilli cv. Pusa Jawala and bell pepper cv. California Wonder were transplanted in the sick pots. Observations on development of wilt symptoms were recorded regularly. The pathogens were re-isolated from the infected plants and their morphological characters compared with the original cultures to prove Koch's postulates.

3.1.3 Pathogens associated with wilt complex of *Capsicum annuum* in Jammu division

In order to determine the association of pathogens with wilt complex of *Capsicum annuum* in different districts of Jammu *viz.*, Kathua, Jammu, Udhampur, Rajouri and Doda, surveys were conducted at pre-flowering, flowering and fruit set stages of plants, during the years 2001 and 2002. Five randomly selected diseased samples from each selected location at every stage were collected in perforated polythene bags and brought to laboratory for further studies. Isolations were made from the roots, stem and branches as described in 3.1.2. The per cent occurrence of pathogen(s) was calculated by using the following formuia :

Per cent occurrence of pathogen(s) =

$$\frac{\text{Number of plants infected by pathogen(s)}}{\text{Total number of diseased samples observed}} \times 100$$

3.1.4 Effect of soil temperature and moisture on the wilt incidence of *Capsicum annuum*

To ascertain the role of soil temperature and moisture on the disease incidence, three hundred plants of chillies cv. Pusa Jawala were planted with 60 × 45 cm spacing in a wilt sick field at Ponichak. Recommended cultural practices were followed in raising the crop. The wilt incidence was recorded weekly. Maximum and minimum soil temperature was recorded at 10 cm depth and moisture content of soil was determined as the amount of water held by soil particles. Three soil samples one from each replication were collected twice a week from 0-15 cm depth with the help of auger. The moisture content was expressed as per cent moisture on an oven-dry basis.

3.1.5 Effect of crop age on the occurrence of wilt complex pathogens

In order to determine the association of pathogens with wilted plants at various stages of crop growth, a susceptible variety Pusa Jawala of chilli was sown in a wilt sick field at Ponichak. Three hundred plants in three replications with 60 × 45 cm spacing were planted. Isolations were made on PDA and $P_{10}VP$ (for *Phytophthora capsici*) media from roots, collar region and stem of wilted plants starting from 30 day after sowing, at 7 day intervals, upto 120 days. The per cent occurrence of pathogens was calculated.

3.2 Disease management

Studies on the management of the disease through host resistance, cultural practices, use of biocontrol agents, chemicals and integration of chemicals and antagonists were conducted in disease sick soil by growing wilt susceptible chilli cv. Pusa Jawala and bell pepper cv. California Wonder.

3.2.1 Host resistance

3.2.1.1 Field evaluation

The field trials were conducted during the years 2001 and 2002 to evaluate 38 lines of chilli and bell pepper germplasm (genotype/varities), obtained from different sources, with susceptible variety, Pusa Jawala, as check. Forty-five days old seedlings were planted in wilt-sick plots with 60 × 45 cm spacing in randomized block design with three replications. The test genotypes/varieties comprised of two rows of twelve plants each separated from each other by a row of susceptible variety Pusa Jawala to ensure the availability of adequate inoculum for development of infection. Frequent irrigation was provided to maintain proper soil moisture in the field. The other agronomic practices were applied as per the recommended practices. The data were recorded 30 days after transplanting till the maturity of the crop and per cent disease incidence was calculated. The reaction of each genotype was categorized on the basis of per cent wilt incidence using the following scale (Singh and Singh, 1998).

Disease reaction		Wilt incidence
Resistant	=	0 – 10%
Moderately resistant	=	11 – 30%
Susceptible	=	31 – 50%
Highly susceptible	=	Above 50%

3.2.1.2 Glasshouse evaluation

All the genotypes/varieties which exhibited moderately resistant to resistant reactions against wilt-complex pathogens under field conditions were further evaluated under glasshouse conditions in completely randomized design with five replications. The pots were filled with sterilized soil + FYM (2:1) and each pot was inoculated with the inoculum of *Fusarium oxysporum*, *Rhizoctonia solani* and *Sclerotium rolfsii* @ 5 g/kg of soil multiplied on sterilized sorghum grains and *Phytophthora capsici* @ 20 g/kg soil multiplied on sand carrot mixture. Inoculum of each pathogen was properly mixed with soil upto 10 cm depth before one week of transplanting. The pots were regularly watered to maintain adequate soil moisture. Forty-five days old seedlings of moderately resistant to resistant germplasm were transplanted in pots separately, with three plants/pot. The number of wilted plants were recorded 30 days after transplanting till the maturity and the per cent disease incidence was calculated. The reaction of each genotype was grouped as mentioned in field experiments (3.2.1.1).

3.2.2 Cultural management

The experiment regarding cultural management of wilt complex disease in each chillies and bell pepper were conducted at the Research Station, Udheywalla, SKUAST-J and at farmer's field at Udheywalla during the years Kharif 2002-2003. The two experiments were conducted in a split-split plot design with treatments comprising four levels of irrigation (applied at 5, 7, 9 and 11 day intervals), four levels of fertilizers kg/ha [80N + 72P + 36K; 80N + 84P + 42K; 120N + 60P + 30K and recommended dose of NPK (100N + 60P + 30K)] and two planting methods (flat-bed and ridge planting) replicated thrice for both the crops separately. The irrigation levels were assigned to main plots, whereas fertilizer levels and planting methods were assigned to sub-plot and sub-sub-plots, respectively. The cultivar Pusa Jawala for chilli and California Wonder for bell pepper were sown with a distance of 60 × 45 cm spacing. The other cultural practices were applied as per the recommended practices. The yield of both crops were recorded on net plot basis and converted to q/ha. The fertilizers in the form of NPK applied treatment to these crops were in the form of urea, DAP and MOP, respectively during both the years of experimentation.

3.2.3 Biological management

3.2.3.1 Isolation and identification of resident fungal antagonists

Isolation of resident fungal antagonists were made from the rhizosphere and rhizoplane of healthy chilli/bell pepper plants in the fields having high disease incidence. The samples were collected from different agroclimatic zones of Jammu region. Soil samples were also collected from the non-rhizosphere region of healthy plants. Soil attached with the complete intact roots was collected gently with the help of a brush. Air dried soil collected from a rhizosphere and non-rhizosphere were used for serial dilution. Serial dilution of 1:10` was prepared in sterilized water and plated on peptone dextrose-Rose-Bengal agar medium *(Appendix-I)* (Martin, 1950) and on *Trichoderma* selective medium *(Appendix-I)* (Shrestha, 1992). One ml soil suspension was placed in each sterilized petri-plate followed by 20 ml of cooled melted medium poured in the same plate and gently rotated horizontally to get uniform distribution of the suspension in medium. The plates were incubated at 25 ± 2^{0}C for 7 days.

The identity of isolated antagonists was attempted through a study of cultural and morphometric characters. Micrometric measurements of spores, chlymadospores and phialides was done by mounting four-day old culture in lactophenol stained with cotton blue and observed under research microscope. All the observations were compared with standard text (Rifai, 1969; Subramanian, 1971; Domsch *et al.*, 1980).

3.2.3.2 *In-vitro* evaluation of antagonists against the test pathogens

Various resident and non-resident (obtained from different places) fungal antagonists were screened under *in-vitro* conditions against the four wilt complex pathogens by using dual culture technique (Morten and Sproube, 1955). The antagonistic properties of twenty-three isolates of selected biocontrol agents belonging to the *Trichoderma*, *Aspergillus*, *Chaetomium* and *Trichothecium* species were tested and on potato dextrose agar medium against *Fusarium oxysporum, Rhizoctonia solani* and *Sclerotium rolfsii* and on oatmeal agar medium *(Appendix-I)* against *Phytophthora capsici.* Five mm discs of each fungal antagonist and the pathogen were taken from the margins of the actively growing cultures and transferred to petri-plates containing culture medium on opposite sides, one cm away from the periphery of the plate. A check having the test pathogen only, was kept for comparison. Each treatment was replicated thrice. Isolates of *Trichoderma* spp. were inoculated three days after the placement of *P. capsici* and *F. oxysporum* to adjust the slow growth rate of the pathogens. In case of *S. rolfsii* and *R. solani*, the cultures of *Aspergillus* spp., *Chaetomium globosum* and *Trichothecium roseum* were placed two days before the placement of the pathogens. The paired cultures were observed for a period of nine days, however, observations were taken upto thirteen days where both antagonists (*Aspergillus, Chaetomium* and *Trichothecium*) and pathogens (*Fusarium oxysporum* and *Phytophthora capsici*) were slowly growing. Observations were recorded from the time of inhibition-zone formation or after contact between pathogen and the antagonist, as the case may be, and the ratings were given after the antagonists overgrew the pathogen using Bell's scale (Bell *et al.*, 1982).

Class 1	=	The antagonist completely overgrew the pathogen (100% overgrowth).
Class 2	=	The antagonist overgrew at least 2/3rd of pathogen surface (75% overgrowth).
Class 3	=	The antagonist overgrew on half of the growth of the pathogen (50% overgrowth).
Class 4	=	The pathogen and the antagonist locked at the point of contact.
Class 5	=	The pathogen overgrew the antagonist.

Mass multiplication of antagonists : The antagonists were mass multiplied on pre-boiled and sterilized sorghum grains, supplemented with 5 per cent anhydrous dextrose. The Erlenmeyer flasks containing sorghum grains were autoclaved for 1 hour at 15 lb pressure (psi) and were inoculated with 5 mm actively growing discs from seven-day old culture of the selected antagonists. The flasks were incubated at 25 ± 2^0C for 20-25 days for complete colonization of grains with the antagonist. The flasks were shaken regularly to ensure thorough colonization. The well-colonized grains were taken out from the flasks, dried in shade and ground to make fine powder by sieving through 80 mesh sieve.

3.2.3.3 Glasshouse studies

The fungal antagonists, which proved efficacious against all the tested pathogens under *in-vitro* conditions, were evaluated in pot experiments under glasshouse conditions to ascertain their efficacy against the wilt complex pathogens. The experiment was conducted in pots filled with soil + FYM (2:1) sterilized with 5 per cent formalin. Each pot was inoculated, one week before sowing, with the inoculum of *Fusarium oxysporum, Rhizoctonia solani* and *Sclerotium rolfsii* @ 5 g/kg soil mass multiplied on sorghum grains and *Phytophthora capsici* @ 20 g/kg soil mass multiplied on carrot sand mixture.

(a) Seed and seedling treatment : Apparently healthy seeds of Pusa Jawala and California Wonder cultivars were surface sterilized with 0.1 per cent $HgCl_2$. The fungal antagonists *viz.*, *Trichoderma harzianum* (Th_2 and Th_4 isolates), *T. viride* (Tv_2 and Tv_5 isolates) and *T. virens* (Gv_3 isolate) which had proved efficacious against all the test pathogens under *in-vitro* conditions were chosen for glasshouse evaluation. The suspension of powder formulation of these antagonists were made in sterilized distilled water having the spore concentration of 10^7/ml (determined by using haemocytometer). Ten gram seeds were coated separately with each fungal antagonist and kept in moist chamber overnight and then 30 seeds were sown in each pot with four replications. The seeds without any treatment served as check. Effect of fungal antagonists on seedling emergence was calculated by using the following formula :

Per cent increase in seedling emergence =

$$\frac{\text{Number of seedlings in treatment} - \text{Number of seedlings in check}}{\text{Number of seedlings in check}} \times 100$$

The seed treatment was also supplemented with seedling treatment with the respective fungal antagonists by immersing forty-five day old seedlings in spore suspension (10^7 spores/ml) of antagonists for 30 minutes. Three treated seedlings were planted in each pot, which were inoculated with pathogens seven days before planting. The seedlings without any treatment served as check. Four replications were maintained for each treatment.

(b) Soil treatment : The selected fungal antagonists (Th_2, Th_4, Tv_2, Tv_5 and Gv_3) were applied in pot soils after seven days of pathogen inoculations. The soil treatment with antagonists was given alone and in combination with seed + seedling treatments.The antagonists mass multiplied on sorghum seeds were added to the top soil @ 5 g/kg soil before the transplanting of Pusa Jawala and California Wonder cultivars. The pots which were not treated with antagonists and inoculated only with the wilt pathogens served as check. Six replications were maintained for each treatment. Observations on per cent wilt incidence were recorded at 40, 60, 80 and 100 days after transplanting.

3.2.4 Chemical management

3.2.4.1 *In-vitro* evaluation of fungicides against wilt complex pathogens

The efficacy of fungicides *viz.* captan, copper oxychloride, mancozeb, mancozeb + carbendazim (Saaf), mancozeb + metalaxyl (Ridomil MZ), carbendazim, metalaxyl, carboxin and thiophanate methyl were tested against each pathogen, found associated with the wilt complex, under *in-vitro* condition, using poisoned food technique (Schmitz, 1930). Petri-plates containing PDA or carrot agar media (for *P. capsici*) amended with desired concentration of fungicides were inoculated with 5 mm discs of individual pathogen and incubated at 25 ± 2^{0}C temperature. The plates without any fungicide served as check. The experiment was conducted in completely randomized design with four replications. The radial growth of mycelium was recorded in each treatment and per cent inhibition over check was calculated using the following formula (Vincent, 1927) :

$$I = 100 (C–T)/C$$

Where, I = Inhibition per cent

C = Colony diameter in control (mm)

T = Colony diameter in fungicide amended medium (mm)

3.2.4.2 Glasshouse studies

The fungicides found effective under *in-vitro* conditions were tested alone and in combinations in glasshouse as seed + seedling treatments supplemented by spraying at crown region of the plants. The studies were carried out in earthen pots containing sterilized soil and FYM (2:1). The seeds of chilli cv. Pusa Jawala and bell pepper cv. California Wonder treated with fungicides *viz.*, carbendazim, carboxin, metalaxyl (@ 0.2%), captan, carboxin + metalaxyl (1:1), carbendazim + metalaxyl (1:1) (@ 0.3%), captan + metalaxyl (1.5:1) and captan + carbendazim (1.5:1) (@ 0.35%) were sown in pathogen inoculated pots. The seeds without any fungicide treatment served as check. The forty-five days old seedlings were uprooted from the pots and subjected to the seedling dip in different fungicide solutions (same fungicidal treatments and concentrations applied as seed treatment) for 30 minutes and were transplanted in pathogen inoculated pots. The spraying of the fungicides at crown region of the plants was done at 15 days interval after transplanting. The fungicides, found most effective under *in-vitro* conditions, *viz.* carbendazim, metalaxyl and carboxin were applied @ 0.1 per cent, whereas, captan was applied @ 0.15 per cent concentrations. Three seedlings were planted in each pot and four replications were maintained for each treatment. Observations regarding per cent seedling emergence and wilt incidence were taken at regular intervals.

3.2.5 Integrated disease management

3.2.5.1 Compatibility of antagonists with fungicides

The fungicides found effective under *in-vitro* conditions viz., carbendazim, metalaxyl and carboxin at 50, 100, 250 ppm and captan at 100, 250, 500 ppm concentrations were tested against the most effective antagonist isolates *viz.*, *Trichoderma harzianum* (Th_2), *T. viride* (Tv_2) and *T. virens* (Gv_3), to examine if there was any inhibitory effect of selected fungicides on the mycelial growth of the antagonist, using poisoned food technique (Schmitz, 1930). The PDA plates containing desired concentration of fungicides were inoculated at the centre with the mycelial discs (5 mm) of actively growing culture of the antagonist to be tested. The plates inoculated with antagonists but containing no fungicide served as check. The plates were incubated at 25 ± 2^0C for 10 days. The observations on radial growth of the antagonists was recorded in each treatment and per cent inhibition over check was calculated.

3.6.2 Glasshouse studies

The fungicides (captan + metalaxyl, carbendazim + metalaxyl and carboxin + metalaxyl) and antagonists (*Trichoderma viride* and *T. virens*) found effective and compatible under *in*-vitro and *in-vivo* conditions were evaluated in integration to observe their effects on wilt complex disease. The seeds of Pusa Jawala and California Wonder cultivars were first treated with the reduced dose of fungicides (half of the actual dose) followed by antagonists suspension (10^7 conidia/ml). Seeds treated separately with fungicides (same fungicidal combinations and their concentrations as mentioned in 3.2.42) and antagonists suspension served as check. The treated and untreated seeds were sown in pots containing sterilized soil. The antagonists grown on sorghum seeds were added to pot soil @ 5 g/kg soil before transplanting of seedlings. Forty-five days old seedlings were uprooted and dipped in respective fungicide and antagonist suspensions. The seedling were transplanted in pots inoculated with all the test pathogens. The fungicides were sprayed at crown region at 15 day intervals after transplanting. Observations on wilt incidence was recorded at regular intervals upto the maturity of the crop.

3.6.3 Field studies

To study the effect of seed + seedling treatments of fungicides and antagonists alone and in combinations alongwith spraying at crown region of the plant against wilt complex disease, field trials were laid out in randomized block design with three replications at Udheywalla (for chillies) and Basht Chenani, Udhampur (for bell pepper), during the years Kharif 2003 and 2004. The irrigation was applied at 9 day intervals in both the crops whereas fertilizer doses of 80N + 72P + 36K and 80N + 84P

+ 42K kg/ha were applied in chilli and bell pepper, respectively. The ridge planting method was followed in both the crops with spacing of 60 cm between ridges and 45 cm between plants. The other agronomic practices were applied as per the recommended practices. Seeds of Pusa Jawala and California Wonder cultivars were treated with fungicides and antagonists as in glasshouse studies (3.2.5.2). Seeds were sown in first week of March and forty-five days old seedlings were uprooted and subjected with each of the treatment as given earlier (as in glasshouse studies) and transplanted during mid-April. Four sprays of fungicides starting with the initiation of flowering were given at crown region of plant. The antagonists (20 g) were first mixed with 2 kg FYM and then mixed with the top soil layer of plots (2×2 m^2). The yield of both the crops were recorded on net plot basis and converted to q/ha.

CHAPTER - 4

Experimental Results

EXPERIMENTAL RESULTS

4.1 Status of wilt complex in *Capsicum annuum* and causal agents involved with it

Surveys of chilli and bell pepper growing areas of Kathua, Jammu, Udhampur, Rajouri and Doda districts of Jammu division were conducted during the years 2001 and 2002 to ascertain the status of wilt complex disease in the region.

4.1.1 Disease prevalence and incidence

During surveys, the wilt complex disease was found prevalent in all the districts in endemic form. The data obtained (Table 1) indicated that the disease was more prevalent in 2001 than in 2002, with overall mean ranging from 19.88 to 66.40 and 19.87 to 65.19 per cent, and overall average incidence 54.56 and 48.96 per cent, respectively. The highest average wilt incidence 90.53 per cent was recorded at Jathi in district Doda, during 2001, and the lowest average incidence of 30.23 per cent at Thandhapani in Rajouri district, during 2002.

The data presented in Table 1 indicated that in district Jammu there was comparatively less variation in average disease incidence recorded in different villages. In 2001, the highest average disease incidence of 48.12 per cent was recorded in Anand Nagar followed by 47.19 per cent in Muthi, 46.24 per cent in Udheywalla, 46.12 per cent in Raya, 43.58 per cent in Ponichak, 40.12 per cent in Badyal and 34.52 per cent in Maria (Akhnoor). In 2002 also, Anand Nagar recorded highest average wilt incidence of 46.19 per cent followed by Udheywalla (45.47%), Muthi (45.19%), Raya (42.10%), Ponichak (41.32%), Badyal (40.45%) and Maria (32.20%). In the district

Udhampur, during the year 2001, the highest average wilt incidence was recorded in Basht (79.12%), which was followed, by Chenani (64.54%), Kud (60.32%) and Tikri (48.12%). The similar trend was observed during the year 2002, when again highest average wilt incidence was recorded in Basht (75.42%) followed by Chenani (63.75%), Kud (58.32%) and Tikri (52.63%).

In district Doda, the average wilt incidence had greater variation among different locations (villages). Jathi recorded highest average wilt incidence of 90.53 and 88.43 per cent, while as Trungal village recorded only 51.99 and 48.24 per cent during 2001 and 2002, respectively. The average wilt incidence recorded in Assar was 85.00 and 82.33 per cent, followed by Batote 66.92 and 49.75 per cent and Nowgam 52.45 and 52.39 per cent during 2001 and 2002, respectively.

In Kathua district, during the year 2001, highest wilt incidence (41.36%) was recorded in Sharepur followed by Jakhbar (38.67%) and Kathua (36.58%), whereas, during 2002, Jakhbar recorded highest wilt incidence (43.42%) followed by Sharepur (40.53%) and Kathua (34.16%).

In Rajouri district the average wilt incidence of 38.58 and 36.40 per cent was recorded during 2001 and 2002, respectively, which was lowest among all the districts surveyed in Jammu division. In the Rajouri district, Thandikassi had highest wilt incidence of 45.82 per cent (2001) and 43.78 per cent (2002) followed by Nowshera 37.43 per cent (2001) and 36.50 per cent (2002) and Thandapani 31.34 per cent (2001) and 30.23 per cent (2002).

Table 1 : **Incidence of wilt complex of *Capsicum annuum* in different districts of Jammu division**

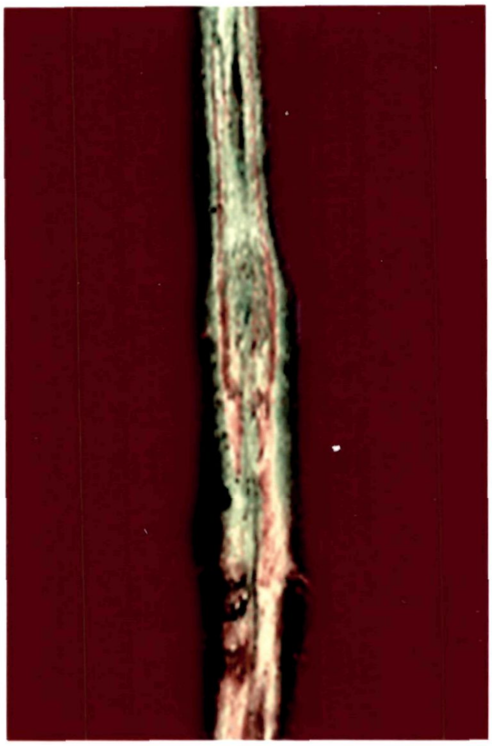
District	Village	Wilt incidence (%)			
		2001		2002	
		Range	Average	Range	Average
Jammu	Udheywalla	10.00 – 78.63	46.24	10.40 – 69.30	45.47
	Ponichak	09.45 – 64.21	43.58	11.43 – 58.71	41.32
	Badyal	15.00 – 59.34	40.12	14.44 – 60.23	40.45
	Raya	14.44 – 70.80	46.12	10.49 – 70.12	42.10
	Anand Nagar	20.19 – 79.32	48.12	16.32 – 72.90	46.19
	Muthi	18.20 – 76.19	47.19	10.45 – 74.13	45.19
	Maria (Akhnoor)	15.23 – 47.80	34.52	14.52 – 42.35	32.20
	Mean	**14.54 – 68.42**	**44.20**	**12.20 – 64.56**	**41.40**
Udhampur	Basht	20.10 – 100.00	79.12	25.00 – 100.00	75.42
	Kud	13.19 – 84.32	60.32	10.12 – 79.19	58.32
	Chenani	19.48 – 88.91	64.54	23.53 – 82.82	63.75
	Tikri	12.24 – 66.35	48.12	14.13 – 68.56	52.63
	Mean	**16.25 – 84.89**	**63.02**	**18.26 – 82.64**	**62.53**
Doda	Assar	55.12 – 100.00	85.00	52.43 – 100.00	82.33
	Jathi	68.23 – 100.00	90.53	64.71 – 100.00	88.43
	Batote	39.21 – 67.18	66.92	35.23 – 60.15	49.75
	Trungal	36.56 – 54.62	51.99	30.23 – 68.32	48.24
	Nowgam	32.16 – 69.32	52.45	24.56 – 65.96	52.39
	Mean	**38.45 – 78.22**	**69.37**	**41.40 – 78.88**	**64.22**
Kathua	Sherpur	18.52 – 53.10	41.36	14.53 – 54.64	40.53
	Jakhbar	17.19 – 49.13	38.67	18.49 – 58.47	43.42
	Kathua	12.43 – 46.78	36.58	11.27 – 44.35	34.16
	Mean	**16.04 – 49.76**	**58.01**	**14.76 – 52.44**	**39.26**
Rajouri	Thandapani	07.23 – 39.12	31.34	08.00 – 35.30	30.23
	Thandikassi	19.96 – 56.32	45.82	15.80 – 55.74	43.78
	Nowshera	12.10 – 46.45	37.43	11.41 – 44.32	36.50
	Mean	13.50 – 47.74	38.58	11.93 – 45.53	36.40
	Overall Mean	**19.88 – 66.40**	**54.56**	**19.87 – 65.19**	**48.96**

Symptomatology: Different types of wilt or wilt like symptoms were found to be produced by different fungi, *viz.*, *Fusarium oxysporum*, *Phytophthora capsici*, *Rhizoctonia solani* and *Sclerotium rolfsii*. The major characteristic symptoms caused by *F. oxysporum* in the field were, epinasty of leaves, petioles and branches; vein clearing, chlorosis of leaves and outright killing of plants. When the collar zones of the affected plants were cut vertically, browning of vascular bundles was observed (Plate 1; Fig. A). It was observed that wilting starts from the lower parts of the plant and progresses upwards. In the field, Fusarium wilt was more pronounced at and after flowering stage of crop growth, however, it was also observed at seedling and pre-flowering stages. The fruit on the affected plants was shriveled, remained small and rotting took place in the latter stages.

Wilt-like symptoms, incited by *Rhizoctonia solani*, was characterized by root rot, leading to wilting and death of plants. The initial symptoms of the disease were the inward curling and folding of upper most young leaves resulting in drooping of the leaves and branches, and ultimately causing wilting and death of the plants. The roots infected by *R. solani* were initially pale and latter turned dark brown (Plate 1; Fig. B) with water-soaked appearance. Secondary and tertiary roots and even main roots were also rotten in advanced stages and the infected plants could easily be pulled out. Although, generally the seedlings were attacked by this pathogen but the symptoms produced on mature plants were not uncommon.

The symptoms produced by *Phytophthora capsici* were characterized by sudden wilting of entire plant, which was caused by rotting of the stem near the soil surface. The aerial parts of plants like leaves, petioles, fruits, stems and branches rotted locally,

PLATE-1



(A) Vascular browning caused by *Fusarium oxysporum*

(B) Root rot symptoms caused by *Rhizoctonia solani*

(C) Disease lesions on stem/ branches caused by *Phytophthora capsici*

(D) Disease lesions near crown region caused by *Sclerotium rolfsii.*

starting with small, water soaked lesions. The light brownish black lesions produced at the stem base extend rapidly towards the upper parts of the stem and branches (Plate 1; Fig. C) or towards the roots. The taproot and root hair became brown and rotten. Whitish grey fungal growth with abundant sporangia was developed on infected plant surfaces under high moisture conditions.

Some diseased plants, exhibiting distinct wilt symptoms, were found to be incited by *Sclerotium rolfsii*. In this case, infection started on the succulent stem as brown lesions just below the soil line (Plate 1; Fig. D). Soon, the lower leaves and then the upper leaves turned yellow and wilted. In the fields, having high moisture levels, the fungus covered the stem lesions with a cottony, white mass of mycelium. The infected stem tissues were usually pale brown and soft but not watery. On infected tissues, small, white and roundish sclerotia of uniform size were found that turned dark brown to black on maturity.

4.1.2 Isolation and identification of pathogens

The fungal pathogens isolated from the infected roots, stems and branches of the plants showing wilting in the surveyed fields (Plate 2; Fig. A) yielded different fungal flora. The Koch's postulates proved that four fungal genera were associated with the wilt complex disease in *Capsicum annuum*. It was observed that the pathogens took 15-25 days to cause complete wilting of chilli and bell pepper plants. The pathogenic fungi were identified on the basis of their morphological and cultural characteristics.

(a) *Fusarium oxysporum* Schlecht: The purified culture of the fungus on PDA (Plate 3; Fig. A) at 25±2^{0}C produced fairly dense, floccose white and pionnotal mycelium. An average growth rate of 0.36 mm/hour was observed on PDA medium.

PLATE-2

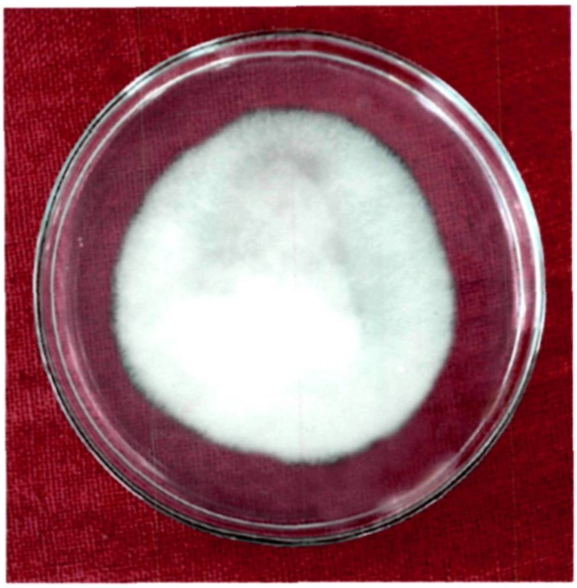
(A) Field view of bell pepper plants showing wilt complex disease

(B) Field trial laid at Udheywalla showing healthy chilli plants

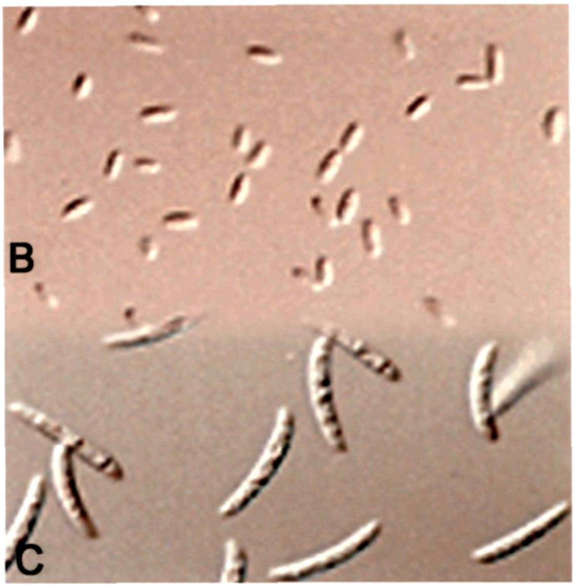
Microscopic examination revealed that the hyphae were 2.81±0.15 μm in diameter, hyaline, branched and septate. Microconidia were abundantly produced and were round, aseptate and measured 8.11–8.15 × 2.60–3.20 μm in size (Plate 3; Fig. B). Macroconidia were sparse and sickle shaped with pointed apical cell and somewhat papillate basal cell and measured 16.38–29.70 × 2.49–2.9 μm in size (Plate 3; Fig. C). Macroconidia were mainly 3 to 5 septate, however, 1 and 2 septate macroconidia were also observed. Chlymadospores were sparse, hyaline, smooth walled intercalary and terminal measuring 7.70–7.81 × 7.23–7.33 μm in size. On the basis of these characteristic features and comparing them with the descriptions given by Subramanian (1971), Booth and Sutton (1984) and Brayford (1993), the fungus was identified as *Fusarium oxysporum* Schlecht.

(b) ***Rhizoctonia solani*:** The purified culture of the fungus on PDA (Plate 3; Fig. D) at 25±2^{0}C produced circular, raised, fluffy, light brown to brown with concentric zones of appressed and aerial mycelium. The microscopic observations revealed that the hyphae were slender, 6.41–7.86 μm wide, septate and branched at right angles near the distal septum of the cells. In young vegetative hyphae, there was formation of a septum in the branch near the point of origin with constriction and presence of moniloid cells (Plate 3; Fig. E). Brown to black coloured sclerotia formed in the culture were irregular in shape, varied in sizes and were distributed over the surface of the colony in the zone of aerial mycelium, often growing together bound by mycelial strands (Plate 3; Fig. F). The mean growth rate of the colony was 0.92 mm/hour at 25±2^{0}C. These characteristics were compared with the description given by Parmeter and Whitney (1970) and the fungus was confirmed as *Rhizoctonia solani* Kuhn.

PLATE-3

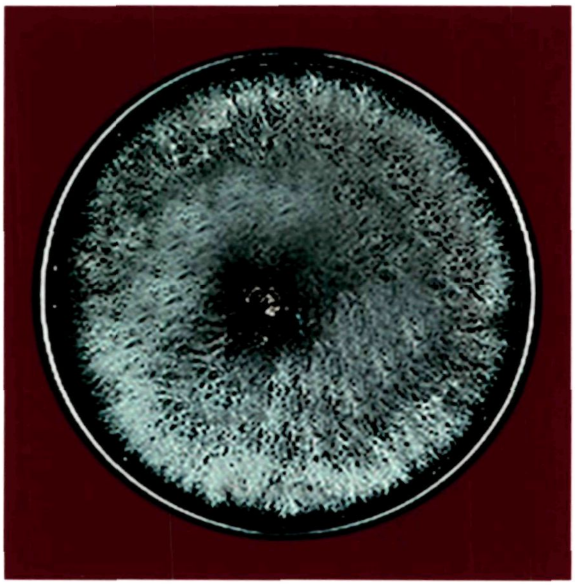


(A) *F. oxysporum* colony growth on PDA

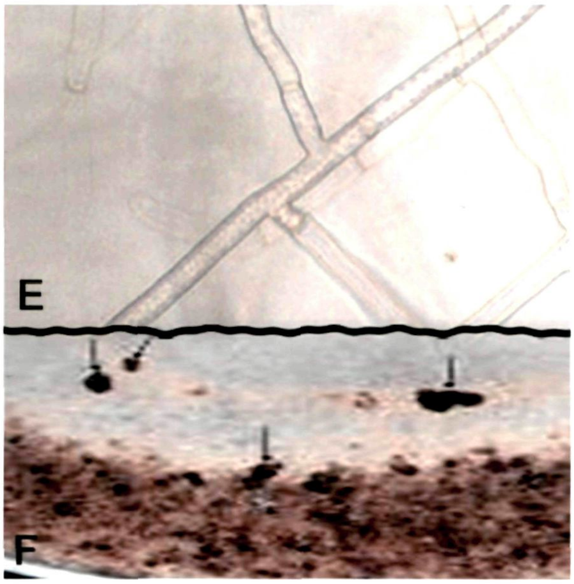


(B) Microconidia of *F. oxysporum*

(C) Sickle shaped macroconidia of *F. oxysporum*



(D) *R. solani* colony growth on PDA .



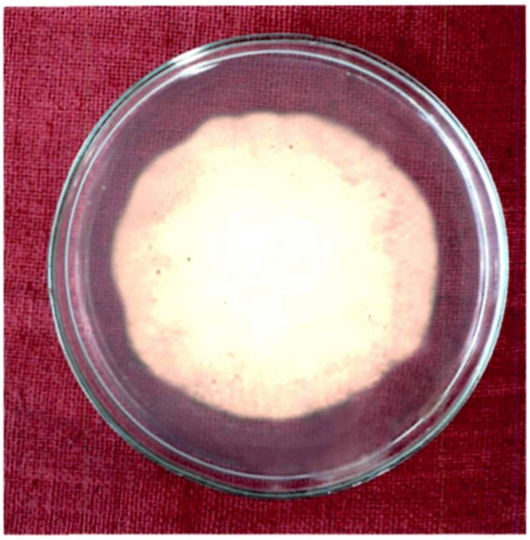
(E) Typical mycelium of *R. Solani*

(F) Sclerotia of *R. solani* viewed under microscope

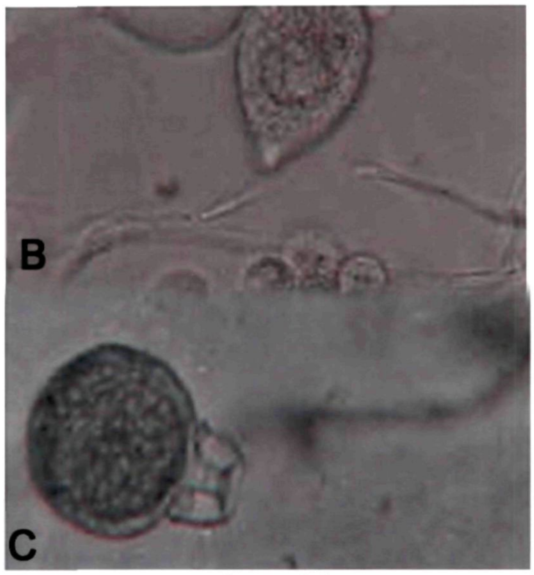
(c) ***Phytophthora capsici* Leonian:** The purified culture of the fungus on PDA (Plate 4; Fig. A) produced fluffy and cottony white colonies at 25±2^{0}C temperature. Hyphae were simple or branched, often becoming variously swollen and tuberous. Sporagiophores were branched and narrow and widening at the base of sporangium. Sporangia were rarely produced in medium but were abundantly produced in tap water. Sporangia were nearly spherical to pyriform, hyaline, papillate, deciduous, pedicillate and measured 35–58 × 25–41 μm (Plate 4; Fig. B). The pathogen did not produce any chlamydospore in culture. The oospores (Plate 4; Fig. C) although observed in host tissues were not formed in culture media. The mean growth rate of the colony was 0.62 mm/hour at 25±2^{0}C. On the basis of morphological features of the isolated fungus, it was identified as *Phytophthora capsici* which was in conformity to the descriptions given by Leonian (1922) and Satour and Butler (1968).

(d) ***Sclerotium rolfsii* Sacc.:** The purified culture of the fungus on PDA medium (Plate 4; Fig. D) at 25±2^{0}C produced abundant, silky white, fluffy, branched mycelium. The radial growth of hyphae, observed on the medium had lot of aerial mycelial strands. No spore or conidium was seen in culture medium. The fungus produced numerous sclerotia of uniform size. Initially the sclerotia were white in colour but latter turned buff coloured and then to black. The sclerotia were formed laterally from main hyphal strands and ranged from 0.5–2.0 mm in diameter (Plate 4; Fig. E). The mean radial growth rate of fungus was 0.98 mm/hour at 25±2^{0}C. On the basis of these characters and on comparing with the descriptions given by Domsch *et al.* (1980), the fungus was identified as *Sclerotium rolfsii* Sacc.

PLATE-4

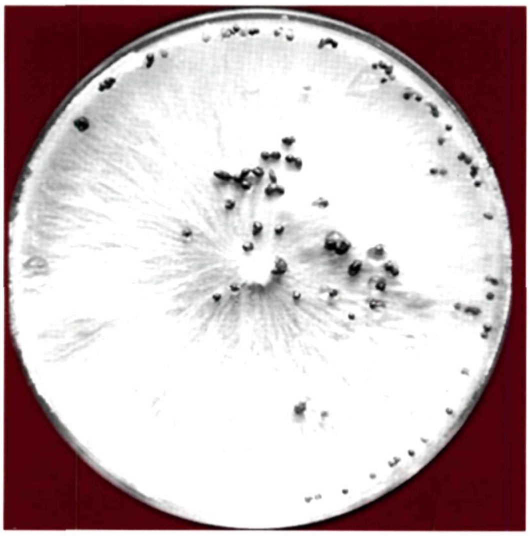


(A) *P. capsici* colony growth on PDA

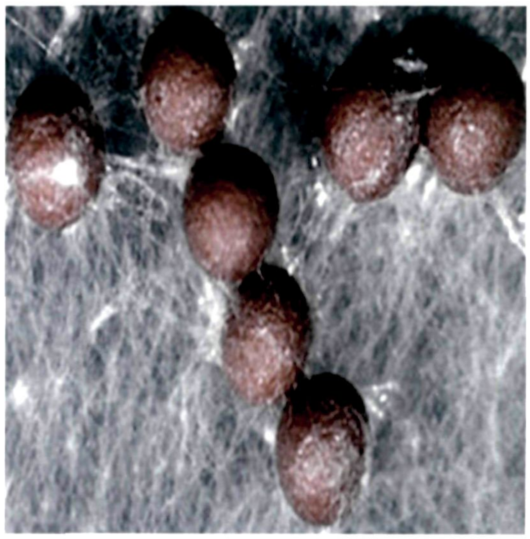


(B) Zoosporangia with encysted zoospores

(C) Oospore of *P. capsici*



(D) *S. rolfsii* colony growth on PDA



(E) Brown coloured sclerotia of *S. rolfsii*

4.1.3 Pathogens associated with wilt complex disease of *Capsicum annuum* in Jammu division

The samples of wilted plants collected from different locations of five districts of Jammu division revealed the presence of four pathogens *viz.*, *Fusarium oxysporum, Phytophthora capsici, Rhizoctonia solani* and *Sclerotium rolfsii* alone and in association with each other. The data (Table 2) indicate that in the year 2001, *F. oxysporum* was most predominant pathogen in all the five districts surveyed followed by *P. capsici* and *R. solani. S. rolfsii* was not found existing independently except at some locations in Rajouri district (13.0 per cent). The average occurrence of *F. oxysporum* in Jammu division was 27.5 per cent followed by 15.5 per cent of *P. capsici*, 14.4 per cent of *R. solani* and 2.6 per cent of *S. rolfsii.* The occurrence of *F. oxysporum, P. capsici* and *R. solani* in Jammu district during 2001 was 22.2, 15.5 and 11.1 per cent, respectively; in Udhampur it was 25.8, 12.9 and 9.6 per cent; in Doda 32.4, 18.9 and 16.2 per cent; in Kathua 31.8, 18.2 and 18.2 per cent; in Rajouri 26.0, 13.0 and 17.3 per cent, respectively. The association of *F. oxysporum* + *P. capsici* was most predominant in the year 2001 as its occurrence was 12.7 per cent followed by 11.2 per cent of *F. oxysporum* + *R. solani.* The association of *F. oxysporum* + *P. capsici* + *R. solani* was equally predominant in the division, with an average occurrence of 10.3 per cent. The association F. *oxysporum* + *S. rolfsii* was not as predominant as its occurrence was only 4.7 per cent.

Table 2 : Occurrence of pathogens associated with wilt complex of *Capsicum annuum* in different districts of Jammu division

District	Occurrence of wilt pathogens (%)															
	Year 2001								Year 2002							
	Fo	Pc	Rs	Sr	Fo + Pc	Fo + Rs	Fo + Sr	Fo + Pc + Rs	Fo	Pc	Rs	Sr	Fo + Pc	Fo + Rs	Fo + Sr	Fo + Pc + Rs
Jammu	22.2	15.5	11.1	–	24.4	11.1	04.4	11.1	22.8	16.6	14.5	–	12.5	08.3	06.2	18.7
Udhampur	25.8	12.9	09.6	–	16.1	19.3	06.4	09.6	24.2	15.1	12.1	–	12.1	09.1	06.1	21.2
Doda	32.4	18.9	16.2	–	05.4	08.1	05.4	13.5	25.5	16.2	16.2	–	11.6	09.3	04.6	16.2
Kathua	31.8	18.2	18.2	–	09.1	09.1	04.5	09.1	24.0	16.0	12.0	–	12.0	16.0	04.0	12.0
Rajouri	26.0	13.0	17.3	13.0	04.3	08.6	13.0	08.6	19.2	11.5	11.5	07.6	11.5	07.6	15.3	15.3
Mean	27.5	15.5	14.4	02.6	12.7	11.2	04.7	10.3	23.1	15.0	13.2	01.5	11.9	10.6	07.2	16.6

Fo = *Fusarium oxysporum* Pc = *Phytophthora capsici* Rs = *Rhizoctonia solani* Sr = *Sclerotium rolfsii*

It is further evident from Table 2, that in the year 2002, *F. oxysporum* was again the most prominent pathogen involved in wilt complex disease across the Jammu division. Its occurrence was 23.1 per cent followed by 15.0 per cent of *P. capsici* and 13.2 per cent of *R. solani*. The independent existence of *S. rolfsii* was again restricted to only in Rajouri district, although in association with *F. oxysporum* it was found in other districts as well. The most predominant association of wilt complex pathogens was that of *F. oxysporum* + *P. capsici* + *R. solani* (16.6%) followed by *F. oxysporum* + *P. capsici* (11.9%), *F. oxysporum* + *R. solani* (10.6%) and *F. oxysporum* + *S. rolfsii* (7.2%). The sole infection of *F. oxysporum, P. capsici* and *R. solani* in Jammu district during 2002 was 22.8, 16.6 and 14.5 per cent, respectively. In Udhampur it was 24.2, 15.1 and 12.1 per cent and, in Doda 25.5, 16.2 and 16.2 per cent, respectively. Kathua district recorded 24.0 per cent occurrence of *F. oxysporum*, 16.0 per cent of *P. capsici* and 12.0 per cent of *R. solani*. In Rajouri district, the occurrence of *F. oxysporum, P. capsici, R. solani* and *S. rolfsii* was 19.2, 11.5, 11.5 and 7.6 per cent, respectively. The association of *F. oxysporum* + *P. capsici* + *R. solani* was observed to be the most predominant in all the districts except Kathua, where the association of *F. oxysporum* + *R. solani* were maximim. The occurrence of *F. oxysporum* + *P. capsici* in Jammu district was 12.5 per cent, in Udhampur it was 12.1 per cent, in Doda 11.6 per cent, in Kathua 12.0 per cent, and in Rajouri 11.5 per cent. The occurrence of *F. oxysporum* + *R. solani* in Jammu, Udhampur, Doda, Kathua and Rajouri was 8.3, 9.1, 9.3, 16.0 and 7.6 per cent, respectively. The occurrence of *F. oxysporum* + *S. rolfsii* in Jammu was 6.2 per cent, in Udhampur 6.1 per cent, in Doda 4.6 per cent, in Kathua 4.0 per cent, and in Rajouri 15.3 per cent. The most predominant association in the year 2002 was that of *F. oxysporum* + *P. capsici* + *R. solani*, which recorded 18.7 per cent occurrence in Jammu, followed by 21.2 per cent in Udhampur, 16.2 per cent in Doda, 12.0 per cent in Kathua and 15.3 per cent in Rajouri district.

4.1.4 Effect of soil temperature and moisture on the wilt incidence of *Capsicum annuum*

The data presented in Table 3 revealed that the disease initiated during last week of April and the incidence increased gradually till maturity of the crop during both the years 2001 and 2002. In the year 2001, the maximum apparent infection rate (0.212 units/day) was observed in 24th standard week (17th June), when the soil temperature of 20.7–32.5^{0}C and soil moisture 37.7 per cent was prevailing in the field, which favoured maximum disease development. In the year 2002, 21.3–33.0^{0}C soil temperature and 36.9 per cent soil moisture favoured maximum infection rate (0.125 units/day) in the 27th standard week (8th July).

The Table 4 indicates that in the year 2001 highly significant and positive correlation (0.913 correlation coefficient) was established between soil moisture and wilt incidence. Positive and significant correlation (0.653 correlation coefficient) was also observed between minimum soil temperature and wilt incidence, however, maximum temperature had non-significant effect on the wilt incidence. In the year 2002 also, similar results were obtained. Soil moisture had significantly positive correlation (0.897 correlation coefficient) with wilt incidence and minimum temperature was also significantly and positively correlated (0.752 correlation coefficient) with wilt incidence, whereas, maximum temperature did not show any correlation with wilt incidence. The multiple regression analysis (Table 4) revealed that soil temperature and soil moisture contributed 92.3 and 90.7 per cent variation in

Table 3 : Effect of soil temperature and soil moisture on the development of wilt complex disease of chilli cv. Pusa Jawala

Standard week	Date of observation	Wilt incidence (%)		Infection rate (units/day)		Soil temperature (^0C)				Soil moisture (%)	
		2001	2002	2001	2002	2001		2002		2001	2002
						Max.	Min.	Max.	Min.		
17	29 Apr	1.3 (6.5)	1.3 (6.5)	–	–	36.4	18.3	37.3	19.8	16.5	14.0
18	06 May	1.3 (6.5)	1.3 (6.5)	–	–	37.6	19.8	37.0	20.1	11.2	10.4
19	13 May	1.3 (6.5)	1.3 (6.5)	–	–	39.0	20.3	39.5	20.5	12.3	10.2
20	20 May	2.6 (9.2)	1.3 (6.5)	0.098	–	35.5	20.1	40.2	21.3	16.5	9.8
21	27 May	2.6 (9.2)	1.3 (6.5)	–	–	37.2	20.6	39.7	21.2	19.9	9.4
22	03 June	3.9 (11.3)	2.6 (9.2)	0.058	0.098	36.0	21.3	36.8	22.0	23.5	10.6
23	10 June	4.2 (11.8)	3.9 (11.3)	0.011	0.058	33.7	23.1	38.4	21.9	26.2	11.7
24	17 June	18.5 (25.4)	7.8 (16.2)	0.212	0.099	32.5	20.7	34.3	21.0	37.7	30.9
25	24 June	21.1 (27.3)	9.1 (17.5)	0.019	0.022	35.1	24.0	35.6	24.4	31.8	27.4
26	01 July	25.0 (30.0)	10.4 (18.8)	0.024	0.020	33.8	25.4	37.6	24.4	30.4	27.8
27	08 July	28.9 (32.5)	25.0 (30.0)	0.021	0.125	30.2	26.3	33.0	21.3	30.1	36.9
28	15 July	35.4 (36.5)	27.6 (31.6)	0.029	0.013	30.1	25.8	34.2	26.1	30.7	32.5
29	22 July	44.5 (41.8)	30.2 (33.3)	0.037	0.013	33.9	26.9	33.6	26.5	34.6	31.6
30	29 July	48.4 (44.0)	38.0 (38.0)	0.012	0.033	32.3	27.4	34.9	27.2	30.0	32.3
31	05 August	58.8 (50.0)	43.2 (41.0)	0.028	0.018	31.5	27.6	35.3	27.5	32.3	31.9
32	12 August	65.3 (53.9)	47.1 (43.3)	0.015	0.012	33.1	27.8	33.4	26.9	30.1	30.4
33	19 August	69.2 (56.2)	53.6 (47.0)	0.010	0.018	33.0	27.6	33.7	27.1	29.5	30.2
34	26 August	75.7 (60.4)	65.3 (53.9)	0.013	0.028	33.1	28.2	32.8	27.2	32.6	33.5

*Figures in parenthesis are transformed angular values

Table 4 : **Correlation between soil temperature and moisture with wilt disease incidence**

Soil characteristics	Wilt incidence	
	Year 2001	Year 2002
Minimum Temperature (^0C) – X_1	0.653*	0.752*
Maximum Temperature (^0C) – X_2	0.413	0.472
Moisture (%) – X_3	0.913**	0.897**

Multiple regression equation :

Year 2001 $Y = 80.24 + (2.10 X_1) + (1.78 X_2) + (3.65 X_3)$; $R^2 = 92.3$**

Year 2002 $Y = 106.51 + (1.23 X_1) + (1.03 X_2) + (2.64 X_3)$; $R^2 = 90.7$**

* Significant at 5%

** Significant at 1%

disease development in the year 2001 and 2002, respectively, which were highly significant.

4.1.5 Effect of crop maturity on the occurrence of wilts complex pathogens

Perusal of the data presented in Table 5 indicate that *F. oxysporum* was present, independently or in association, with other wilt complex pathogens in the disease samples at all the stages of crop growth. However, at latter stages it was more prevalent in associations with *P. capsici*. The occurrence of *P. capsici* started only after 10th of June in the year 2001, when the flowering had just started, and was dominantly present alone and in association with *F. oxysporum* till the harvesting stage of crop. In the year 2002, although the occurrence of *P. capsici* started after 1st July, at flowering stage, in association with *F. oxysporum* and *R. solani* but its independent occurrence started only after 29th July, at fruit-set stage. The data also revealed that *R. solani* was more prevalent, at seedling and pre flowering stages, of crop growth. In 2001, the independent occurrence of *R. solani* was observed only upto flowering stage (17th June), however, in association with *F. oxysporum* and *P. capsici* its occurrence remained up to fruiting stage (5th August). In 2002, *R. solani* was predominantly found only up to flowering stage (8th July), latter on its occurrence was only in association with other pathogens.

4.2 Disease management

4.2.1 Host resistance

4.2.1.1 Field evaluation

The field evaluation of thirty-eight germplasm (genotypes/varieties) of chilli and bell pepper was conducted in sick plots during the years 2001 and 2002 and

Table 5 : Effect of crop maturity on the occurrence of wilt complex pathogens associated with chilli cv. Pusa Jawala

Standard week	Date of observation	Occurrence of wilt complex pathogens (%)											
		Year 2001						Year 2002					
		Fo	Pc	Rs	Fo+Rs	Fo+Pc	Fo+Pc+Rs	Fo	Pc	Rs	Fo+Rs	Fo+Pc	Fo+Pc+Rs
17	29 Apr	37.5	–	62.5	–	–	–	41.6	–	58.3	–	–	–
18	06 May	–	–	100.0	–	–	–	33.3	–	66.6	–	–	–
19	13 May	–	–	–	–	–	–	–	–	–	–	–	–
20	20 May	25.0	–	50.0	25.0	–	–	–	–	–	–	–	–
21	27 May	–	–	–	–	–	–	–	–	–	–	–	–
22	03 Jun	25.0	–	25.0	50.0	–	–	25.0	–	75.0	–	–	–
23	10 Jun	28.5	–	28.5	14.2	–	28.5	28.5	–	42.8	28.5	–	–
24	17 Jun	20.0	13.3	13.3	–	20.0	33.3	25.0	–	75.0	–	–	–
25	24 Jun	23.8	19.0	–	4.7	23.8	28.5	28.5	–	42.8	28.5	–	–
26	01 Jul	20.0	13.3	–	13.3	20.0	33.3	33.3	–	16.6	33.3	–	16.6
27	08 Jul	26.6	33.3	–	–	26.6	13.3	21.4	–	14.2	14.2	21.4	28.5
28	15 Jul	20.0	30.0	–	–	35.0	15.0	33.3	–	–	–	33.3	33.3
29	22 Jul	19.0	28.5	–	–	38.1	14.2	30.0	–	–	–	40.0	30.0
30	29 Jul	15.0	25.0	–	–	50.0	10.0	16.6	25.0	–	–	33.3	25.0
31	05 Aug	18.1	27.2	–	–	45.4	9.0	19.0	28.5	–	–	38.1	14.2
32	12 Aug	16.6	27.2	–	–	55.5	–	21.0	31.5	–	–	47.3	–
33	19 Aug	–	–	–	–	100.0	–	20.0	30.0	–	–	50.0	–
34	26 Aug	20.0	26.6	–	–	53.3	–	19.0	28.5	–	–	52.3	–

Fo = *Fusarium oxysporum* Pc = *Phytophthora capsici* Rs = *Rhizoctonia solani* observations on per cent wilt incidence were recorded for each year. The results (Table 6) revealed that eighteen genotypes/varieties of chilli *viz.*, Suraj Mukhi, SC-105 (SC = Shalimar Collection; genotypes obtained from SKUAST-K, Shalimar), SC-108 (01), RS Pura Collection, Pusa Sadhabhar, SC-107, Punjab Lal, Solan Red, Pant C_2, NP-46A, Pulwama Collection, SC-909, Rajasthan Special, SC-304 (01), SC-907, DKC-8, SC-36 and SC-880 (01) with moderately resistant reaction showing mean wilt incidence ranging from 12.4 to 27.7 per cent. Whereas, nine genotypes *viz.*, SC-79, SC-274, SC-885, SC-101, SC-903, SC-304, SC-505, SC-03 and SC-23 exhibited susceptible reaction with average wilt incidence ranging from 34.7 to 50.0 per cent. Seven genotypes/varieties, namely Kathua Collection, SC-863, SC-962, SC-1004, SC-908, Udheywalla Collection and Pusa Jawala exhibited highly susceptible reaction with the wilt incidence ranging from 54.1 to 75.0 per cent. Among the four bell pepper varieties evaluated, Yolo Wonder exhibited moderately resistant disease reaction with average wilt incidence of 23.6 per cent. California Wonder, Chenani collection and Pulwama Collection exhibited highly susceptible reaction with wilt incidence of 62.4, 63.8 and 73.6 per cent, respectively.

The pooled data of the years 2001 and 2002 indicate that Suraj Mukhi, which recoded 12.4 per cent wilt incidence, was significantly superior over other genotypes and varieties. SC-108 (08) and SC-105 each recording 15.2 per cent wilt incidence were significantly superior over other genotypes evaluated under field conditions in the present studies. Among the bell pepper varieties, Yolo Wonder recorded the least wilt incidence of 23.6 per cent which was significantly lower than 62.6, 63.8 and 73.6 per cent incidence observed in California Wonder, Chenani Collection and Pulwama Collection, respectively.

Table 6 : Evaluation of *Capsicum annuum* germplasm against wilt complex disease under field conditions

Variety / Genotype	Wilt incidence (%)			Disease reaction
	2001	2002	Pooled	
Chilli				
Suraj Mukhi	13.8 (21.8)	11.1 (19.4)	12.4 (20.6)	MR
SC – 108 (01)	13.8 (21.8)	16.6 (24.0)	15.2 (22.9)	MR
SC – 105	13.8 (21.8)	16.6 (24.0)	15.2 (22.9)	MR
R.S. Pura Collection	16.6 (24.0)	19.4 (26.1)	19.4 (26.1)	MR
Pusa Sadhabhar	19.4 (26.1)	19.4 (26.1)	19.4 926.1)	MR
SC – 107	19.4 (26.1)	22.2 (28.1)	20.8 (27.1)	MR
Punjab Lal	19.4 (26.1)	25.0 (30.0)	22.2 (28.1)	MR
Solan Red	22.2 (28.1)	27.7 (31.7)	24.9 (29.9)	MR
Pant C_2	22.2 (28.1)	25.0 (30.0)	23.6 (29.0)	MR
NP46A	22.2 (28.1)	27.7 (31.7)	24.9 (29.9)	MR
Pulwama Collection	25.0 (30.0)	27.7 (31.7)	26.3 (30.8)	MR
SC – 909	25.0 (30.0)	25.0 (30.0)	25.0 (30.0)	MR
Rajasthan Special	25.0 (30.0)	19.4 (26.1)	22.2 (28.1)	MR
SC – 304 (01)	27.7 (31.7)	22.2 (28.1)	24.9 (29.9)	MR
SC – 907	27.7 (31.7)	22.2 (28.1)	24.9 (29.9)	MR
DKC – 8	27.7 (31.7)	25.0 (30.0)	26.3 (30.8)	MR
SC – 36	27.7 (31.7)	27.7 (31.7)	27.7 (31.7)	MR
SC – 880 (01)	27.7 (31.7)	27.7 (31.7)	27.7 (31.7)	MR
SC – 79	33.3 (35.2)	36.1 (36.9)	34.7 (36.0)	S
SC – 274	33.3 (35.2)	38.8 (38.5)	36.0 (36.8)	S
SC – 885	36.1 (36.9)	36.1 (36.9)	36.1 (36.9)	S
SC – 101	38.8 (38.5)	38.8 (38.5)	38.8 (38.5)	S
SC – 903	38.8 (38.5)	41.6 (40.1)	41.6 (40.1)	S
SC – 304	41.6 (40.1)	41.6 (40.1)	41.6 (40.1)	S
SC – 505	41.6 (40.1)	50.0 (45.0)	45.8 (42.5)	S
SC – 03	41.6 (40.1)	50.0 (45.0)	45.8 (42.5)	S
SC – 23	50.0 (45.0)	50.0 (45.0)	50.0 (45.0)	S
Kathua Collection	52.7 (46.5)	55.5 (48.1)	54.1 (47.3)	HS
SC – 863	52.7 (46.5)	55.5 (48.1)	54.1 (47.3)	HS
SC – 962	55.5 (48.1)	52.7 (46.5)	54.1 (47.3)	HS
SC – 1004	55.5 (48.1)	61.1 (51.4)	58.3 (49.7)	HS
SC – 908	61.1 (51.1)	75.0 (60.0)	68.0 (54.3)	HS
Udheywalla Collection	61.1 (51.1)	61.1 (51.1)	61.1 (51.1)	HS
Pusa Jawala	75.0 (60.0)	75.0 (60.0)	75.0 (60.0)	HS
Bell pepper				
Yolo Wonder	25.0 (30.0)	22.2 (28.1)	23.6 (29.0)	MR
California Wonder	63.8 (53.0)	61.1 (51.1)	62.4 (52.1)	HS
Chenani Collection	66.6 (54.6)	61.1 (51.1)	63.8 (53.0)	HS
Pulwama Collection	72.2 (58.1)	75.0 (60.0)	73.6 (59.0)	HS
CD (p = 0.05)			**2.29**	

Figures in parenthesis are transformed angular values

MR – Moderately Resistant; S – Susceptible; HS – Highly Susceptible

4.2.1.2 Glasshouse evaluation

Eighteen chilli and one bell pepper genotypes/varieties, which exhibited moderately resistant reaction to wilt complex pathogens under field studies, were further evaluated under glasshouse conditions during the years 2002 and 2003. The results presented in Table 7 revealed that Suraj Mukhi, SC-108 (01) and SC-105 were found moderately resistant and exhibited average wilt incidence of 16.6, 25.0 and 25.0 per cent, respectively. Whereas, nine genotypes/varieties *viz.*, RS Pura Collection, Pusa Sadhabahar, SC-107, Punjab Lal, Solan Red, Pant C_2, NP-46A, Pulwama Collection and SC-880 (01) exhibited susceptible reaction with the wilt incidence ranging from 33.3 to 50.0 per cent. The remaining six genotypes/varieties *viz.,* Rajasthan special, DKC-08, SC-36, SC-907, SC-304 (01) and SC-909 were found highly susceptible with wilt incidence of 62.3, 66.6, 100, 100, 100 and 100 per cent, respectively. The bell pepper variety, Yolo Wonder exhibited susceptible reaction with wilt incidence of 37.4 per cent under glasshouse conditions.

The data also indicate that Suraj Mukhi (16.6% wilt incidence) was significantly superior over other varieties and genotypes followed by SC-108 (01) and SC 105 each having 25.0 per cent wilt incidence. The Table 7 also revealed that R.S. Pura Collection, Pusa Sadhabahar, SC- 107, Yolo Wonder and Punjab Lal were statistically at par with each other. No difference in wilt incidence was observed in SC-36, SC-907, SC-304 (01) and SC-909.

Table 7 : **Evaluation of *Capsicum annuum* germplasm against wilt pathogens under glasshouse conditions**

Variety / Genotype	Wilt incidence (%)			Disease reaction
	2002	2003	Pooled	
Chilli				
Suraj Mukhi	16.6 (24.0)	16.6 (24.0)	16.6 (24.0)	MR
SC – 108 (01)	25.0 (30.0)	25.0 (30.0)	25.0 (30.0)	MR
SC – 105	25.0 (30.0)	25.0 (30.0)	25.0 (30.0)	MR
R.S. Pura Collection	33.3 (35.2)	33.3 (35.2)	33.3 (35.2)	S
Pusa Sadhabhar	33.3 (35.2)	33.3 (35.2)	33.3 (35.2)	S
SC-107	33.3 (35.2)	33.3 (35.2)	33.3 (35.2)	S
Punjab Lal	33.3 (35.2)	41.6 (40.1)	37.4 (37.7)	S
Solan Red	41.6 (40.1)	50.0 (45.0)	45.8 (42.5)	S
Pant C_2	41.6 (40.1)	33.3 (35.2)	37.4 (37.7)	S
NP46A	50.0 (45.0)	41.6 (40.1)	45.8 (42.5)	S
Pulwama Collection	50.0 (45.0)	50.0 (45.0)	50.0 (45.0)	S
SC – 880 (01)	50.0 (45.0)	41.6 (40.1)	45.8 (42.5)	S
Rajasthan Special	58.0 (49.6)	66.6 (54.6)	62.3 (52.1)	HS
DKC – 08	66.6 (54.6)	66.6 (54.6)	66.6 (54.6)	HS
SC – 36	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	HS
SC – 907	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	HS
SC – 304 (01)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	HS
SC – 909	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	HS
Bell pepper				
Yolo Wonder	33.3 (35.2)	41.6 (40.1)	37.4 (37.7)	S
CD (p = 0.05)			**12.21**	

Figures in parenthesis are transformed angular values

MR – Moderately Resistant; S – Susceptible; HS – Highly Susceptible

4.3 Cultural management

Effect of four levels of irrigation (applied at 5, 7, 9 and 11 day intervals), four levels of fertilizer (kg/ha.) [80N+84P+42K; 80N+72P+36K; 120N+60P+30K and recommended dose (100N+60P+30K)] and two planting methods (flat-bed and ridge planting) on wilt incidence and yield of chilli cv. Pusa Jawala and bell pepper cv. California Wonder were studied during the years 2002 and 2003.

(A) Chillies cv. Pusa Jawala

(i) **Effect on wilt incidence:** The data presented in Table 8 indicated that the varying irrigation frequencies had a significant influence on the wilt incidence. The application of irrigation at an interval of 11 days recorded significantly lowest wilt incidence (39.7 and 34.4 per cent in 2002 and 2003, respectively) than other irrigation frequencies in both the years of experimentations. Among the application of fertilizer combinations 80N+72P+36K kg/ha though at par with 80N+84P+42K kg/ha produced significantly lower wilt incidence (48.2 and 43.1% in 2002 and 2003, respectively) than 100N+60P+30K kg/ha (52.4 and 48.2% in 2002 and 2003, respectively) and 120N+60P+30K kg/ha (55.4 and 53.4% in 2002 and 2003, respectively). However ridge planting method had shown significantly lower wilt incidence (48.1 and 43.4% in 2002 and 2003, respectively) than flat-bed planting method (52.5 and 49.1% in 2002 and 2003, respectively) during both the cropping seasons.

(ii) **Effect on fresh yield:** In general it has been observed that the irrigation levels, fertilizer levels and planting methods influence the yield in chilli significantly (Table 8). The perusal of data indicates that the application of irrigation at 7 day intervals

Table 8 : Effect of irrigation frequencies, fertilizer levels and planting methods on wilt incidence and yield of chilli cv. Pusa Jawala

Treatment	Wilt incidence (%)			Yield q / ha		
	Year 2002	Year 2003	Mean	Year 2002	Year 2003	Mean
Irrigations levels						
I_1 (5DI)	61.1 (51.4)	57.4 (49.2)	59.2	39.8	41.1	40.4
I_2 (7DI)	54.3 (47.4)	51.6 (45.9)	52.9	43.3	47.1	45.2
I_3 (9DI)	46.1 (42.7)	41.61 (40.1)	43.8	43.2	46.9	45.0
I_4 (11DI)	39.7 (39.0)	34.4 (35.9)	37.0	37.9	41.5	39.7
CD (p = 0.05)	**0.52**	**0.47**		**2.64**	**1.73**	
Fertilizer levels						
F_1 (NPK = 100, 60, 30)	52.4 (46.3)	48.2 (43.3)	50.0	39.3	42.6	40.9
F_2 (NPK = 120, 60, 30)	55.4 (48.1)	51.6 (45.9)	53.5	36.5	38.0	37.2
F_3 (NPK = 80, 72, 36)	48.2 (43.9)	43.1 (41.0)	45.6	43.6	47.5	45.5
F_4 (NPK = 80, 84, 42)	47.2 (43.3)	43.1 (41.0)	45.1	44.7	48.8	46.7
CD (p = 0.05)	**1.24**	**1.63**		**1.48**	**1.79**	
Planting methods						
Ridge planting	48.1 (45.7)	43.4 (41.2)	45.7	38.7	42.2	40.4
Flat bed planting	52.5 (46.4)	49.1 (44.2)	50.8	43.3	46.5	44.9
CD (p = 0.05)	**2.39**	**2.58**		**2.89**	**2.20**	

Figures in parenthesis are transformed angular values
DI = days interval

resulted in significantly higher yield (43.3 and 47.1 q/ha in 2002 and 2003, respectively) than 5 and 11 days of irrigation intervals. Among the fertilizer combinations 80N+84P+42K and 80N+72P+36K kg/ha realized significant yield differences than other treatments in comparison. The application of fertilizer combination 80N+72P+36K kg/ha though at par with 80N+84P+42K kg/ha produced significantly higher yield (43.6 and 47.5 q/ha in 2002 and 2003, respectively) than 120N+60P+30K (36.5 and 38.0 q/ha in 2002 and 2003, respectively) and 100N+60P+30K kg/ha (39.3 and 42.6 q/ha in 2002 and 2003, respectively). Among the planting method the ridge planting had resulted in significantly higher yield than flat-bed method of planting.

(B) Bell Pepper cv. California Wonder

(i) **Effect on wilt incidence:** The perusal of data presented in Table 9 revealed that the varying irrigation frequencies had a significant influence on the wilt incidence of bell pepper also. The irrigation applied at an interval of 11 days recorded significantly lower wilt incidence (46.9 and 41.4 per cent in 2002 and 2003, respectively) than other irrigation frequencies in both the years of experimentation. Among the application of fertilizer combinations 80N+84P+42K kg/ha produced significantly lower wilt incidence (52.9 and 45.7% in 2002 and 2003, respectively) than other fertilizer doses. The higher dose of nitrogen (120 kg/ha) along with recommended doses of phosphorus (60 kg/ha) and potassium (30 kg/ha) recorded significantly higher wilt incidence (57.9 and 54.1% in 2002 and 2003, respectively) than the recommended dose 100N+60P+30K kg/ha. Ridge planting method had shown significantly lower wilt incidence (53.8 and 49.2% in 2002 and 2003, respectively) than flat-bed planting

Table 9 : Effect of irrigation frequencies, fertilizer levels and planting methods on wilt incidence and yield of bell pepper cv. California Wonder

Treatment	Wilt incidence (%)			Yield q / ha		
	Year 2002	Year 2003	Mean	Year 2002	Year 2003	Mean
Irrigations levels						
I_1 (5DI)	65.1 (53.7)	60.1 (50.8)	62.6	83.2	89.2	86.2
I_2 (7DI)	61.5 (51.6)	54.7 (47.6)	58.1	88.3	93.9	92.1
I_3 (9DI)	54.2 (47.4)	47.1 (43.3)	50.6	87.9	92.8	90.3
I_4 (11DI)	46.9 (43.2)	41.4 (40.0)	44.1	87.9	88.9	88.4
CD (p = 0.05)	**1.60**	**1.47**		**1.80**	**1.76**	
Fertilizer levels						
F_1 (NPK = 100, 60, 30)	57.9 (49.5)	54.1 (47.3)	56.0	84.7	89.6	87.1
F_2 (NPK = 120, 60, 30)	62.6 (52.2)	60.9 (51.2)	61.7	79.6	84.9	82.2
F_3 (NPK = 80, 72, 36)	53.6 (47.0)	46.2 (42.8)	49.9	88.4	94.5	91.4
F_4 (NPK = 80, 84, 42)	52.9 (46.6)	45.7 (42.5)	49.3	89.9	95.8	92.8
CD (p = 0.05)	**0.49**	**0.37**		**1.06**	**0.95**	
Planting methods						
Ridge planting	53.8 (47.1)	49.2 (44.5)	51.5	88.0	93.1	90.5
Flat bed planting	60.0 (50.7)	52.5 (46.4)	56.2	83.5	89.3	86.4
CD (p = 0.05)	**2.03**	**1.98**		**3.62**	**2.57**	

Figures in parenthesis are transformed angular values
DI = days interval

method (60.0 and 52.5% in 2002 and 2003, respectively) during both the cropping seasons.

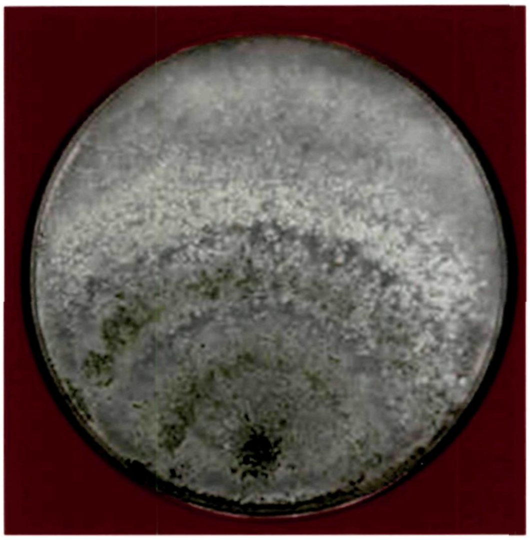
(ii) Effect on fresh yield: It is clear from the data (Table 9) that irrigation levels, fertilizer levels and planting methods influence the yield in bell pepper crop significantly. The application of irrigation at 7 day intervals though being at par with 9 day intervals resulted in significantly higher yield of bell pepper crop (88.3 and 93.9 q/ha in 2002 and 2003, respectively) than 5 and 11 day of irrigation intervals. Among the fertilizer levels 80N+84P+42K recorded significantly superior yield (89.9 and 95.8 q/ha in 2002 and 2003, respectively) than other fertilizer combinations. The minimum yield (79.6 and 84.9 q/ha in 2002 and 2003, respectively) was observed in fertilizer combination 120N+60P+30K kg/ha. The ridge planting method resulted in significantly higher yield (88.0 and 93.1 q/ha in 2002 and 2003, respectively) than flat-bed method of planting (83.5 and 89.3 q/ha in 2002 and 2003, respectively).

4.4 Biological management

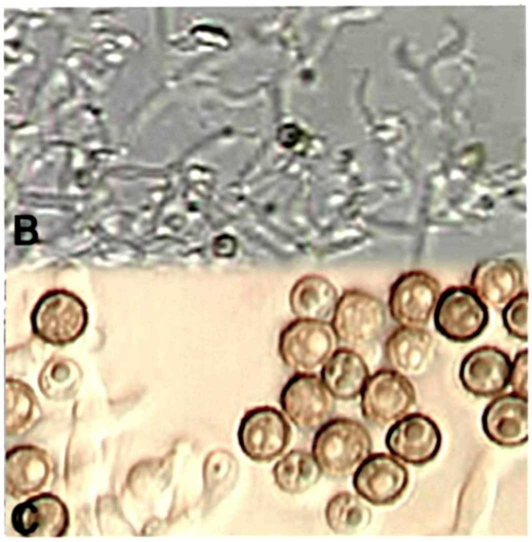
4.4.1 Isolation and identification of resident fungal antagonists

Eleven isolates of fungal antagonists belonging to *Trichoderma viride* (Tv_1 and Tv_2 from Udheywalla, Jammu; Tv_3 from Basht, Udhampur; Tv_4 from Chenani, Udhampur), *T. harzianum* (Th_1 from Anand Nagar, Jammu; Th_2 from Kud, Udhampur), *T. virens* (Gv_2 from Chenani, Udhampur; Gv_3 from Jathi, Doda), *Aspergillus niger* (An_2 from Kud, Udhampur), *A. flavus* (Af from Udheywalla, Jammu) were isolated from the soil, rhizosphere and rhizoplane of *Capsicum annuum* plants collected from different locations of Jammu division.

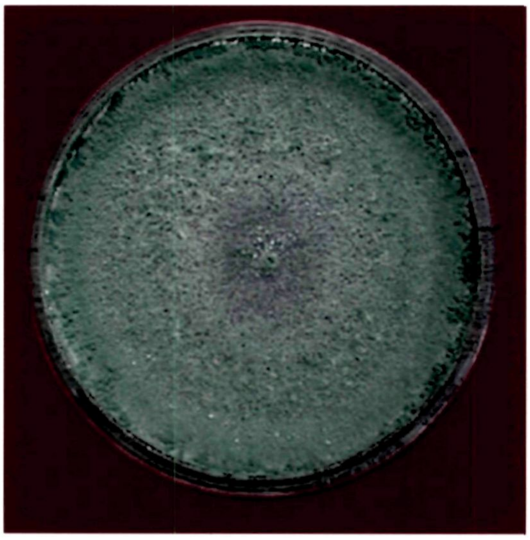
PLATE-5



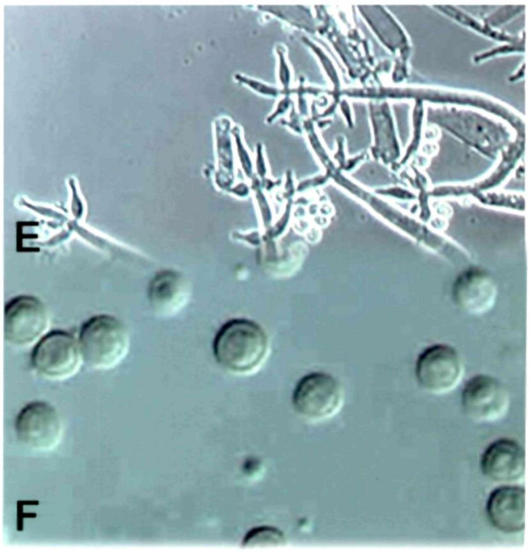
(A) *Trichoderma viride* colony growth on PDA



(B) Curved phialides of *T. viride*
(C) Conidia of *T. viride*



(D) *T. harzianum* colony growth on PDA



(E) Phialides of *T. harzianum*
(F) Conidia of *T. harzianum*

The identification of antagonist isolates was done on the basis of their cultural and morphometric characters, and by comparing them with the established keys and manuals (Rifai, 1969; Domsch *et al.*, 1980).

(a) *Trichoderma* isolates: The cultural and morphometric characters of *Trichoderma* isolates on PDA medium was observed visually and under microscope (Table 10). The colonies of *T.* viride isolates on PDA were dull green to dark green in colour (Plate 5; Fig. A), whereas *T. harzianum* and *T. virens* colonies were green to greenish white (Plate 5; Fig. D) and gray green (Plate 6; Fig. A) to yellow green in colour, respectively.

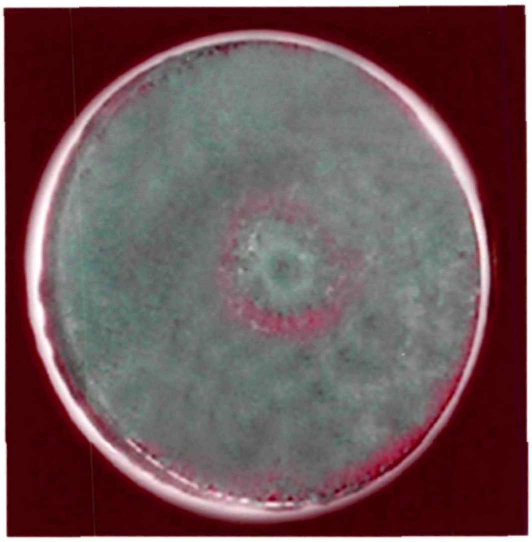
The curved phialides (Plate 5; Fig. B) arised singly from the main axis or in whorls of 2-3 at the tip of conidiophore in *T. viride* isolates, whereas, in *T. harzianum*, the phialides were formed in whorls of 2-4 and were typically flask shaped (Plate 5; Fig. E). In *T. virens* isolates, phialides (Plate 6; Fig. B) arised in closely apprised whorls of 3-6. The conidia were dry in *T. viride* and *T. harzianum*, however, in *T. virens* conidia were held in drops of liquid.

Micrometric measurements showed that the conidial size of *T. viride* isolates ranging from 3.4–5.5 × 2.7–4.5 μm. The conidial size of *T. harzianum* ranged from 2.7–4.1 × 2.2–3.6 μm, whereas, the conidial size of *T. virens* ranged from 4.2–5.0 × 3.6–4.5 μm. The conidia of *T. viride* (Plate 5; Fig. D) isolates were globose to subglobose having conspicuously warted wall, (in Tv_3), and green to gray green in colour. The conidia of *T. harzianum* (Plate 5; Fig. F) isolates were globose to subglobose (Th_1) and subglobose to ovoid (Th_2) in shape, smooth walled, and greenish white to dark green in colour. The shapes of conidia produced by *T. virens* isolates

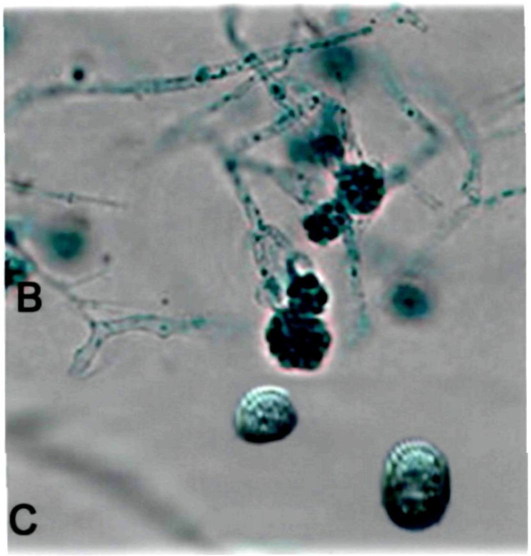
Table 10 : Cultural and morphological characters of *Trichoderma* isolates

Character	*T. viride* isolates				*T. harzianum* isolates		*T. virens* isolates		
	Tv_1	Tv_2	Tv_3	Tv_4	Th_1	Th_2	Gv_2	Gv_3	Gv_5
A. Conidia									
i) Length (µm)	3.4 – 4.1	4.2 – 4.8	4.7 – 5.5	4.5 – 4.9	2.7 – 3.2	3.5 – 4.1	4.2 – 4.8	4.7 – 5.0	4.3 – 4.9
ii) Width (µm)	2.7 – 3.2	3.3 – 3.6	4.0 – 4.5	4.0 – 4.5	2.2 – 2.7	3.0 – 3.6	3.6 – 4.0	4.1 – 4.5	3.7 – 4.4
iii) Ornamentation	Conspicuously warted	Conspicuously warted	Tuberculate	Conspicuously warted	Smooth	Smooth	Smooth	Smooth	Smooth
iv) Pigmentation	Green	Dull green	Dark green	Dirty green	Greenish white	Dark green	Green	Gray green	Yellowish green
v) Shape	Globose	Globose to subglobose	Globose to subglobose	Globose to subglobose	Globose to subglobose	Subglobose to ovoidal	Ellipsoidal	Ellipsoidal	Ellipsoidal
vi) Conidia dry or held in drops of clear liquid	Dry	Dry	Dry	Dry	Dry	Dry	Drops of clear liquid	Drops of clear liquid	Drops of clear liquid
B. Phialides	Phialides curved arised singly from the main axis		Phialides curved arised in whorls of 2-3		Arised in whorls of 2-4		Arised in closely apprised whorls of 3-6		
C. Chlamydospore									
i) Presence	Present	Present	Present	Present	Absent	Absent	Present	Present	Present
ii) Shape	Globose to subglobose				Globose to subglobose		Subglobose to ellipsoidal		
D. Culture									
i) Radius at 28±1°C after 48 hr. in darkness (mm)	20 – 28	22 – 30	16 – 25	15 – 22	30 – 40	32 – 41	25 – 35	26 – 36	25 – 35
ii) Coconut odour	Present	Present	No odour detected	No odour detected	No odour detected	No odour detected	No odour detected	No odour detected	No odour detected
iii) Pustules	Formed on PDA, 0.5 – 1.0 mm diameter, hemispherical, uniformly cottony and difficult to remove from the agar				Minute pustules formed in older cultures		Not formed on PDA, but conidiophores formed in fascicles over a wide area		

PLATE-6

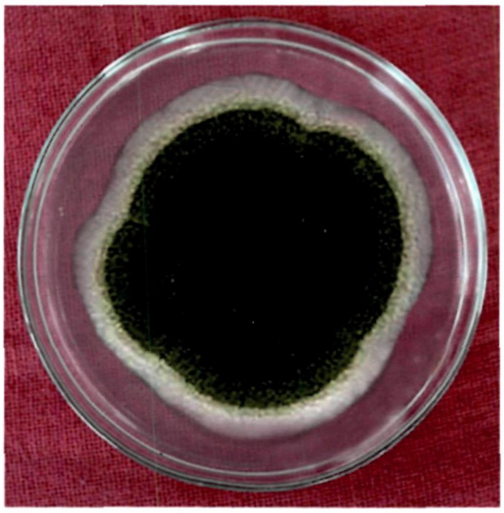


(A) *T. virens* colony growth on PDA

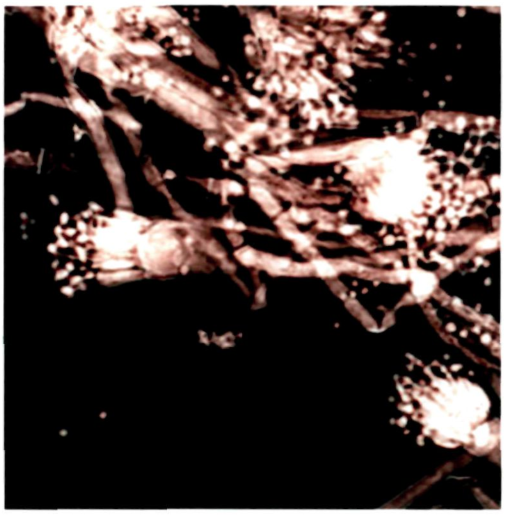


(B) Phialides of T. virens

(C) Conidia of *T. virens*



(D) *Aspergillus flavus* colony growth on PDA



(E) *A. flavus* conidia arising in chains from phialides

(Plate 6; Fig. C) were ellipsoidal, green, gray green with yellowish green pigmentation and smooth walled.

The isolates of *T. harzianum* grew rapidly when compared to the isolates of *T. viride* and *T. virens*. The linear growth of *T. viride* isolates on PDA after 48 hours at 28±2^{0}C ranged from 15 to 30 mm, whereas, in *T. harzianum* isolates it was from 30 to 40 mm and in *T. virens* isolates from 25 to 30 mm.

The coconut odour was observed in Tv_1 and Tv_2 isolates of *T. viride*. However, no such odour was detected in other isolates of *T. viride* and the isolates of *T. harzianum* or *T. virens*.

The pustules formed on PDA media in all *T. viride* isolates were 0.5–1.0 mm in diameter, hemispherical, uniformly cottony and difficult to remove from the medium. However, minute pustules were formed in older cultures of *T. harzianum* isolates and no pustule formation was observed in *T. virens* isolates.

(b) *Aspergillus* isolates

(i) *Aspergillus flavus* (Af): Colonies on PDA (Plate 6; Fig. D) were lime green in colour, slightly floccose at the margins of the colony due to growth of sterile hyphae. Conidiophores mostly arised from submerged hyphae, 400-1000 µm long, 5-15 µm wide, with walls rough in appearance, broadening upwards and gradually enlarging into globose vesicles, 10-30 µm in diameter. Phialides were borne directly on the vesicle. Conidia pyriform to almost globose in shape, yellowish green, 3 to 4 µm in diameter and form long chains (Plate 6; Fig. E). Sclerotia formed were white first, which later turned to brown in colour. Sclerotia were hard and produced abundantly.

(ii) ***Aspergillus*** **niger (An_2):** Colonies black in colour, grew with abundant submerged mycelium (Plate 7; Fig. A). The mycelia were colourless. Aerial hyphae were scanty. Conidiophores arised directly from the substratum having thick smooth walls, measuring 170–360 × 5–10 µm in size. Vesicles were globose in shape, thick walled 20–50 µm in diameter. Phialides measuring 5–10 × 2–3 µm, arised circumferentially and black conidia obscure the vesicle (Plate 7; Fig. B). Conidia were globose, rough mostly 2.5–5.0 µm in diameter. Superficial sclerotia were regularly formed which were globose in shape.

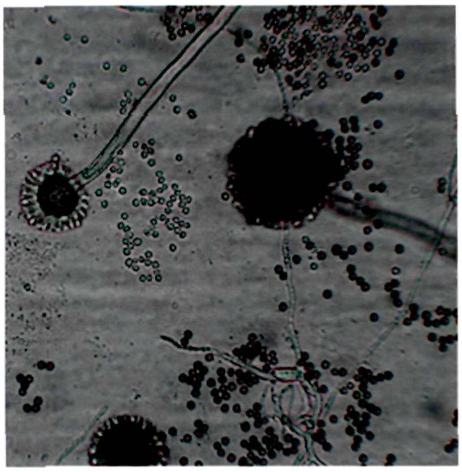
The fungal antagonists *viz.*, *Chaetomium globosum* (Plate 7; Fig. C), *Aspergillus tereus* (Plate 7; Fig. D) and *Trichothecium roseum* (Plate 7; Fig. E) were obtained from Sher-e-Kashmir University of Agricultural Sciences and Technology, Kashmir, Shalimar.

4.4.2 ***In vitro*** **evaluation of antagonists against the test pathogens**

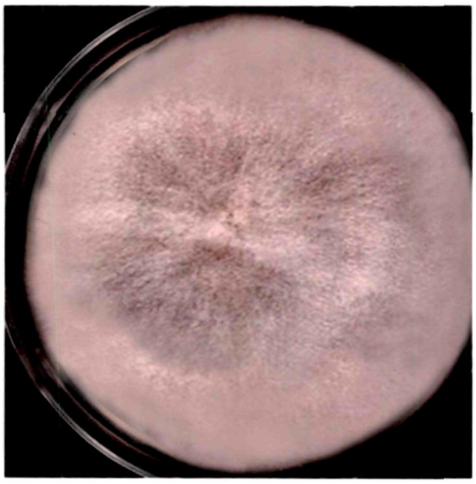
(a) ***Fusarium oxysporum*:** The results (Table 11) showed that two isolates of *T. viride* (Tv_2 and Tv_5), and one isolate of *T. harzianum* (Th_2) were most effective against *F. oxysporum* and overgrew 75 per cent of pathogen surface within seven days of inoculation (Plate 8; Fig. A). These isolates were categorized in class 2 as per Bell's scale. The antagonist isolates Th_1, Gv_5 (*Trichoderma virens*) Af (*Aspergillus flavus*) and Cg (*Chaetomium globosum*) also overgrew pathogen colony and covered 50 per cent of the pathogen surface up to 7 days of inoculation. The fungal isolates Tv_1, Tv_7, Gv_4, At (*A. tereus*) and Tr (*Trichothecium roseum*) and pathogen were locked at the point of contact and were categorized in class 4 according to Bell's scale. Some isolates produced zone of inhibition with the pathogen and could not be categorized according to Bell's scale. The maximum zone of inhibition was formed by Gv_3 (5.4 mm) (Plate 8;

PLATE-7

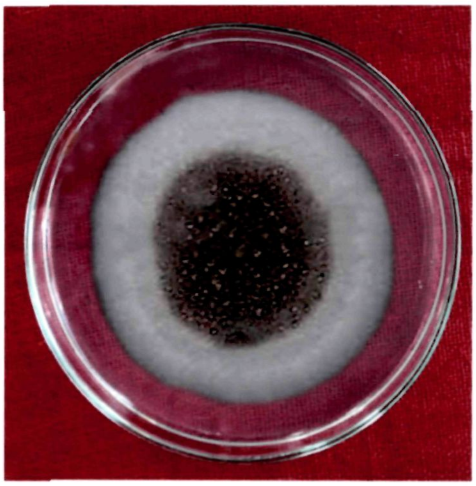
(A) *A. niger* colony growth on PDA



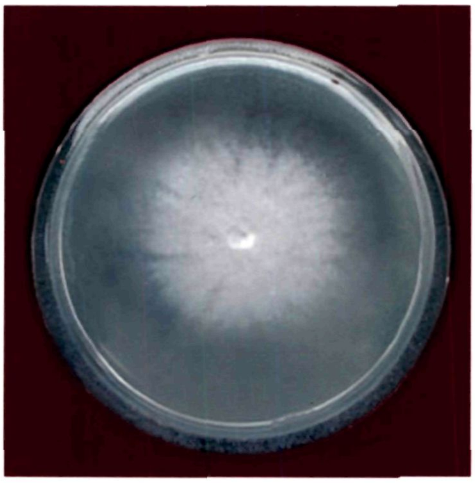
(B) Sporophores, Phialides and conidia of *A. niger*



(D) *Chaetomium globosum* colony growth on PDA



(C) *A. tereus* colony growth on PDA



(E) *Trichothecium roseum* colony growth on PDA

Table 11 : ***In-vitro* screening of fungal antagonists against *Fusarium oxysporum***

Isolates of fungal antagonists		Antagonistic reaction (Bell's Scale) (Days after inoculation)						Inhibition zone (mm)
		4	5	6	7	8	9	
Tv_1	(Udheywalla)	4	4	4	4	4	4	–
Tv_2	(Udheywalla)	4	4	3	2	2	2	–
Tv_3	(Basht)	–	–	–	–	–	–	1.3
Tv_4	(Chenani)	4	4	3	3	3	3	–
Tv_5	(Bangalore)	4	4	3	2	2	2	–
Tv_6	(Srinagar)	–	–	–	–	–	–	2.0
Tv_7	(IARI, New Delhi)	4	4	4	4	4	4	–
Tv_8	(RRL, Jammu)	–	–	–	–	–	–	1.1
Th_1	(Anand Nagar)	4	4	4	3	3	3	–
Th_2	(Kud)	3	3	2	2	2	2	–
Th_3	(Srinagar)	4	4	4	4	4	4	–
Th_4	(Bangalore)	–	–	–	–	–	–	4.7
Gv_1	(Bangalore)	–	–	–	–	–	–	1.4
Gv_2	(Chenani)	–	–	–	–	–	–	2.1
Gv_3	(Jathi)	–	–	–	–	–	–	5.4
Gv_4	(Srinagar)	4	4	4	4	4	4	–
Gv_5	(Udheywalla)	4	3	3	3	3	3	–
		Antagonistic reaction (Bell's Scale) (Days after inoculation)						
		8	**9**	**10**	**11**	**12**	**13**	
Af	(Udheywalla)	4	4	4	3	3	3	–
At	(Srinagar)	4	4	4	4	4	4	–
An_1	(Srinagar)	–	–	–	–	–	–	1.0
An_2	(Kud)	–	–	–	–	–	–	1.2
Cg	(Srinagar)	4	4	4	3	3	3	–
Tr	(Srinagar)	4	4	4	4	4	4	–

Tv = *Trichoderma viride* Th = *Trichoderma harzianum* Gv = *Trichoderma virens*
Af = *Aspergillus flavus* At = *Aspergillus tereus* An = *Aspergillus niger*
Cg = *Chaetomium globosum* Tr = *Trichothecium roseum*

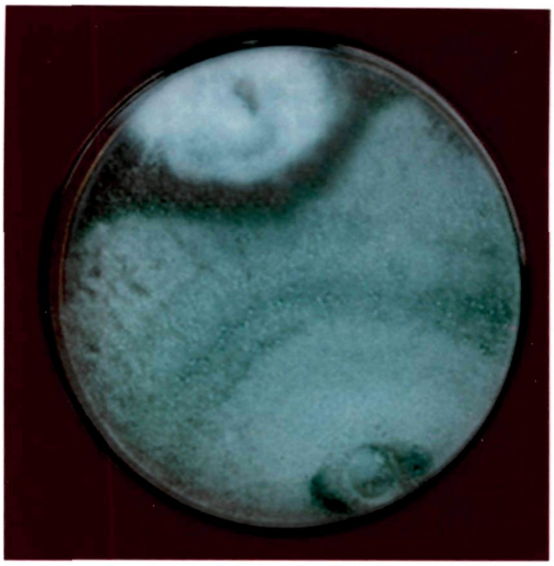
Fig. B) followed by Th_4 (4.7 mm). The minimum zone of inhibition was produced by An_1 (1.0 mm) followed by Tv_8 (1.1 mm) and An_2 (1.2 mm).

(b) ***Rhizoctonia solani*****:** The data presented in Table 12 revealed that Tv_2 and Th_2 isolates were most effective against *R. solani* as complete overgrowth of the pathogen was observed 7^{th} and 8^{th} days after inoculation, respectively, and these isolates were categorized in class 1 according to Bell's scale. Tv_4, Tv_5 and Af overgrew up to 75 per cent of pathogen surface and were categorized in class 2 of Bell's scale. The fungal isolates *viz.*, Tv_1, Th_1, Gv_4, Gv_5 and Cg covered only 50 per cent of the pathogen surface (Plate 8; Fig. C). The maximum zone of inhibition (5.9 mm) was formed by Gv_3 isolate followed by Th_4 (4.8 mm) and Gv_2 (2.7 mm). The least zone of inhibition was formed in case of An_2 (1.2 mm).

(c) ***Sclerotium rolfsii*****:** The perusal of data presented in Table 13 indicate that the fungal antagonists which showed effectiveness against *F. oxysporum* and *R. solani* were also effective against *S. rolfsii*. None of the fungal isolates was able to completely overgrow the pathogen surface although the most effective antagonists *viz.*, Tv_1, Tv_2, Tv_5, Th_2, Gv_4, Gv_5 and Af overgrew 75 per cent of pathogen surface by 9^{th} day of inoculation (Plate 8; Fig. D). These isolates were categorized in class 2 as per Bell's scale. The isolates Tv_4 and Th_1 overgrew 50 per cent of the pathogen surface and were categorized in class 3 of Bell's scale. The other isolates *viz.*, Tv_7, Th_3, At, Cg and Tr were not effective as they were locked at the point of contact with the pathogen. A number of isolates formed inhibition zones of varied dimensions, maximum being formed by Gv_3 (5.9 mm), followed by Th_4 (4.8 mm) and Gv_2 (2.7 mm). The isolates

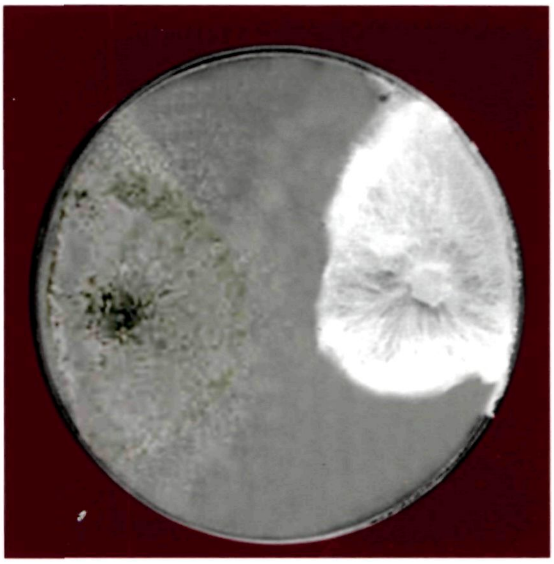
PLATE-8

(A) Overgrowth of *T. viride* on *F. oxysporum*

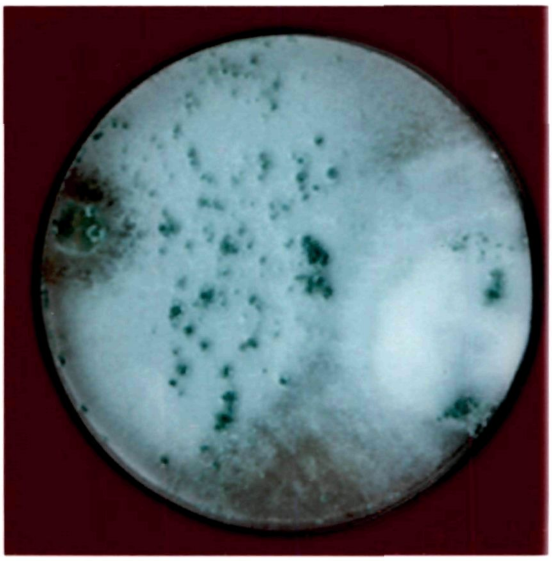


(B) Inhibition zone formation by *T. virens* against *F. oxysporum*

(C) Overgrowth of *T. harzianum* on *R. solani*



(D) Overgrowth of *T. harzianum* on *S. rolfsii*



(E) Overgrowth of *T. virens* on P. capsici

Table 12 : ***In-vitro* screening of fungal antagonists against *Rhizoctonia solani***

Isolates of fungal antagonists		Antagonistic reaction (Bell's Scale) (Days after inoculation)						Inhibition zone (mm)
		4	5	6	7	8	9	
Tv$_1$	(Udheywalla)	4	4	4	3	3	3	–
Tv$_2$	(Udheywalla)	4	3	2	1	1	1	–
Tv$_3$	(Basht)	–	–	–	–	–	–	1.5
Tv$_4$	(Chenani)	4	3	3	2	2	2	–
Tv$_5$	(Bangalore)	3	3	3	2	2	2	–
Tv$_6$	(Srinagar)	–	–	–	–	–	–	2.4
Tv$_7$	(IARI, New Delhi)	4	4	4	4	4	4	–
Tv$_8$	(RRL, Jammu)	–	–	–	–	–	–	1.3
Th$_1$	(Anand Nagar)	4	4	4	3	3	3	–
Th$_2$	(Kud)	3	3	2	2	1	1	–
Th$_3$	(Srinagar)	4	4	4	4	4	4	–
Th$_4$	(Bangalore)	–	–	–	–	–	–	4.8
Gv$_1$	(Bangalore)	–	–	–	–	–	–	1.5
Gv$_2$	(Chenani)	–	–	–	–	–	–	2.7
Gv$_3$	(Jathi)	–	–	–	–	–	–	5.9
Gv$_4$	(Srinagar)	4	4	4	3	3	3	–
Gv$_5$	(Udheywalla)	4	4	3	3	3	3	–
Af	(Udheywalla)	4	3	3	3	2	2	–
At	(Srinagar)	4	4	4	4	4	4	–
An$_1$	(Srinagar)	–	–	–	–	–	–	1.3
An$_2$	(Kud)	–	–	–	–	–	–	1.2
Cg	(Srinagar)	4	4	4	3	3	3	–
Tr	(Srinagar)	4	4	4	4	4	4	–

Tv = *Trichoderma viride* Th = *Trichoderma harzianum* Gv = *Trichoderma virens*
Af = *Aspergillus flavus* At = *Aspergillus tereus* An = *Aspergillus niger*
Cg = *Chaetomium globosum* Tr = *Trichothecium roseum*

Table 13 : *In-vitro* screening of fungal antagonists against *Sclerotium rolfsii*

Isolates of fungal antagonists		Antagonistic reaction (Bell's Scale) (Days after inoculation)						Inhibition zone (mm)
		4	5	6	7	8	9	
Tv_1	(Udheywalla)	4	4	3	3	2	2	–
Tv_2	(Udheywalla)	3	3	3	2	2	2	–
Tv_3	(Basht)	–	–	–	–	–	–	1.0
Tv_4	(Chenani)	4	4	3	3	3	3	–
Tv_5	(Bangalore)	3	3	3	2	2	2	–
Tv_6	(Srinagar)	–	–	–	–	–	–	2.1
Tv_7	(IARI, New Delhi)	4	4	4	4	4	4	–
Tv_8	(RRL, Jammu)	–	–	–	–	–	–	1.3
Th_1	(Anand Nagar)	4	4	4	3	3	3	–
Th_2	(Kud)	3	3	3	2	2	2	–
Th_3	(Srinagar)	4	4	4	4	4	4	–
Th_4	(Bangalore)	–	–	–	–	–	–	4.8
Gv_1	(Bangalore)	–	–	–	–	–	–	1.5
Gv_2	(Chenani)	–	–	–	–	–	–	2.7
Gv_3	(Jathi)	–	–	–	–	–	–	5.9
Gv_4	(Srinagar)	4	4	3	3	2	2	–
Gv_5	(Udheywalla)	4	4	3	3	2	2	–
Af	(Udheywalla)	4	3	3	2	2	2	–
At	(Srinagar)	4	4	4	4	4	4	–
An_1	(Srinagar)	–	–	–	–	–	–	1.2
An_2	(Kud)	–	–	–	–	–	–	0.8
Cg	(Srinagar)	4	4	4	4	4	4	–
Tr	(Srinagar)	4	4	4	4	4	4	–

Tv = *Trichoderma viride* Th = *Trichoderma harzianum* Gv = *Trichoderma virens*
Af = *Aspergillus flavus* At = *Aspergillus tereus* An = *Aspergillus niger*
Cg = *Chaetomium globosum* Tr = *Trichothecium roseum*

Tv_6, Tv_8 and An_1 produced 2.1, 1.3 and 1.2 mm zones of inhibition, respectively. The least zone of inhibition was formed by An_2 (0.8 mm).

(d) ***Phytophthora capsici***: The results presented in Table 14 indicate that the antagonist isolates *viz.*, Tv_2, Tv_5, Th_2 and Af were most effective against *P. capsici* as these antagonists overgrew 75 per cent of pathogen surface and were categorized in Class 2 as per Bell's scale (Plate 8; Fig. E). The isolates *viz.*, Tv_4, Tv_7 Th_1, Gv_4 and Gv_5 overgrew 50 per cent of pathogen surface by the 9^{th} day of inoculation and were categorized in class 3 as per Bell's scale. Some isolates *viz.*, Tv_1, Th_3, At and Tr were locked at the point of contact with the pathogen. Gv_3 produced maximum zone of inhibition (5.1 mm), followed by Th_4 (4.4 mm) and Gv_2 (2.5 mm). Tv_3 produced the minimum zone of inhibition (0.8 mm).

4.4.3 Glasshouse studies

Five isolates of fungal antagonists *viz., Trichoderma harzianum* (Th_2–Kud isolate, Th_4–Bangalore isolate), *T. viride* (Tv_2–Udheywalla isolate, Tv_5–Bangalore isolate) and *T. virens* (Gv_3–Jathi isolate), found highly effective against all the wilt complex pathogens under *in-vitro* conditions were applied as seed treatment, seedling dip, soil treatment and seed+soil treatment under glasshouse conditions, to observe their effectiveness on seedling emergence and wilt incidence on chillies cv. Pusa Jawala and bell pepper cv. California Wonder.

4.4.3.1 Effect of antagonists on seedling emergence of *Capsicum annuum*

(A) Chilli cv. Pusa Jawala

(a) Seed treatment: The results presented in Table 15 revealed that the seed treatment with Tv_2 and Gv_3 significantly increased seedling emergence of chilli as

Table 14 : ***In-vitro* screening of fungal antagonists against *Phytophthora capsici***

Isolates of fungal antagonists		Antagonistic reaction (Bell's Scale) (Days after inoculation)						Inhibition zone (mm)
		4	**5**	**6**	**7**	**8**	**9**	
Tv_1	(Udheywalla)	4	4	4	4	4	4	–
Tv_2	(Udheywalla)	3	3	3	2	2	2	–
Tv_3	(Basht)	–	–	–	–	–	–	0.8
Tv_4	(Chenani)	4	3	3	3	3	3	–
Tv_5	(Bangalore)	4	4	3	3	2	2	–
Tv_6	(Srinagar)	–	–	–	–	–	–	2.1
Tv_7	(IARI, New Delhi)	4	4	3	3	3	3	–
Tv_8	(RRL, Jammu)	–	–	–	–	–	–	1.2
Th_1	(Anand Nagar)	4	4	4	3	3	3	–
Th_2	(Kud)	3	3	2	2	2	2	–
Th_3	(Srinagar)	4	4	4	4	4	4	–
Th_4	(Bangalore)	–	–	–	–	–	–	4.4
Gv_1	(Bangalore)	–	–	–	–	–	–	1.4
Gv_2	(Chenani)	–	–	–	–	–	–	2.5
Gv_3	(Jathi)	–	–	–	–	–	–	5.1
Gv_4	(Srinagar)	4	4	4	3	3	3	–
Gv_5	(Udheywalla)	4	3	3	2	2	2	–
		Antagonistic reaction (Bell's Scale) (Days after inoculation)						
		8	**9**	**10**	**11**	**12**	**13**	
Af	(Udheywalla)	4	4	4	3	3	3	–
At	(Srinagar)	4	4	4	4	4	4	–
An_1	(Srinagar)	–	–	–	–	–	–	1.0
An_2	(Kud)	–	–	–	–	–	–	1.3
Cg	(Srinagar)	4	4	4	4	4	4	–
Tr	(Srinagar)	4	4	4	4	4	4	–

Tv = *Trichoderma viride* Th = *Trichoderma harzianum* Gv = *Trichoderma virens*
Af = *Aspergillus flavus* At = *Aspergillus tereus* An = *Aspergillus niger*
Cg = *Chaetomium globosum* Tr = *Trichothecium roseum*

Table 15 : Effect of fungal antagonists on seedling emergence of *Capsicum annuum* under glasshouse conditions

Treatment	Seedling emergence (%)							
	Pusa Jawala (chilli)				California Wonder (bell pepper)			
	2001	2002	Pooled	Increase over check	2001	2002	Pooled	Increase over check
Seed Treatment								
Th_2 (*T. harzianum*)	58.0 (49.0)	57.1 (49.0)	57.5 (49.3)	8.0	62.6 (52.2)	62.6 (52.2)	62.6 (52.2)	14.4
Th_4 (*T. harzianum*)	58.0 (49.6)	56.2 (48.5)	57.1 (49.0)	7.3	56.2 (48.5)	56.2 (48.5)	56.2 (48.5)	2.7
Tv_2 (*T. viride)*	64.7 (53.5)	63.9 (53.0)	64.2 (53.2)	20.6	57.1 (49.0)	56.2 (48.5)	56.6 (48.7)	3.4
Tv_5 (*T. viride*)	54.2 (47.4)	54.2 (47.4)	54.2 (47.4)	1.8	55.2 (47.9)	54.2 (47.4)	54.7 (47.6)	0.0
Gv_3 (T. virens)	63.4 (52.7)	62.6 (52.2)	63.0 (52.5)	18.4	62.6 (52.2)	64.7 (53.5)	63.6 (52.8)	16.2
Check	54.2 (47.4)	52.3 (46.3)	53.2 (46.8)	–	55.2 (47.9)	54.2 (47.4)	54.7 (47.6)	–
CD (p = 0.05)	**3.38**	**3.46**	**3.31**		**2.92**	**3.11**	**2.73**	
Soil Treatment								
Th_2 (*T. harzianum*)	56.2 (48.5)	56.2 (48.5)	56.2 (48.5)	5.6	60.9 (51.2)	61.9 (51.8)	61.4 (51.5)	12.9
Th_4 (*T. harzianum*)	55.2 (47.9)	55.2 (47.9)	55.2 (47.9)	3.7	55.2 (47.9)	54.2 (47.4)	54.7 (47.6)	0.0
Tv_2 (*T. viride)*	61.9 (51.8)	60.9 (51.2)	61.4 (51.5)	15.4	55.2 (47.9)	55.2 (47.9)	55.2 (47.9)	0.9
Tv_5 (*T. viride*)	54.7 (47.4)	54.7 (47.4)	54.7 (47.4)	2.8	55.2 (47.9)	54.2 (47.4)	54.7 (47.6)	0.0
Gv_3 (T. virens)	60.9 (51.2)	60.9 (51.2)	60.9 (51.2)	14.4	59.0 (50.1)	59.0 (50.1)	59.0 (50.1)	7.8
Check	54.7 (47.4)	52.3 (46.3)	53.2 (46.8)	–	55.2 (47.9)	54.2 (47.4)	54.7 (47.6)	–
CD (p = 0.05)	**3.05**	**3.02**	**2.80**		**1.91**	**1.95**	**1.56**	
Seed + Soil Treatment								
Th_2 (*T. harzianum*)	60.9 (49.0)	60.9 (47.9)	60.9 (51.2)	14.4	65.7 (54.1)	65.7 (54.1)	65.7 (54.1)	20.1
Th_4 (*T. harzianum*)	59.0 (50.1)	59.0 (50.1)	59.0 (50.1)	10.9	58.0 (49.6)	57.1 (49.0)	57.5 (49.3)	5.1
Tv_2 (*T. viride)*	66.6 (51.2)	64.7 (51.2)	65.6 (54.0)	23.3	59.0 (50.1)	58.0 (49.6)	58.5 (49.8)	6.9
Tv_5 (*T. viride*)	58.0 (54.6)	55.2 (53.5)	56.6 (48.7)	6.3	58.0 (49.6)	57.1 (49.0)	57.5 (49.3)	5.1
Gv_3 (T. virens)	67.6 (55.3)	66.6 (54.6)	67.1 (54.9)	26.1	64.7 (53.5)	64.7 (53.5)	64.7 (53.5)	18.2
Check	54.2 (47.4)	52.3 (46.3)	53.2 (46.8)	–	55.2 (47.9)	54.2 (47.4)	54.7 (47.6)	–
CD (p = 0.05)	**3.05**	**3.06**	**2.87**		**1.60**	**1.82**	**1.46**	

Figures in parenthesis are transformed angular values compared to other treatments. The data obtained in the year 2001 indicated that seedling emergence observed in Tv_2 (64.7%) and Gv_3 (63.4%) were significantly superior over other treatments, whereas, Th_2 and Th_4 were also effective with 58.0 per cent seedling emergence in each treatment, compared to 54.2% in check. In the year 2002, highest seedling emergence of 63.9 per cent was recorded in treatment Tv_2, which was followed by Gv_3 (62.6%), Th_2 (57.1%) and Th_4 (56.2%) recording significantly higher seedling emergence than check (52.3%). No significant difference was observed between the treatment Tv_5 and check.

The pooled data of the years 2001 and 2002 indicate that all the antagonists were effective in increasing the seedling emergence over check except Tv_5. The maximum seedling emergence (64.2%) was obtained by Tv_2 which was at par with Gv_3 (63.0%). These treatments recorded 20.6 and 18.4 per cent increase in seedling emergence over check. Th_2 and Th_4 were also effective as 57.5 and 57.1 per cent seedling emergence with 8.0 and 7.3 per cent increase in emergence over check was observed in these treatments.

(b) Soil treatment: The data presented in the Table 15 indicate that Tv_2 and Gv_3 were also the most effective antagonists when applied as soil treatments, though lesser seedling emergence was recorded as compared to seed treatment. The seedling emergence of 61.9 and 60.9 per cent were observed with Tv_2 and Gv_3, respectively. The other treatments, Th_2, Th_4 and Tv_5 recorded 56.2, 55.2 and 54.7 per cent seedling emergence, respectively, which were statistically at par with 54.7 per cent seedling emergence observed in check. In the year 2002, similar observations were recorded except in treatment Tv_2 which recorded slightly lesser (60.9%) seedling emergence.

The pooled data of the year 2001 and 2002 indicate that Tv_2 and Gv_3 recorded higher seedling emergence of 61.4 and 60.9 per cent with 15.4 and 14.4 per cent increase in seedling emergence, respectively, over check. Th_2 recorded 56.2 per cent seedling emergence, followed by 55.2 and 54.7 per cent emergence observed in Th_4 and Tv_5 respectively. The increase of seedling emergence of 5.6, 3.7 and 2.8 per cent over check was observed in the soil treatment with Th_2, Th_4 and Tv_5, respectively.

(c) Seed + soil treatment: The perusal of data in Table 15 revealed that in the year 2001, when the antagonists were applied as seed and soil treatment, the maximum seedling emergence of 67.6 per cent was observed in Gv_3, followed by Tv_2 (66.6%). The seedling emergence of 60.9, 59.0 and 58.0 per cent was observed in Th_2, Th_4 and Tv_5 respectively, all these treatments were significantly superior to check (54.2%). The data for the year 2002 also revealed that the significantly higher seedling emergence of 66.6 and 64.7 per cent was recorded with Gv_3 and Tv_2, respectively, compared to other treatments. Th_2 and Th_4 recorded 60.9 and 59.0 per cent seedling emergence, respectively, which were significantly superior over check. However, treatment Tv_5 resulted in 55.2 per cent seedling emergence, which was statistically at par with check.

The pooled data of years 2001 and 2002 indicate that the maximum seedling emergence (67.1%) with 26.1 per cent increase over check was obtained with Gv_3. The seedling emergence recorded in Tv_2, Th_2, Th_4 and Tv_5 was 65.6, 60.9, 59.0 and 56.6 per cent, having an increase of 23.3, 14.4, 10.9 and 6.3 per cent in seedling emergence, respectively, over check.

The data presented in the Table 16 further indicated that application of the selected antagonists as seed + soil treatments resulted in better seedling emergence than

Table 16 : Effect of fungal antagonists and their methods of application on seedling emergence of *Capsicum annuum* under glasshouse conditions

Antagonist	**Seedling emergence (%)**	
	Chillies cv. Pusa Jawala	**Bell pepper cv. California Wonder**
Th_2	58.2	63.2
Th_4	57.1	56.1
Tv_2	63.7	56.7
Tv_5	55.1	55.6
Gv_3	63.6	62.4
Check	53.2	54.7
CD at 0.05%	2.35	1.86
Methods of application		
Seed treatment	58.2	58.0
Soil treatment	56.8	56.5
Seed + soil treatment	60.3	59.7
CD at 0.05%	**0.96**	**0.81**

when applied either as seed treatments or soil treatments alone. The average seedling emergence in seed + soil treatment of antagonists resulted in 60.3 per cent seedling emergence which was significantly better than 58.2 and 56.8 per cent emergence in seed and soil treatments, respectively. Seed treatment with antagonists was significantly superior over soil treatment. The treatment with Tv_2 and Gv_3 were superior over others as the average seedling emergence observed in all three methods *viz.*, seed treatment, soil treatment and seed + soil treatment was 63.7 and 63.6 per cent, respectively compared to 53.2 per cent in check. Th_2, Th_4 were also significantly superior over check, however, Tv_5 recorded 55.1 per cent seedling emergence which was statistically at par with check.

(B) Bell pepper cv. California Wonder

(a) Seed treatment: The data on the effect of seed treatment with the selected antagonists on seedling emergence of bell pepper presented in Table 15 revealed that most of the antagonists increased seedling emergence over untreated check. In the year 2001, the highest seedling emergence of 62.6 per cent was recorded in the treatment with Th_2 and Gv_3, which were significantly superior to other treatments. These were followed by 57.1 per cent emergence in Tv_2 treatment. Treatment Th_4 recorded 56.2 per cent seedling emergence and was at par with Tv_2, however, it was also statistically at par with check where 55.2 per cent seedling emergence was recorded. Per cent seedling emergence observed in Tv_5 treatment and the check was similar. In the year 2002, the data indicated that Th_2 and Gv_3 were again the superior treatments recording seedling emergence of 64.7 and 62.6 per cent, respectively, which were significantly superior to other treatments. Th_4 and Tv_2, each recording 56.2 per cent seedling emergence was statistically at par with 54.2 per cent emergence observed each with Tv_5 and check.

The pooled data of 2001 and 2002 indicated that the seed treatment with Gv_3 and Th_2 recorded highest seedling emergence, which amounted to 16.2 and 14.4 per cent increase in seedling emergence over check, respectively. This was followed by 3.4 and 2.7 per cent increase in seedling emergence observed in Tv_2 and Th_4 treatments. The treatment with Tv_5 resulted in no increase in seedling emergence over check (54.7%).

(b) Soil treatment: The data presented in Table 15 revealed that in the year 2001, the maximum seedling emergence of 60.9 per cent was recorded when Th_2 was applied as soil treatment, this was followed by 59.0 per cent emergence observed in Gv_3. Both the treatments were superior to other treatments. The treatments with Th_4, Tv_2 and Tv_5 were not effective in increasing the seedling emergence and were at par with check (55.2%). In the year 2002, maximum seedling emergence was recorded in Th_2 (61.9%), which was significantly superior to other treatments except Gv_3 (59.0 %), both being at par and significantly higher than Th_4, Tv_5 and check.

The pooled data of 2001 and 2002 showed that the highest seedling emergence (61.4%) was observed in treatment Th_2, followed by Gv_3 (59.0%), resulting in 12.9 and 7.8 per cent increase in seedling emergence over check, respectively. The treatment Tv_2 recorded 55.2 per cent seedling emergence and 0.9% increase in seedling emergence over check. The treatment was statistically at par with 54.7 per cent emergence observed in check. No increase in seedling emergence over check was observed when fungal antagonists Th_4 and Tv_5 were applied in the soil.

(c) Seed + soil treatment: The perusal of data in Table 15 revealed that all the fungal antagonists had significantly increased the seedling emergence over check when applied as seed + soil treatment. The data pertaining the year 2001 indicate that the application of Th_2 and Gv_3 resulted in highest seedling emergence of 65.7 and 64.7 per cent, respectively. The treatment Tv_2, Th_4 and Tv_5 recorded 59.0, 58.0 and 58.0 per cent seedling emergence, respectively, which were statistically at par with each other but significantly higher than 55.2 per cent emergence observed in check. In the year 2002 also similar results were observed, where maximum seedling emergence was observed in Th_2 (65.7%), followed by Gv_3 (64.7%). The seedling emergence of 58.0, 57.1 and 57.1 per cent was recorded in treatment Tv_2, Th_4 and Tv_5, respectively. These treatments were significantly superior over check (54.2%).

The pooled data of the years 2001 and 2002 indicate that highest seedling emergence was observed in Th_2 (65.7%), followed by Gv_3 (64.7%) with an increase of 20.1 and 18.2 per cent seedling emergence over check, respectively. The treatment Tv_2, Th_4 and Tv_5 recorded 58.5, 57.5 and 57.5 per cent seedling emergence, with increase in emergence by 6.9, 5.1 and 5.1 per cent respectively, over check. In check, 54.7 per cent emergence was observed.

The data presented in Table 16 revealed that Th_2 was most effective antagonist as it recorded the highest average seedling emergence (63.2%) in all the methods tested *viz.*, seed treatment, soil treatment and seed + soil treatment. The next best treatment was Gv_3 which recorded 62.4 per cent seedling emergence and was statistically at par with Th_2 and significantly superior over check (54.7%). No significant difference between Th_4, Th_5 and check was observed. However, Tv_5 recorded 56.7 per cent seedling emergence, which was significantly higher than check. The data further indicate that application of antagonist as seed + soil treatment resulted in significantly higher seedling emergence (59.7%) than when applied either as seed treatment (58.0%) or as soil treatment (56.5%).

4.4.3.2 Effect of fungal antagonists on wilt complex disease of *Capsicum annuum*

(A) Chilli cv. Pusa Jawala

The effect of selected isolates of fungal antagonists (Tv_2, Tv_5, Th_2 Th_4 and Gv_3) as seed + seedling, soil and seed + seedling + soil treatments on the wilt incidence of chilli were studied at 40, 60, 80 and 100 days after transplanting (DAT) in pots under glasshouse conditions. The data presented in Table 17 revealed that antagonists were more effective in reducing the disease when applied as seed + seedling + soil than individual seed + seedling or soil treatment. In the year 2001, observations recorded at 40 DAT indicate that in seed + seedling treatment and soil treatment with Gv_3 resulted in 25.0 and 33.3 per cent wilt incidence, which were statistically superior to all other antagonist treatments except Tv_2. However, with Gv_3 the wilt incidence was further reduced to 16.6 per cent when seed + seedling treatment was combined with soil treatment. With the combination of all the three types of applications, treatment with Tv_2 resulting in 25.0 per cent disease incidence, were superior to Th_2, Th_4, Tv_5 and check. At 60 DAT, Gv_3 again remained superior to other treatments when applied as seed + seedling treatment or soil treatment with 33.3 and 41.6 per cent wilt incidence, respectively, followed by Tv_2 with 41.6 and 50.0 per cent incidence, respectively. All other treatments except Th_2 recorded 100 per cent wilt incidence in all the three types of applications. Gv_3 isolate with 25.0 per cent disease incidence was most efficacious

Table 17 : Effect of fungal antagonists on wilt incidence in chilli cv. Pusa Jawala under glass house conditions

Antagonist	Per cent wilt incidence (Days after transplanting)											
	40			60			80			100		
	2001	2002	Pooled	2001*	2002*	Pooled*	2001*	2002*	Pooled*	2001*	2002*	Pooled*
Seed + Seedling Treatment												
Gv_3	25.0 (30.0)	25.0 (30.0)	25.0 (30.0)	33.3 (35.2)	33.3 (35.2)	33.3 (35.2)	41.6 (40.1)	50.0 (45.0)	45.8 (42.5)	50.0 (45.0)	50.0 (45.0)	50.0 (45.0)
Th_2	50.0 (45.0)	58.3 (49.7)	54.1 (47.3)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Tv_2	25.0 (30.0)	25.0 (30.0)	29.1 (32.6)	41.6 (40.1)	50.0 (45.0)	45.8 (42.5)	50.0 (45.0)	50.0 (45.0)	50.0 (45.0)	58.3 (49.7)	66.6 (54.6)	62.4 (52.2)
Th_4	66.6 (54.6)	75.0 (60.0)	70.8 (57.2)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Tv_5	75.0 (60.0)	75.0 (60.0)	75.0 (60.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Soil Treatment												
Gv_3	33.3 (35.2)	33.3 (35.2)	33.3 (35.2)	41.6 (40.1)	41.6 (40.1)	41.6 (40.1)	58.3 (49.7)	58.3 (49.7)	58.3 (49.7)	66.6 (54.6)	66.6 (54.6)	66.6 (54.6)
Th_2	50.0 (45.0)	58.3 (49.7)	54.1 (47.3)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Tv_2	33.3 (35.2)	33.3 (35.2)	33.3 (35.2)	50.0 (45.0)	50.0 (45.0)	50.0 (45.0)	66.6 (54.6)	75.0 (60.0)	70.8 (57.2)	75.0 (60.0)	83.3 (65.8)	79.1 (62.7)
Th_4	75.0 (60.0)	75.0 (60.0)	75.0 (60.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Tv_5	75.0 (60.0)	75.0 (60.0)	75.0 (60.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Seed + Seedling + Soil Treatment												
Gv_3	16.6 (24.0)	16.6 (24.0)	16.6 (24.0)	25.0 (30.0)	33.3 (35.2)	29.1 (32.6)	33.3 (35.2)	33.3 (35.2)	33.3 (35.2)	41.6 (40.1)	41.6 (40.1)	41.6 (40.1)
Th_2	50.0 (45.0)	50.0 (45.0)	50.0 (45.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Tv_2	25.0 (30.0)	25.0 (30.0)	25.0 (30.0)	33.3 (35.2)	41.6 (40.1)	45.8 (42.5)	41.6 (40.1)	41.6 (40.1)	41.6 (40.1)	41.6 (40.1)	41.6 (40.1)	41.6 (40.1)
Th_4	66.6 (54.6)	75.0 (60.0)	70.8 (57.2)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Tv_5	66.6 (54.6)	75.0 (60.0)	70.8 (57.2)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Check	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
CD (p = 0.05)	11.4	12.1	10.7	14.6	15.4	12.3	21.8	22.4	18.6	23.6	24.0	22.7

Figures in parenthesis are transformed angular value

*The treatments excluding check, recorded 100 per cent wilt incidence, were not included in statistical analysis

bio-agent, when seed + seedling treatment was supplemented with soil treatment. At 80 and 100 DAT, Gv_3 again out performed all other antagonists tried, with 41.6 and 50.0, and 58.3 and 66.6 per cent wilt incidence when applied either as seed + soil treatment or as soil treatment, respectively. Treatment with Gv_3 followed by Tv_2, resulted in 33.3 and 41.6 per cent wilt incidence at 80 DAT, respectively, when applied as seed + seedling + soil treatment. At 100 DAT, Gv_3 and Tv_2 with 41.6 per cent wilt incidence each, were the most effective antagonists when applied as seed + seedling + soil treatments.

In the year 2002, the wilt incidence observed at 40 DAT again revealed the superiority of Gv_3 treatment. The wilt incidence of 16.6, 25.0 and 33.3 per cent was observed when Gv_3 was applied as seed + seedling + soil, seed + seedling and soil treatment alone, respectively. Tv_2 was next best treatment in checking the disease as 25.0 per cent incidence each in seed + seedling + soil, and seed + seedling treatment and 33.3 per cent in soil treatment was observed compared to check (100%). At 60 DAT, application of Gv_3 as seed + seedling + soil treatment recorded 25.0 per cent wilt incidence, whereas, 33.3 and 41.6 per cent disease incidence was recorded when applied either as seed + seedling or soil treatment, respectively. Seed + seedling + soil treatment with Tv_2 recorded lesser wilt incidence of 41.6 per cent compared to wilt incidence of 50.0 per cent each when applied either as seed + seedling or soil treatment, respectively. The antagonists Th_4 and Tv_5 were completely ineffective as 100 per cent wilt incidence was observed. The data recorded at 80 DAT indicates that Gv_3 and Tv_2 were more effective in minimizing the wilt incidence, resulting in 33.3 and 41.6 per cent wilt incidence, respectively, when applied as seed + seedling + soil treatment. At

100 DAT, the minimum wilt incidence of 41.6 per cent was recorded when Gv_3 was applied as seed + seedling + soil treatment, however, higher wilt incidence of 50.0 and 66.6 per cent, respectively, was recorded when applied as either seed + seedling or soil treatment. Tv_2 also recorded significantly lower wilt incidence of 41.6, 66.6 and 83.3 per cent when treated as seed + seedling + soil, seed + seedling and only to soil, respectively, compared to 100 per cent wilt incidence in all other treatments.

The pooled data of the years 2001 and 2002 presented in Table 17 revealed that all the fungal antagonists recorded significantly lower wilt incidence compared to check at 40 DAT. However, Gv_3 and Tv_2 proved significantly superior over other treatments at all the dates of observation. The isolate Gv_3 was responsible for low wilt incidence of 16.6, 25.0, 33.3 and 41.6 per cent at 40, 60, 80 and 100 DAT, respectively, when applied as seed + seedling + soil treatment. In other modes of antagonist applications, *viz.* seed + seedling treatment and soil treatment, Gv_3 again proved superior to other antagonists and, at 100 DAT, 50.0 and 66.6 per cent wilt incidence was recorded, respectively. The other bio-control agent which also provided some protection to the plants up to 100 DAT of the crop was Tv_2 when applied as seed + seedling + soil treatment, resulting in 25.0, 33.3, 41.6 and 41.6 per cent wilt incidence at 40, 60, 80 and 100 DAT of the crop, respectively, and was significantly superior over other treatments including check.

(B) Bell pepper cv. California Wonder : The data presented in Table 18 indicate that at 40 DAT all the treatments resulted in significantly lesser wilt incidence, compared to check. The antagonists were most effective when applied as seed + seedling + soil treatment compared to seed + seedling or soil treatment alone.

Table 18 : Effect of fungal antagonists on wilt incidence in bell pepper cv. California Wonder under glass house conditions

Antagonist	Wilt incidence (%) (Days after transplanting)											
	40			60			80			100		
	2001	2002	Pooled	2001*	2002*	Pooled*	2001*	2002*	Pooled*	2001*	2002*	Pooled*
Seed + Seedling Treatment												
Gv_3	33.3 (35.2)	41.6 (40.1)	37.4 (37.7)	41.6 (40.1)	50.0 (45.0)	45.8 (42.5)	41.6 (40.1)	50.0 (45.0)	45.8 (42.5)	50.0 (45.0)	58.3 (49.7)	54.1 (47.3)
Th_2	33.3 (35.2)	41.6 (40.1)	37.4 (37.7)	41.6 (40.1)	50.0 (45.0)	45.8 (42.5)	50.0 (45.0)	58.3 (49.7)	54.1 (47.3)	58.3 (49.7)	66.6 (54.6)	62.1 (52.0)
Tv_2	58.3 (49.7)	58.3 (49.7)	58.3 (49.7)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Th_4	75.0 (60.0)	75.0 (60.0)	75.0 (60.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Tv_5	75.0 (60.0)	83.3 (65.8)	79.1 (62.7)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Soil Treatment												
Gv_3	41.6 (40.1)	41.6 (40.1)	41.6 (40.1)	50.0 (45.0)	58.3 (49.7)	54.1 (47.3)	58.3 (49.7)	58.3 (49.7)	58.3 (49.7)	58.3 (49.7)	66.6 (54.6)	62.1 (52.0)
Th_2	41.6 (40.1)	50.0 (45.0)	45.8 (42.5)	58.3 (49.7)	58.3 (49.7)	58.3 (49.7)	75.0 (60.0)	66.6 (54.6)	70.8 (57.2)	75.0 (60.0)	75.0 (60.0)	75.0 (60.0)
Tv_2	58.3 (49.7)	58.3 (49.7)	58.3 (49.7)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Th_4	83.3 (65.8)	83.3 (65.8)	83.3 (65.8)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Tv_5	83.3 (65.8)	83.3 (65.8)	83.3 (65.8)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Seed + Seedling + Soil Treatment												
Gv_3	16.6 (24.0)	25.0 (30.0)	20.8 (27.1)	25.0 (30.0)	33.3 (35.2)	29.1 (32.6)	33.3 (35.2)	33.3 (35.2)	33.3 (35.2)	33.3 (35.2)	33.3 (35.2)	33.3 (35.2)
Th_2	25.0 (30.0)	33.3 (35.2)	29.1 (32.6)	33.3 (35.2)	33.3 (35.2)	33.3 (35.2)	50.0 (45.0)	41.6 (40.1)	45.8 (42.5)	50.0 (45.0)	50.0 (45.0)	50.0 (45.0)
Tv_2	50.0 (45.0)	58.3 (49.7)	54.1 (47.3)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Th_4	75.0 (60.0)	75.0 (60.0)	75.0 (60.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Tv_5	66.6 (54.6)	75.0 (60.0)	70.8 (57.2)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Check	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
CD (p = 0.05)	10.8	11.3	9.6	21.6	22.4	18.9	22.8	22.6	20.5	22.8	23.6	22.8

Figures in parenthesis are transformed angular value

*The treatments excluding check, recorded 100 per cent wilt incidence, were not included in statistical analysis

In the year 2001, the data recorded at 40 DAT indicated that minimum wilt incidence of 16.6 and 25.0 per cent and 33.3 per cent each was observed with Gv_3 and Th_2 when applied as seeds + seedling + soil treatment and seed + seedling treatment, respectively. However, higher wilt incidence of 41.6 and 50.0 per cent, respectively, was observed when the same antagonists were used only as soil treatments. At 60 DAT, the least wilt incidence (25.0%) was observed with seed + seedling + soil treatment using Gv_3. It was followed by seed + seedling + soil treatment with Th_2 (33.3%). These antagonists (Gv_3 and Tv_2) recorded significantly higher wilt incidence when applied with soil treatment. Th_4 and Tv_5 were completely ineffective as 100 per cent wilt incidence was observed. At 80 DAT, seed + seedling + soil treatment with Gv_3 and Th_2 recorded wilt incidence of 33.3 and 50.0 per cent, respectively. However, the wilt incidence of 41.6 and 50.0 per cent in seed + seedling and 58.3 and 75.0 per cent in soil treatment with these antagonists (Gv_3 and Th_2) was observed, respectively. At 100 DAT, there was no increase in the wilt incidence (33.3%) compared to the results obtained at 80 DAT, when Gv_3 was applied as seed + seedling + soil treatment. Treatment with Gv_3 was followed by Th_2 (50.0% wilt incidence) as seed + seedling + soil treatment.

In the year 2002, observations recorded at 40 DAT indicate that in seed + seedling treatment and soil treatment with Gv_3 and Th_2 resulted in 41.6 per cent each and 41.6 and 50.0 per cent wilt incidence, respectively, which were statistically superior to Th_4, Tv_5 and check. However, wilt incidence with Gv_3 and Th_2 further reduced to 25.0 and 33.3 per cent when seed + seedling treatments were combined with soil treatments. With such combination, treatment with Tv_2, with 58.3 per cent disease incidence was superior to Th_4, Tv_5 and check. At 60 DAT, Gv_3 and Th_2 again remained superior to other treatments when applied as seed + seedling or soil treatment with 50.0 (in each treatment) and 58.3 (in each treatment), per cent wilt incidence, respectively. Statistically Gv_3 and Th_2 with 33.3 per cent wilt incidence each were most efficacious bio-agents, when used as seed + seedling + soil treatment. At 80 and 100 DAT, Gv_3 and Th_2 out performed all other antagonists tried, with 50.0 and 58.3 (80 DAT) and 58.3 and 66.6 (100 DAT) per cent wilt incidence when applied as seed + seedling treatment and 58.3 and 66.6 (80 DAT) and 66.6 and 75.0 (100 DAT) per cent wilt incidence when applied as soil treatment, respectively. At 100 DAT, Gv_3 and Th_2 recorded wilt incidence of 33.3 and 50.0 per cent, respectively, when applied as seed + seedling + soil, whereas all other antagonist treatments recorded 100 per cent wilt incidence.

The pooled data of the years 2001 and 2002 revealed that at 40 DAT seed + seedling treatment and soil treatment with Gv_3 and Th_2 resulted in 37.4 per cent each and 41.6 and 45.8 per cent wilt incidence, respectively, which were statistically superior to all other antagonist treatments. However, wilt incidence with Gv_3 and Th_2 further reduced to 20.8 and 29.1 per cent in each when seed + seedling treatment was combined with soil treatment. At 60 DAT, Gv_3 and Th_2 again remained superior to other treatments when applied as seed + seedling or soil treatment with 45.8 (in each treatment) and 54.1 and 58.3 per cent wilt incidence, respectively. Gv_3 and Th_2 with 29.1 and 33.3 per cent wilt incidence were most efficacious bio-agents, when seed + seedling treatment was supplemented with soil treatment. At 80 and 100 DAT, soil treatment in combination with seed + seedling treatment with Gv_3 resulted in minimum wilt incidence of 33.3 per cent (at each stage) followed by treatment with Th_2 (45.8 and 50.0 per cent at 80 and 100 DAT, respectively).

4.5 Chemical management

4.5.1 *In vitro* evaluation of fungicides against wilt complex pathogens

Nine fungicides *viz.*, copper oxychloride, captan, mancozeb, mancozeb + carbendazim (Saaf), mancozeb + metalaxyl (Ridomil MZ), thiophanate methyl, carboxin, carbendazim and metalaxyl were evaluated at different concentrations against wilt complex pathogens *viz., Fusarium oxysporum, Phytophthora capsici, Rhizoctonia solani* and *Sclerotium rolfsii* under *in vitro* conditions. The data presented in Table 19 indicate that carbendazim completely inhibited the mycelial growth of *F. oxysporum* at all the concentrations tested, whereas, captan completely inhibited the growth of *F. oxysporum* at 500 ppm concentration. No other fungicide could completely inhibit the growth of *F. oxysporum* at any of the concentrations tested. The next best fungicide against *F. oxysporum* was mancozeb + carbendazim (Saaf) which recorded 18.6, 10.3 and 6.0 mm growth with 79.3, 88.5 and 93.3 per cent inhibition over check at 100, 250 and 500 ppm concentrations, respectively. Mancozeb + metalaxyl recorded mycelial growth of 24.3, 15.3, 10.6 mm with 73.0, 83.3 and 88.2 per cent inhibition over check at 100, 250, 500 ppm concentrations, respectively. The mycelial growth of 23.0, 16.0 and 10.3 mm was observed with thiophanate methyl at 100, 250 and 500 ppm concentrations which was statistically at par with metalaxyl + mancozeb. Mancozeb and copper oxychloride have also shown effectiveness at 500 ppm recording 16.0 and 20.3 mm radial growth, respectively. The least effective fungicide was metalaxyl which recorded 85.6, 81.3 and 76.0 mm mycelial growth at 50, 100 and 250 ppm concentrations.

Table 19 : *In-vitro* evaluation of fungicides against wilt complex pathogens

Fungicide	Concentration (ppm)	Radial growth (mm)				Inhibition over check (%)			
		F. oxysporum	*P. capsici*	*R. solani*	*S. rolfsii*	*F. oxysporum*	*P. capsici*	*R. solani*	*S. rolfsii*
Copper oxychloride	100	37.3	24.0	40.0	45.0	58.5	73.3	55.5	50.0
	250	28.0	18.6	33.6	36.6	68.8	79.3	62.6	59.3
	500	20.3	8.0	25.0	34.3	77.4	91.1	72.2	61.8
Captan	100	18.6	25.6	39.3	32.0	79.3	71.5	56.3	64.4
	250	10.0	15.3	31.6	22.6	88.8	83.0	64.8	74.8
	500	0.0	0.0	26.0	18.6	100.0	100.0	71.1	79.3
Mancozeb	100	30.0	25.0	26.3	45.6	66.6	72.2	70.7	49.3
	250	22.0	18.3	19.3	34.3	75.5	79.6	78.5	61.8
	500	16.0	8.0	15.0	28.3	82.2	91.1	83.3	68.5
Mancozeb + Carbendazim (Saaf)	100	18.6	31.6	24.0	40.3	79.3	64.8	73.3	55.2
	250	10.3	21.6	13.6	32.0	88.5	76.0	84.8	64.4
	500	6.0	18.0	0.0	28.0	93.3	80.0	100.0	68.8
Mancozeb + Metalaxyl (Ridomil MZ.)	100	24.3	18.0	20.6	39.0	73.0	80.0	77.1	56.6
	250	15.3	12.6	13.0	32.6	83.3	86.0	85.5	63.7
	500	10.6	0.0	8.3	27.0	88.2	100.0	90.7	70.0
Thiophanate methyl	50	23.0	76.3	19.3	67.0	74.4	15.2	78.5	25.5
	100	16.0	72.0	9.6	62.0	82.2	20.0	89.3	31.1
	250	10.3	70.6	0.0	58.6	88.5	21.5	100.0	34.8
Carboxin	50	60.3	74.6	0.0	78.6	33.0	17.1	100.0	12.6
	100	55.6	71.6	0.0	72.0	38.2	20.4	100.0	20.0
	250	44.0	67.6	0.0	68.6	51.1	22.4	100.0	23.7
Carbendazim	50	0.0	86.6	24.3	68.3	100.0	3.7	73.0	24.1
	100	0.0	83.0	12.3	56.3	100.0	7.7	86.3	37.4
	250	0.0	80.3	0.0	53.0	100.0	10.7	100.0	41.1
Metalaxyl	50	85.6	0.0	65.0	70.0	4.8	100.0	27.7	22.2
	100	81.3	0.0	58.6	63.3	9.6	100.0	53.5	29.6
	250	76.0	0.0	53.0	58.0	15.5	100.0	41.1	35.5
Check	–	90.0	90.0	90.0	90.0	–	–	–	–
CD (p = 0.05)	–	3.18	3.46	3.75	3.84	–	–	–	–

The perusal of data in Table 19 further revealed that metalaxyl was highly effective against *Phytophthora capsici* at all the concentrations tested resulting in 100 per cent inhibition over check, this was followed by metalaxyl + mancozeb, which recorded 18.0, 12.6 and 0.0 mm growth with 80.0, 86.0 and 100 per cent inhibition over check at 100, 250 and 500 ppm concentrations, respectively. Captan at 500 ppm resulted in 100 per cent inhibition over check, whereas, mancozeb and copper oxychloride gave 72.2, 79.6, 91.1 and 73.3, 79.3, 91.1 per cent growth inhibition over check at 100,250 and 500 ppm, respectively. The mycelial growth of *P. capsici* was also restricted significantly by mancozeb + carbendazim and 64.8, 76.0 and 80.0 per cent growth inhibition over check was observed at 100, 250 and 500 ppm, respectively. Carboxin and thiophanate methyl resulted in comparatively lesser inhibition of mycelial growth as 17.1, 20.4, 22.4 and 15.2, 20.0, 21.5 per cent inhibition over check was recorded at 50, 100 and 250 ppm concentrations, respectively. The difference in these fungicides was non-significant but compared to check they were significantly superior. Carbendazim was least effective against *P. capsici* at 50, 100, 250 ppm concentrations resulting in the mycelial growth of 86.6, 83.0 and 80.3 mm, having only 3.7, 7.7 and 10.7 per cent growth inhibition over check.

An insight of Table 19 revealed that most of the fungicides were completely or partially effective against *R. solani*. The complete inhibition of the mycelial growth was observed by carboxin at all concentrations tested, thiophanate methyl and carbendazim each at 250 ppm and mancozeb + carbendazim at 500 ppm. Mancozeb + metalaxyl restricted the mycelial growth of *R. solani* to 20.6, 13.0 and 8.3 mm with 77.1, 85.5 and 90.7 per cent inhibition over check at 100, 250 and 500 ppm concentrations, respectively. The radial growth of 26.3, 19.3, and 15.0 mm with 70.7, 78.5 and 83.3 per cent inhibition over check was observed with mancozeb at 100, 250 and 500 ppm concentrations, respectively. Captan recorded 56.3, 64.8 and 71.1 per cent growth inhibition over check at 100, 250 and 500 ppm concentrations, respectively. Metalaxyl and copper oxychloride were comparatively lesser effective as 27.7, 53.5, 41.1 and 55.5, 62.6 and 72.2 per cent reduction over check was observed, at 50, 100 and 250 and 100, 250 and 500 ppm, respectively.

It is evident from Table 19 that none of the fungicides could completely inhibit the mycelial growth of *S. rolfsii* at any of the concentrations tested. However, the most effective fungicide was captan at 500 ppm, as 79.3 per cent radial growth inhibition over check was observed. Captan was followed by Mancozeb + metalaxyl and mancozeb + carbendazim which resulted in the mycelial growth of 39.0, 32.6 and 27.0 and 40.3, 32.0 and 28.0 mm at 100, 250 and 500 ppm concentrations, respectively. In these treatments 56.6, 63.7, 70.0 and 55.2, 64.4 and 68.81 per cent inhibition over check was observed, respectively. Carbendazim and thiophanate methyl treatments resulted in 68.3, 56.3, 53.0 (24.1, 37.4, 41.1 per cent inhibition over check) and 67.0, 62.0, 58.6 mm (25.5, 31.1, 34.8 per cent inhibition over check) mycelial growth, at 50, 100, 250 ppm concentrations, respectively.

4.5.2 Glasshouse studies

4.5.2.1 Effect of fungicides on seedling emergence

The fungicides and their combinations found effective under *in-vitro* conditions against wilt pathogens were further tested by applying as seed treatment in chillies cv. Pusa Jawala and bell pepper cv. California Wonder to observe their effectiveness on seedling emergence of crop.

(A) Chillies cv. Pusa Jawala : It is evident from Table 20 that seed treatment with fungicides resulted in increased seedling emergence over check. The data obtained in year 2001 indicated that highest seedling emergence of 80.0 per cent was observed in carbendazim + metalaxyl followed by captan + carbendazim (79.0%). The seedling emergence of 78.0, 78.0, 77.0 and 76.1 per cent was recorded in captan + metalaxyl, carbendazim, carboxin + metalaxyl and captan, respectively, which were at par with each other. The least effective fungicide was metalaxyl which recorded 73.3 per cent seedling emergence, however, it was significantly higher than check (57.6).

In the year 2002, similar trends were observed as in 2001. The combinations of carbendazim + metalaxyl, captan + carbendazim and captan + metalaxyl recorded 79.0, 78.0 and 78.0 per cent seedling emergence, respectively, which were statistically at par with each other but significantly higher than other treatments. The treatment with carboxin + metalaxyl recorded seedling emergence of 77.0 per cent which was followed by carbendazim (76.1%) and captan (75.2%). All these treatments were significantly superior to check (50.0%). The minimum seedling emergence of 73.3 per cent was observed each in metalaxyl and carboxin, however, both the treatments were superior to check.

The pooled data of the years 2001 and 2002 revealed that highest seedling emergence of 79.5 per cent with 47.7 per cent increase over check was observed with carbendazim + metalaxyl followed by carbendazim + captan (78.5%) and captan + metalaxyl (78.0%) which were at par with each other. Carboxin + metalaxyl and carbendazim each resulted in 77.0 per cent seedling emergence with 43.1 per cent increase over check. Captan and carboxin recorded 75.6 and 74.2 per cent seedling

Table 20 : Effect of seed treatment with different fungicides on seedling emergence of *Capsicum annuum* under glasshouse conditions

Fungicide	Conc. (%)	Seedling emergence (%)							
		Chilli cv. Pusa Jawala				Bell pepper cv. California Wonder			
		Year 2001	Year 2002	Pooled	Increase over check	Year 2001	Year 2002	Pooled	Increase over check
Captan	0.30	76.1 (60.7)	75.2 (60.1)	75.6 (60.3)	40.5	66.6 (54.6)	60.9 (51.2)	63.7 (52.9)	31.8
Carbendazim	0.20	78.0 (62.0)	76.1 (60.7)	77.0 (61.3)	43.1	70.4 (57.0)	65.7 (54.1)	68.0 (55.5)	40.7
Metalaxyl	0.20	73.3 (58.8)	73.3 (58.8)	73.3 (58.8)	36.1	62.8 (52.4)	62.8 (52.4)	62.8 (52.4)	30.0
Carboxin	0.20	75.2 (60.1)	73.3 (58.8)	74.2 (59.4)	37.9	65.7 (54.1)	62.8 (52.4)	64.2 (53.2)	32.9
Captan + Metalaxyl	0.20 + 0.15	78.0 (62.0)	78.0 (62.0)	78.0 (62.0)	44.9	70.4 (57.0)	66.6 (54.6)	68.5 (55.8)	41.8
Captan + Carbendazim	0.20 + 0.15	79.0 (62.7)	78.0 (62.0)	78.5 (62.3)	45.9	75.2 (60.1)	71.4 (57.6)	73.3 (58.8)	51.7
Carbendazim + Metalaxyl	0.15 + 0.15	80.0 (63.4)	79.0 (62.7)	79.5 (63.0)	47.7	77.1 (61.4)	74.2 (59.4)	75.6 (60.3)	56.5
Carboxin + Metalaxyl	0.15 + 0.15	77.0 (61.3)	77.0 (61.3)	77.0 (61.3)	43.1	68.5 (55.8)	65.7 (54.1)	67.1 (54.9)	38.9
Check	–	57.6 (49.3)	50.0 (45.0)	53.8 (47.1)	–	50.0 (45.0)	46.6 (43.0)	48.3 (44.0)	–
CD (p = 0.05)	–	**1.98**	**1.97**	**1.78**	–	**2.40**	**2.27**	**2.01**	–

Figures in parenthesis are transformed angular values emergence, respectively, which were statistically at par with each other but significantly higher than check (53.8%). Metalaxyl resulted in 73.3 per cent seedling emergence.

(B) Bell pepper cv. California Wonder: The data (Table 20) obtained in the year 2001 indicated that highest seedling emergence (77.1%) was observed when seeds were treated with carbendazim + metalaxyl, this was followed by the treatment with captan + carbendazim (75.2%). Carbendazim and captan + metalaxyl with 70.4 per cent seedling emergence in each were significantly superior over check (50.0%). The seedling emergence of 68.5, 66.6, 65.7 and 62.8 was recorded in treatments with carboxin + metalaxyl, captan, carboxin and metalaxyl, respectively.

In the year 2002, all the treatments recorded significantly higher seedling emergence than check. The maximum seedling emergence (74.2%) was observed with carbendazim + metalaxyl, this was followed by captan + carbendazim (71.4%). The treatments captan + metalaxyl, carbendazim and carboxin + metalaxyl recorded 66.6, 65.7 and 65.7 per cent seedling emergence, respectively, which were at par with each other. Seedling emergence of 62.8, 62.8 and 60.9 per cent was recorded in metalaxyl, carboxin and captan, respectively, with no significant difference among the treatments.

The pooled data of the years 2001 and 2002 indicated that highest seedling emergence (75.6%) was observed when seeds were treated with carbendazim + metalaxyl, which increased 56.5 per cent seedling emergence over check. The combination of captan + carbendazim was also effective as 73.3 per cent seedling emergence and 51.7 per cent increase in seedling emergence over check was observed. Captan + metalaxyl, carbendazim and carboxin + metalaxyl recorded 68.5, 68.0 and

67.1 per cent seedling emergence with 41.8, 40.7 and 38.9 per cent increase in seedling emergence over check, respectively. An increase of 32.9, 31.8 and 30.0 per cent seedling emergence over check was observed in carboxin, captan and metalaxyl, respectively.

4.5.2.2 Effect of fungicides on wilt complex disease

Four fungicides individually and in combinations were applied as seed treatment (ST), seedling dip treatment (SD) and as spray at crown region of plant at 15 day intervals to observe their efficacy against wilt complex disease of chillies and bell pepper at different stages.

(A) Chilli cv. Pusa Jawala: The data presented in the Table 21 reveal that in the year 2001, at 40 DAT all the treatments recorded significantly lower wilt incidence than check (100%). As ST + SD, combinations of carbendazim + metalaxyl, captan + metalaxyl and captan + carbendazim with disease incidence of 33.3, 41.6 and 41.6 per cent, respectively were superior to ST + SD with metalaxyl, however statistically at par with other treatments. However, supplementing ST + SD with spraying at 15 day intervals the above mentioned treatments completely controlled the disease, whereas, there was 100 per cent wilt incidence in check. At 60 DAT only carbendazim + metalaxyl and captan + metalaxyl, when used as ST + SD, were able to register some control over wilt with 66.6 and 75.0 per cent disease incidence, whereas, in the remaining treatments there was 100 per cent wilt incidence. However, when ST + SD was followed with spraying, combinations of captan + metalaxyl and carbendazim + metalaxyl completely controlled the disease, whereas, with captan + carbendazim and carboxin + metalaxyl there was 16.6 and 33.3 per cent wilt incidence. At 80 and 100

Table 21 : Effect of fungicides on wilt incidence in chilli cv. Pusa Jawala, under glass house conditions

	Fungicide	Wilt incidence (%) (Days after transplanting)											
		40			60			80			100		
		2001	2002	Pooled	2001*	2002*	Pooled*	2001*	2002*	Pooled*	2001*	2002*	Pooled*
Seed Treatment (ST) + Seedling Dip (SD)													
T_1	Captan	50.0 (45.0)	50.0 (45.0)	50.0 (45.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
T_2	Carbendazim	58.3 (49.7)	58.3 (49.7)	58.3 (49.7)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
T_3	Metalaxyl	66.6 (54.6)	66.6 (54.6)	66.6 (54.6)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
T_4	Carboxin	58.3 (49.7)	66.6 (54.6)	62.4 (52.1)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
T_5	Captan + Metalaxyl	41.6 (40.1)	33.3 (35.2)	37.4 (37.7)	75.0 (60.0)	66.6 (54.6)	70.8 (57.2)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
T_6	Captan + Carbendazim	41.6 (40.1)	41.6 (40.1)	41.6 (40.1)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
T_7	Carbendazim + Metalaxyl	33.3 (35.2)	41.6 (40.1)	37.4 (37.7)	66.6 (54.6)	66.6 (54.6)	66.6 (54.6)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
T_8	Carboxin + Metalaxyl	58.3 (49.7)	50.0 (45.0)	54.1 (47.3)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Seed treatment (ST) + Seedling Dip (SD) + Spraying (15 days interval)													
T_9	Captan + Metalaxyl	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	8.3 (16.7)	4.1 (11.6)	25.0 (30.0)	25.0 (30.0)	25.0 (30.0)	25.0 (30.0)	33.3 (35.2)	29.1 (32.6)
T_{10}	Captan + Carbendazim	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	16.6 (24.0)	16.6 (24.0)	16.6 (24.0)	33.3 (35.2)	25.0 (30.0)	29.1 (32.6)	41.6 (40.1)	33.3 (35.2)	37.4 (37.7)
T_{11}	Carbendazim + Metalaxyl	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	16.6 (24.0)	16.6 (24.0)	16.6 (24.0)	25.0 (30.0)	25.0 (30.0)	25.0 (30.0)
T_{12}	Carboxin + Metalaxyl	16.6 (24.0)	25.0 (30.0)	20.8 (27.1)	33.3 (35.2)	33.3 (35.2)	33.3 (35.2)	50.0 (45.0)	41.6 (40.1)	45.8 (42.5)	58.3 (49.7)	50.0 (45.0)	54.1 (47.3)
	Control	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
	CD (p = 0.05)	**16.9**	16.7	**16.6**	**24.6**	**22.5**	22.2	**9.8**	9.3	**8.8**	**8.7**	**8.9**	7.6

Figures in parenthesis are transformed angular values

T_1 @ 0.3%; T_2, T_3, T_4 @ 0.2%; T_5, T_6 @ 0.35%; T_7, T_8 @ 0.25%; T_9, T_{10}, ST, SD @ 0.35, Spraying @ 0.25%; T_{11} and T_{12} ST, SD @ 0.25%, Spraying @ 0.2%

*The treatments excluding check, recorded 100 per cent wilt incidence, were not included in statistical analysis

DAT, all the treatments applied as ST + SD proved completely ineffective as in all the cases 100 per cent wilt incidence was recorded. At 80 DAT, supplementing ST + SD with spraying of carbendazim + metalaxyl was the most efficacious treatment resulting in 16.6 per cent disease incidence, followed by ST + SD + spraying with captan + metalaxyl (25.0%) and ST + SD + spraying with captan + carbendazim (33.3%). At 100 DAT, the minimum wilt incidence of 25.0 per cent each was recorded with ST + SD + spraying with carbendazim + metalaxyl and captan + metalaxyl, followed by statistically at par wilt incidence of 41.6 per cent observed in captan + carbendazim.

In the year 2002, at 40 DAT, all the treatments were significantly superior to check, where in 100 per cent wilt incidence was observed. Applying ST + SD with captan + metalaxyl, captan + carbendazim and carbendazim + metalaxyl, with disease incidence of 33.3, 41.6 and 41.6 per cent, were superior to all other treatments. In addition to ST + SD, spraying of captan + metalaxyl, carbendazim + metalaxyl and captan + carbendazim resulted in no wilt incidence. This was followed by ST + SD + spraying with carboxin + metalaxyl recording 25.0 per cent wilting. At 60 DAT, ST + SD using captan + metalaxyl and carbendazim each with 66.6 per cent wilt incidence, gave some control against the disease, whereas, in the remaining treatments there was 100 per cent disease. However, ST + SD + spraying with carbendazim + metalaxyl resulted in zero per cent wilt incidence. The wilt incidence of 8.3 and 16.6 per cent was observed in ST + SD + spraying with captan + metalaxyl and ST + SD + spraying with captan + carbendazim, respectively. At 80 DAT, with the wilt incidence of 16.6, 25.0 and 25.0 per cent observed in ST + SD + spraying with carbendazim + metalaxyl, captan + metalaxyl and captan + carbendazim, respectively, were superior to all other treatments. Using ST + SD + spraying with carboxin + metalaxyl recorded 41.6 per cent wilt incidence which was significantly superior to check. At 100 DAT, the wilt incidence recorded in ST + SD + spraying with carbendazim + metalaxyl was only 25.0 per cent which was statistically at par with 33.3 per cent observed each with captan + metalaxyl (T_9) and captan + carbendazim (T_{10}). The wilt incidence of 50.0 per cent was observed in ST + SD + spraying with carboxin + metalaxyl.

The pooled data of the years 2001 and 2002 revealed that integration of seed and seedling treatment with spraying was the best approach to reduce the wilt incidence. At 40 DAT, complete protection from disease was observed when captan + metalaxyl, captan + carbendazim, or carbendazim + metalaxyl were sprayed at regular intervals in addition to treating seeds and seedlings with these fungicides. ST + SD + spraying with carboxin + metalaxyl resulting in 20.8 per cent disease incidence and ST + SD with captan + metalaxyl and carbendazim + metalaxyl, with 37.4 and 37.4 per cent disease incidence, respectively, were significantly superior to ST + SD with carboxin and metalaxyl. At 60 DAT of crop, ST + SD + spraying of carbendazim + metalaxyl and captan + metalaxyl resulted in the wilt incidence of 0.0 and 4.1 per cent. The treatments were at par with ST + SD + spraying of captan + carbendazim but significantly superior to all other treatments. At 80 DAT, ST + SD + spraying of carbendazim + metalaxyl and captan + metalaxyl recorded 16.6 and 25.0 per cent wilt incidence, respectively which was statistically at par with the wilt incidence of 29.1 per cent observed in ST + SD + spraying of captan + carbendazim, however, significantly lower than 45.8 per cent observed with ST + SD + spraying with carboxin + metalaxyl. At 100 DAT, again the most effective treatment was ST + SD + spraying of carbendazim + metalaxyl and captan + metalaxyl as only 25.0 and 29.1 per cent wilt incidence was observed. Captan + carbendazim (ST + SD + spraying) recorded 37.4

per cent wilt incidence while as 54.1 per cent incidence was observed in the treatment of carboxin + metalaxyl (T_{12}). All these treatments were significantly superior to check.

(B) Bell pepper cv. California Wonder: The data presented in Table 22 indicate that under glasshouse conditions ST + SD alone was not sufficient but following it with spraying at crown region at 15 day intervals resulted in protection of plants from wilt complex disease. In the year 2001, the data indicate that all the treatments were effective in reducing the wilt disease at 40 days after transplanting (DAT) of crop although ST + SD resulted in higher wilt incidence than ST + SD + spraying. ST + SD + spraying with captan + metalaxyl (T_9) and carbendazim + metalaxyl (T_{11}) completely checked the disease. The wilt incidence of 8.3 per cent was observed in ST + SD + spraying with captan + carbendazim which was at par with ST + SD + spraying with carboxin + metalaxyl (25.0%). At 60 DAT, most of the fungicides applied as ST + SD resulted in 100 per cent wilt incidence. However, ST + SD + spraying of carbendazim + metalaxyl was effective in protecting the plants as only 8.3 per cent wilt incidence was observed. The wilt incidence of 16.6 and 25.0 per cent was observed in ST + SD + spraying of captan + metalaxyl (T_9) and captan + carbendazim (T_{10}), respectively. The treatments, ST + SD with captan + metalaxyl and carbendazim + metalaxyl recorded 83.3 and 75.0 per cent wilt incidence, respectively. ST + SD + spraying of carboxin + metalaxyl were partially effective as 33.3 per cent wilt incidence was observed at 60 DAT. The results revealed that 100 per cent wilting was observed at 80 DAT when fungicides were applied only as ST + SD and not followed by spraying, however, when fungicides were also sprayed at regular intervals, lower wilt incidence was recorded. The least wilt incidence (25.0%) was recorded with carbendazim + metalaxyl (T_{11}), followed by captan + metalaxyl and captan + carbendazim (33.3% each). The least

Table 22 : Effect of fungicides on wilt incidence in bell pepper cv. California Wonder, under glass house conditions

	Fungicide	Wilt incidence (%) (Days after transplanting)											
		40			60			80			100		
		2001	2002	Pooled	2001*	2002*	Pooled*	2001*	2002*	Pooled*	2001*	2002*	Pooled*
Seed Treatment (ST) + Seedling Dip (SD)													
T_1	Captan	58.3 (49.7)	58.3 (49.7)	58.3 (49.7)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
T_2	Carbendazim	41.6 (40.1)	50.0 (45.0)	45.8 (42.5)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
T_3	Metalaxyl	75.0 (60.0)	66.6 (54.6)	70.8 (57.2)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
T_4	Carboxin	66.6 (54.6)	66.6 (54.6)	66.6 (54.6)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
T_5	Captan + Metalaxyl	58.3 (49.7)	50.0 (45.0)	54.1 (47.3)	83.3 (65.8)	91.6 (73.1)	87.4 (69.2)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
T_6	Captan + Carbendazim	41.6 (40.1)	58.3 (49.7)	50.0 (45.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
T_7	Carbendazim + Metalaxyl	41.6 (40.1)	41.6 (40.1)	41.6 (40.1)	75.0 (60.0)	83.3 (65.8)	79.1 (62.7)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
T_8	Carboxin + Metalaxyl	58.3 (49.7)	66.6 (54.6)	62.4 (52.1)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
Seed treatment (ST) + Seedling Dip (SD) + Spraying (15 days interval)													
T_9	Captan + Metalaxyl	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	16.6 (24.0)	25.0 (30.0)	20.8 (27.1)	33.3 (35.2)	25.0 (30.0)	29.1 (32.6)	33.3 (35.2)	33.3 (35.2)	33.3 (35.2)
T_{10}	Captan + Carbendazim	8.3 (16.7)	0.0 (0.0)	4.1 (11.6)	25.0 (30.0)	16.6 (24.0)	20.8 (27.1)	33.3 (35.2)	25.0 (30.0)	29.1 (32.6)	50.0 (45.0)	41.6 (40.1)	45.8 (42.2)
T_{11}	Carbendazim + Metalaxyl	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	8.3 (16.7)	8.3 (16.7)	8.3 (16.7)	25.0 (30.0)	25.0 (30.0)	25.0 (30.0)	25.0 (30.0)	25.0 (30.0)	25.0 (30.0)
T_{12}	Carboxin + Metalaxyl	25.0 (30.0)	16.6 (24.0)	20.8 (27.1)	33.3 (35.2)	33.3 (35.2)	33.3 (35.2)	50.0 (45.0)	50.0 (45.0)	50.0 (45.0)	58.3 (49.7)	58.3 (49.7)	58.3 (49.7)
	Check	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)
	CD (p = 0.05)	**17.4**	**17.1**	**16.9**	**22.4**	**23.3**	**22.2**	**10.3**	**10.0**	**9.5**	**8.6**	**8.5**	**8.0**

Figures in parenthesis are transformed angular values

T_1 @ 0.3%; T_2, T_3, T_4 @ 0.2%; T_5, T_6 @ 0.35%; T_7, T_8 0.25%; T_9, T_{10} @ ST, SD @ 0.35, Spraying @ 0.25%; T_{11} and T_{12} ST, SD @ 0.25%, Spraying @ 0.2%

*The treatments excluding check, recorded 100 per cent wilt incidence, were not included in statistical analysis

effective fungicide carboxin + metalaxyl (T_{12}) when sprayed at regular intervals recoded 50.0 per cent wilt incidence which was significantly lower than check. At 100 DAT of the seedling, ST + SD + spraying of carbendazim + metalaxyl (T_{11}) and captan + metalaxyl (T_9) recorded 25.0 and 33.3 per cent wilt incidence, respectively, which was at par with each other. The wilt incidence of 50.0 and 58.3 per cent was observed in ST + SD + spraying of captan + carbendazim (T_{10}) and carboxin + metalaxyl (T_{12}), respectively. All these treatments recorded wilt incidence significantly lower than the incidence recorded in check.

In the year 2002, almost similar trend in results was observed as in the year 2001. The data recorded at 40 DAT indicate that application of metalaxyl as ST+SD resulted in minimum wilt incidence of 41.6 per cent. However, no wilt incidence was observed when captan + metalaxyl, captan + carbendazim or carbendazim + metalaxyl were sprayed at 15 day intervals in addition to ST + SD treatments. Whereas, in the check pots 100 per cent wilt incidence was observed. At 60 DAT, ST + SD treatments did not prove effective, as in all the treatments, baring two, 100 per cent wilting was recorded, with minimum disease incidence of 83.3 per cent was observed with carbendazim + metalaxyl (T_7). When in addition to ST + SD, carbendazim + metalaxyl was sprayed at regular intervals the minimum wilt incidence of 8.3 per cent was observed. ST + SD + spraying of captan + metalaxyl were also effective as only 16.6 per cent of disease was observed. The other treatments were also significantly superior over check (100% wilting). At 80 and 100 DAT, restricting only to ST + SD resulted in 100 per cent wilting. However, at 80 DAT, ST + SD followed by regular spraying of captan + metalaxyl, captan + carbendazim or carbendazim + metalaxyl were most effective, each resulting in only 25.0 per cent wilt incidence. Whereas, at 100 DAT, ST

+ SD followed by carbendazim + metalaxyl spraying was the most efficacious treatment (25.0% wilting), followed by the treatment where spraying with captan + metalaxyl (33.3%) was carried out.

The pooled data of the years 2001 and 2002 revealed that at 40 DAT all the treatments were significantly superior over check with varying wilt incidence. However ST + SD + spraying of captan + metalaxyl (T_9) and carbendazim + metalaxyl (T_{11}) completely protected the plants from wilt pathogens and no wilt incidence was observed. ST + SD + spraying with captan + carbendazim recorded 4.1 per cent wilt incidence. At 60 DAT, ST + SD with carbendazim + metataxyl and captan + metalaxyl recorded 79.1 and 87.4 per cent wilt incidence, whereas, in the remaining treatments it was 100 per cent. However, the least wilt incidence of 8.3 per cent was recorded in ST + SD + spraying with carbendazim + metalaxyl which was statistically at par with 20.8 per cent each incidence, obtained in the treatments where ST + SD was followed by spraying of captan + carbendazim (T_{10}) and captan + metalaxyl (T_9), respectively. It is evident from the pooled data recorded at 80 DAT that the fungicides applied as ST + SD were completely ineffective as 100 per cent wilt incidence was observed. However ST + SD followed by spraying of carbendazim + metalaxyl (T_{11}), captan + metalaxyl (T_9) and captan + carbendazim (T_{10}) recorded 25.0, 29.1 and 29.1 per cent wilt incidence, respectively, which were statistically at par with each other, however superior to carboxin + metalaxyl spraying (T_{12}) which recorded 50.0 per cent disease incidence. At 100 DAT, the least wilt incidence of 25.0 per cent was observed in ST + SD + spraying with carbendazim + metalaxyl, followed by captan + metalaxyl (33.3%). The wilt incidence of 45.8 and 58.3 per cent was recorded in ST + SD + spraying with captan + carbendazim (T_{10}) and carboxin + metalaxyl (T_{12}), respectively, which showed no significant difference.

4.6 Integrated disease management

4.6.1 Compatibility of antagonists with fungicides

Four fungicides, *viz.*, carbendazim, carboxin, metalaxyl and captan were tested under *in-vitro* conditions to evaluate their compatibility with the three selected antagonists *viz.*, *Trichoderma harzianum* (Th_2), *T. viride* (Tv_2) and *T. virens* (Gv_3) The data recorded is presented in Table 23, which indicate that carboxin at 50 ppm concentration resulted in the maximum radial growth (90.0 mm) in all the three antagonists. This was as good as in the check (90.0 mm) and at par with carboxin at 100 ppm in Th_2 (85.3 mm), Tv_2 (84.6 mm) and Gv_3 (90.0 mm). At 50 ppm concentration of metalaxyl, the radial growth of Th_2, Tv_2 and Gv_3 was 85.3, 84.6 and 88.3 mm, respectively, which was also at par with the growth recorded in check. In case of Gv_3, carboxin at 250 ppm resulted in 85.0 mm radial growth which was again at par with check. At 250 ppm concentration of carboxin, the radial growth of 74.6 and 72.3 mm was recorded in Th_2 and Tv_2, respectively. It was evident from the data that antagonists had shown some tolerance to metalaxyl as mycelial growth of 74.6 and 67.3 mm in Th_2; 73.3 and 70.0 mm in Tv_2 and; 80.0 and 75.3 mm in Gv_3 was observed at 100 and 250 ppm concentrations, respectively. Captan also showed compatibility with antagonists as growth recorded at 100, 250 and 500 ppm concentrations was 75.6, 67.3 and 54.0 mm in Th_2; 75.6, 66.3 and 54.0 in Tv_2; 80.3, 71.0 and 61.6 mm in Gv_3, respectively. Carbendazim completely inhibited the mycelial growth of Th_2, Tv_2 and Gv_3 at all concentrations tested (50, 100, 250 ppm).

Table 23 : *In-vitro* evaluation of compatibility of different fungicides with the antagonists

Fungicides	Concentration (ppm)	Radial growth (mm)			Inhibition over check (%)		
		T. harzianum (Th_2)	*T. viride* (Tv_2)	*T. virens* (Gv_3)	*T. harzianum* (Th_2)	*T. viride* (Tv_2)	*T. virens* (Gv_3)
Carbendazim	50	0.0	0.0	0.0	100.0	100.0	100.0
	100	0.0	0.0	0.0	100.0	100.0	100.0
	250	0.0	0.0	0.0	100.0	100.0	100.0
Carboxin	50	90.0	90.0	90.0	0.0	*0.0*	0.0
	100	85.3	84.6	90.0	5.2	*6.0*	0.0
	250	74.6	72.3	85.0	17.1	*19.6*	5.5
Captan	100	75.6	75.6	80.3	16.0	*16.0*	10.7
	250	67.3	67.3	71.0	25.2	*25.2*	21.1
	500	54.0	54.0	61.6	40.0	*40.0*	31.5
Metalaxyl	50	85.3	84.6	88.3	5.2	*6.0*	1.8
	100	74.6	73.3	80.0	17.1	*18.5*	11.1
	250	67.3	70.0	75.3	25.2	*22.2*	16.3
Check	–	90.0	90.0	90.0	–	–	–
CD (p = 0.05)	–	**7.4**	**6.4**	**6.5**	–	–	–

4.6.2 Glasshouse studies

(A) Effect of antagonists and fungicides alone and in combinations on wilt complex disease of chilli cv. Pusa Jawala

Three fungicide combinations *viz.*, captan + metalaxyl, carbendazim + metalaxyl and carboxin + metalaxyl, which had proved more effective in managing wilt complex of chilli in the previous experiment (4.6), along with two antagonist isolates *Trichoderma viride* (Tv_2) and *T. virens* (Gv_3) which had performed better than other isolates of fungal antagonists in earlier experiments (4.5) were tried individually and in integration (fungicide + antagonist) to study their efficacy in managing the disease. Fungicidal combinations *viz.*, captan + metalaxyl (T_1), carbendazim + metalaxyl (T_2), carboxin + metalaxyl (T_3) were applied as seed + seedling treatments and also sprayed at 15 day intervals. Two fungal antagonists *viz.*, *T. viride* (T_4) and *T. virens* (T_5) were applied as seed + seedling + soil treatments. Fungicide combinations were integrated with the compatible antagonists to form the treatments like captan + metalaxyl + *T. viride* (T_6), captan + metalaxyl + *T. virens* (T_7), carboxin + metalaxyl + *T. viride* (T_8) and carboxin + metalaxyl + *T. virens* (9).

The data obtained in the year 2003 (Table 24) revealed that all the treatments resulted in significantly lesser wilt incidence as compared to the check. Fungicide combinations were significantly superior to antagonists in minimizing the wilt complex disease, except the treatment carboxin + metalaxyl (50.0% wilt incidence) which was significantly inferior to *T. viride* (T_4) and *T. virens* (T_5) treatments. The treatment, T_6 (captan + metalaxyl + *T. viride*), T_7 (captan + metalaxyl + *T. virens*) and T_2 (carbendazim + metalaxyl), were found highly effective and reduced the incidence of

Table 24 : Effect of fungicides and antagonists alone and in combinations on wilt complex disease of *Capsicum annuum* under glass house conditions

Treatment (ST + SD + Spraying)		Chilli cv. Pusa jawala				Bell pepper cv. California wonder			
		2003	2004	Pooled	Disease reduction over control (%)	2003	2004	Pooled	Disease reduction over control (%)
T_1	Captan + Metalaxyl	33.3 (35.2)	38.8 (38.0)	36.0 (36.8)	63.2	33.3 (35.2)	44.4 (41.7)	38.8 (38.0)	61.2
T_2	Carbendazim + Metalaxyl	25.0 (30.0)	33.3 (35.2)	29.1 (32.6)	70.9	25.0 (30.0)	38.8 (38.0)	31.9 (34.3)	68.1
T_3	Carboxin + Metalaxyl	50.0 (45.0)	55.5 (48.1)	52.7 (46.5)	47.3	58.3 (49.7)	61.1 (51.3)	59.7 (50.5)	40.3
T_4	*T. viride* (Tv_2)	41.6 (39.8)	50.0 (45.0)	45.8 (42.5)	54.2	50.0 (45.0)	55.5 (48.1)	52.7 (46.5)	47.3
T_5	*T. virens* (Gv_3)	41.6 (39.8)	44.4 (41.7)	43.0 (40.9)	57.0	41.6 (40.1)	44.4 (41.7)	43.0 (40.9)	57.0
T_6	$T_1^* + T_4$	25.0 (30.0)	33.3 (35.2)	29.1 (32.6)	70.9	25.0 (30.0)	33.3 (35.2)	29.1 (32.6)	70.9
T_7	$T_1^* + T_5$	25.0 (30.0)	33.3 (35.2)	29.1 (32.6)	70.9	25.0 (30.0)	33.3 (35.2)	29.1 (32.6)	70.9
T_8	$T_3^* + T_4$	41.6 (39.8)	44.4 (41.7)	43.0 (40.9)	57.0	41.6 (40.1)	50.0 (45.0)	45.8 (42.5)	54.2
T_9	$T_3^* + T_5$	33.3 (35.2)	38.8 (38.0)	36.0 (36.8)	63.2	33.3 (35.2)	44.4 (41.7)	38.8 (38.0)	61.2
T_{10}	Control	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	–	100.0 (90.0)	100.0 (90.0)	100.0 (90.0)	–
	CD (p = 0.05)	**3.9**	**3.8**	**3.7**	–	**6.3**	**5.5**	**5.0**	–

Figures in parenthesis are transformed angular value

T_1 = ST, SD @ 0.35%, Spraying @ 0.25%; T_2, T_3, ST, SD @ 0.25%, Spraying @ 0.2%;

T_4, T_5, ST, SD with antagonist suspension (10^7 spores/ml); Soil treatment @ 20 g/plot soil.

*Half dose of fungicides applied as ST + SD

ST – Seed Treatment; SD – Seedling Dip

wilt complex disease. Wilt incidence in each of these treatments was 25.0 per cent. The wilt incidence of 33.3 per cent was observed in captan + metalaxyl (T_1) and carboxin + metalaxyl + *T. virens* (T_9) treatment. The wilt incidence of 50.0 per cent was observed in carboxin + metalaxyl and 41.6 per cent each in *T. viride, T. virens*, and carboxin + metalaxyl + *T. viride* (T_8) treatments.

The data obtained in 2004 also indicated the same trend in results as observed in year 2003. Among the fungicide combinations, carbendazim + metalaxyl (T_2) recorded least wilt incidence of 33.3 per cent followed by captan + metalaxyl (T_1) and carboxin + metalaxyl (38.8 and 55.5%, respectively). *T. virens* (T_5) was significantly better than *T. viride* (T_4) in reducing the wilt disease. The integration of antagonists with captan + metalaxyl proved very effective. The wilt incidence of 33.3 per cent in each captan + metalaxyl + *T. viride* (T_6) and captan + metalaxyl + *T. virens* (T_7) was observed which was significantly lower than the wilt incidence observed in the treatments only with the fungicides (38.8%) or antagonists (44.4% in *T. virens* and 50.0% in *T. viride*). Similarly, the combination of carboxin + metalaxyl + antagonists (T_8 and T_9) yield significantly lower wilt incidence than wilt incidence obtained when fungicides and antagonists were applied separately.

The pooled data of the years 2003 and 2004 revealed the superiority of combinations of captan + metalaxyl + antagonists (Tv_2 or Gv_3) and carbendazim + metalaxyl treatment as the minimum wilt incidence of 29.1 per cent with 70.9 per cent disease reduction over check was observed in each of these treatments. The integration of carboxin + metalaxyl with *T. virens* resulted in 36.0 per cent wilt incidence (63.2% disease reduction over check) which was at par with wilt incidence observed in captan

+ metalaxyl. The least effective treatment was carboxin + metalaxyl which recorded 52.7 per cent wilt incidence although in comparison to 100 per cent wilt incidence in check, this treatment was significantly superior.

(B) Effect of antagonists and fungicides alone and in combinations on wilt complex disease of bell pepper cv. California wonder

The fungicide combinations alone and alongwith antagonists *viz., T. harzianum* (Th_2) and *T. virens* (Gv_3) were tested agaist wilt complex disease in bell pepper during the years 2003 and 2004 under glasshouse conditions. The data presented in Table 24 revealed that in the year 2003, carbendazim + metalaxyl, captan + metalaxyl + *T. harzianum* and captan + metalaxyl + *T. virens* recorded minimum wilt incidence (25.0% in each). The wilt incidence of 33.3 per cent was observed when carboxin + metalaxyl was integrated with *T. virens* compared to 58.3 and 41.6 per cent recorded in individual treatments of carboxin + metalaxyl (T_3) and *T. virens* (T_5), respectively. *T. virens* proved significantly superior over *T. harzianum* in reducing wilt disease.

In the year 2004, carbendazim + metalaxyl recorded significantly lower wilt incidence (38.8%) than other fungicide treatments *viz.*, captan + metalaxyl (44.4%) and carboxin + metalaxyl (61.1%). However, when *T. harzianum* or *T. virens* were applied in combination with captan + metalaxyl (T_6 and T_7) the wilt incidence of 33.3 per cent was recorded in each treatment. Similarly, integration of *T. harzianum* or *T. virens* with carboxin + metalaxyl recorded only 44.4 (*T. virens*) and 50.0 per cent (*T. harzianum*) wilt incidence which was significantly lower than wilt incidence recorded in individual treatments of carboxin + metalaxyl (61.1%), *T. harzianum* (55.5%) and *T. virens* (44.4%).

The pooled data of the years 2003 and 2004 indicated that the highest disease reduction over control of 70.9 per cent each was recorded in T_6 (captan + metalaxyl + *T. virens*) and T_7 (captan + metalaxyl + *T. viride*) treatments, these were followed by carbendazim + metalaxyl (68.1%). The antagonists *T. virens* and *T. harzianum* were also effective as 57.0 and 47.3 per cent disease reduction over check was observed. The treatment carboxin + metalaxyl + *T. virens* and captan + metalaxyl were equally effective and each recorded 61.2 per cent disease reduction over check. The least effective treatment was carboxin + metalaxyl which recorded only 40.3 per cent disease reduction over check.

4.6.3 Field studies

4.6.3.1 Effect of antagonists and fungicides alone and in combinations on wilt complex disease

(A) Chillies cv. Pusa Jawala: The data obtained in the year 2003 (Table 25) indicate that all the treatments were significantly superior over check under field conditions. The wilt incidence recorded in fungicide treatments was significantly lower than that observed with antagonists. Among the fungicidal treatments, carbendazim + metalaxyl was most effective, as only 26.9 per cent wilt incidence was recorded compared to 30.3 and 34.5 per cent observed in captan + metalaxyl and carboxin + metalaxyl, respectively. Gv_3 and Tv_2 recorded 44.4 and 45.9 per cent incidence, respectively, and both were statistically at par with each other. The integration of antagonists with compatible fungicides resulted in the wilt incidence of 26.9 per cent observed in captan + metalaxyl + *T. virens* which was significantly lower than wilt incidence recorded in individual treatments of *T. virens* (44.4% wilt incidence) or

Table 25 : Effect of fungicides and antagonists alone and in combinations on wilt complex disease of *Capsicum annuum* under field conditions

	Treatment (ST + SD + Spraying)	Chilli cv. Pusa jawala							Bell pepper cv. California wonder						
		Wilt incidence (%)			Disease reduction over control (%)	Yield q/ha			Wilt incidence (%)			Disease reduction over control (%)	Yield q/ha		
		2003	2004	Pooled		2003	2004	Pooled	2003	2004	Pooled		2003	2004	Pooled
T_1	Captan + Metalaxyl	30.3 (33.3)	32.4 (34.6)	31.3 (34.0)	48.6	62.7	61.5	62.1	29.3 (32.7)	31.0 (33.8)	30.1 (33.2)	53.6	132.6	128.3	130.4
T_2	Carbendazim + Metalaxyl	26.9 (31.2)	28.3 (32.1)	27.6 (31.6)	54.7	67.2	64.3	65.7	25.2 (30.1)	26.9 (31.2)	26.1 (30.7)	59.8	142.0	135.2	138.6
T_3	Carboxin + Metalaxyl	34.5 (35.9)	38.9 (38.5)	36.7 (37.2)	39.8	58.3	56.7	57.5	32.5 (34.7)	35.6 (36.6)	34.0 (35.6)	47.6	125.2	120.1	122.6
T_4	*T. harzianum* (Th_2)	45.9 (42.6)	50.7 (45.4)	48.3 (38.2)	20.8	47.4	44.8	46.1	50.7 (45.4)	50.7 (45.4)	51.9 (46.0)	20.1	81.5	82.7	82.1
T_5	*T. virens* (Gv_3)	44.4 (41.7)	49.2 (44.5)	46.8 (43.1)	23.2	48.5	45.4	46.9	51.5 (45.8)	52.3 (46.3)	50.0 (45.0)	22.0	83.3	85.3	84.3
T_6	$T_1^* + T_4$	28.3 (32.1)	30.3 (33.3)	29.3 (32.7)	51.9	64.3	62.5	63.9	26.9 (31.2)	27.7 (31.7)	27.3 (32.2)	58.0	138.1	133.2	135.6
T_7	$T_1^* + T_5$	26.9 (31.2)	29.3 (32.7)	28.1 (31.8)	53.9	65.7	63.6	64.6	26.9 (31.2)	26.9 (31.2)	26.9 (31.2)	58.6	139.0	135.1	137.0
T_8	$T_3^* + T_4$	30.3 (33.3)	32.4 (34.6)	31.3 (34.0)	48.6	62.0	60.9	61.4	29.3 (32.7)	32.4 (34.6)	30.8 (33.7)	52.6	132.6	126.5	129.5
T_9	$T_3^* + T_5$	30.3 (33.3)	32.4 (34.6)	31.3 (34.0)	48.6	62.3	61.0	61.6	29.3 (32.7)	31.0 (33.8)	30.6 (33.5)	52.9	133.2	128.5	130.5
T_{10}	Control	58.7 (50.0)	63.4 (52.7)	61.0 (51.3)	–	40.2	37.6	38.9	64.1 (53.1)	66.0 (54.3)	65.0 (53.7)	–	65.8	61.4	63.1
	CD (p = 0.05)	**2.9**	**3.3**	**2.4**	–	**2.9**	**1.9**	**1.8**	**2.3**	**2.4**	**2.0**	–	**4.2**	**3.1**	**3.0**

Figures in parenthesis are transformed angular value

T_1 = ST, SD @ 0.35%, Spraying @ 0.25%; T_2, T_3, ST, SD @ 0.25%, Spraying @ 0.2%;

T_4, T_5, ST, SD with antagonist suspension (10^7 spores/ml); Soil treatment @ 20 g/plot soil.

*Half dose of fungicides applied as ST + SD

ST – Seed Treatment; SD – Seedling Dip

captan + metalaxyl (30.3%). Similarly, only 30.3 per cent wilt incidence was observed in each *T. virens* and *T. viride* when applied in combination with carboxin + metalaxyl (T_8 and T_9).

In the year 2004, similar results were observed as in the year 2003. The treatment carbendazim + metalaxyl recorded minimum wilt incidence of 28.3 per cent followed by captan + metalaxyl + *T. virens* (29.0%) and captan + metalaxyl + *T. viride* (30.3%). The antagonists when applied individually were least effective as 49.2 (Gv_3) and 50.7 (Tv_2) per cent wilt incidence was observed. However, compared to check (63.4% wilt incidence) these antagonist were significantly superior. Carboxin + metalaxyl recorded higher wilt incidence of 38.9 per cent compared to other fungicide treatments. When antagonists (Gv_3 and Tv_2) were used in combination with carboxin + metalaxyl (T_8 and T_9) the wilt incidence of 32.4 per cent was recorded in each treatment which was at par with captan + metalaxyl treatment.

The pooled data of the years 2003 and 2004 revealed that carbendazim + metalaxyl recorded highest disease reduction over check (54.7%), it was followed by captan + metalaxyl + *T. virens* (54.2%) and captan + metalaxyl + *T. viride* (51.9%), respectively. The integration of carboxin + metalaxyl with either *T. virens* or *T. viride* proved effective under field conditions. Carboxin + metalaxyl + *T. virens*, carboxin + metalaxyl + *T. viride* and captan + metalaxyl were equally effective and each recorded 48.6 per cent disease reduction over check. The fungicide combination of carboxin + metalaxyl was least effective treatment compared to other fungicide treatments as only 39.8 per cent disease reduction over check was observed. However, the treatment was better than antagonist treatments which recorded 20.8 (*T. viride*) and 23.2 per cent (*T. virens*) disease reduction over check.

(B) Bell pepper cv. California Wonder: The data obtained in the year 2003 presented in Table 25 indicated the superiority of fungicides over antagonists. Among the fungicides the minimum wilt incidence (25.2%) was observed in carbendazim + metalaxyl followed by 29.3 per cent observed in captan + metalaxyl. The least effective fungicide combination was carboxin + metalaxyl which recorded 32.5 per cent wilt incidence. The wilt incidence of 26.9 per cent each in carboxin + metalaxyl + *T. harzianum* and carboxin + metalaxyl + *T. virens* was observed, which was significantly lower than wilt incidence observed in individual treatments of carboxin + metalaxyl (29.3%), *T. harzianum* (50.7%) and *T. virens* (51.5%). The integration of carboxin + metalaxyl with *T. harzianum* or *T. virens* (T_8 and T_9) resulted in lesser wilt incidence (29.3% in each treatment) compared to wilt incidence in their individual treatments.

In the year 2004 also, carbendazim + metalaxyl, captan + metalxyl + *T. virens* and captan + metalaxyl + *T. harzianum* proved more effective than other treatments as wilt incidence of 26.9, 26.9 and 27.7 per cent, respectively, was observed. The antagonists *T. harzianum* (50.7% wilt incidence) and *T. virens* (52.3% wilt incidence) were found least effective treatments, though superior over check (66.0%). The wilt incidence of 31.0, 32.4 and 31.0 per cent was recorded in carboxin + metalaxyl + *T. harzianum*, carboxin + metalaxyl + *T. virens* and captan + metalaxyl, respectively. These treatments were statistically at par with each other.

The pooled data of the years 2003 and 2004 also showed the effectiveness of carbendazim + metalaxyl under field conditions as 59.8 per cent disease reduction over check was observed, followed by treatments T_7 (captan + metalaxyl + *T. virens*) and T_6 (captan + metalaxyl + *T. harzianum*) which recorded 58.6 and 58.0 per cent disease reduction over check, respectively. The treatments T_1 (captan + metalaxyl), T_9 (carboxin + metalaxyl + *T. virens*) and T_8 (carboxin + metalaxyl + *T. harzianum*) were almost equally effective and recorded 53.6, 52.9 and 52.6 per cent disease reduction over check, respectively. Among fungicide treatments, carboxin + metalaxyl was less effective although it was superior over fungal antagonist and check recording 47.6 per cent disease reduction over check. The fungal antagonists *T. virens* and *T. harzianum* recorded 22.0 and 20.1 per cent disease reduction over check, respectively.

4.6.3.2 Effect of antagonists and fungicides alone and in combinations on yield

(A) Chillies cv. Pusa Jawala: It is evident from the Table 25 that the treatments which were effective in reducing the wilt complex disease under field conditions resulted in higher yield/ha than the treatments which were less effective in minimizing the disease. The data obtained during 2003 revealed that highest yield (67.2 q/ha) was observed in carbendazim + metalaxyl treatment which was followed by 65.7 and 64.3 q/ha obtained in captan + metalaxyl + *T. virens* and captan + metalaxyl + *T. viride*, respectively. These treatments were statistically at par with each other. Although captan + metalaxyl when applied alone without integration with antagonists recorded significantly lower yield (62.7 q/ha) than carbendazim + metalaxyl (67.2 q/ha), however, integration of captan + metalaxyl with Th_2 or Gv_3 resulted in higher yields of 64.3 and 65.7q/ha, respectively, which were statistically at par with the yield recorded in carbendazim + metalaxyl treatment. The combination of carboxin + metalaxyl with *T. viride* or *T. virens* (T_8 and T_9) resulted in 62.0 and 62.3 q/ha yield, respectively, which was significantly higher than yield realised in individual treatments of carboxin + metalaxyl (58.3 q/ha) and *T. viride* (47.4 q/ha) or *T. virens* (48.5 q/ha). All the treatments recorded significantly higher yield than check (40.2 q/ha).

The data obtained in the year 2004 also revealed the superiority of all the treatments over check. The most effective treatment which recorded the highest yield (64.3 q/ha) was carbendazim + metalaxyl, it was followed by carbendazim + metalaxyl + *T. virens* (65.7 q/ha) and carbendazim + metalaxyl + *T. viride* (64.3 q/ha). The higher yields were observed in carboxin + metalaxyl + *T. virens* (62.3 q/ha) and carboxin + metalaxyl + *T. viride* (62.0 q/ha) compared to individual treatments of carboxin + metalaxyl (56.7 q/ha) and *T. virens* (45.4 q/ha) or T. *viride* (44.8 q/ha). No significant difference was observed between the yields observed in two antagonists. Although antagonists recorded the lower yield, but compared to 37.6 q/ha observed in check, it was significantly superior.

The pooled data of the years 2002 and 2003 revealed that highest yield of 65.7 q/ha was recorded in the treatment T_2 (carbendazim + metalaxyl) followed by non-significantly different yield of 63.9 and 64.6 q/ha in the treatment T_6 (captan + metalaxyl + *T. viride*) and T_7 (captan + metalaxyl + *T. virens*), respectively. The yield of 62.1, 61.6 and 61.4 q/ha was observed in the treatment T_1 (captan + metalaxyl), T_8 (carboxin + metalaxyl + *T. viride*) and T_9 (carboxin + metalaxyl + *T. virens*), respectively. Among the fungicide treatments the lowest yield was observed in carboxin + metalaxyl (57.5 q/ha). However, this was significantly superior to fungal antagonists and check. Treatment T_4 (*T. viride*) recorded the yield of 46.1 q/ha which was statistically at par with 46.9 q/ha, the yield observed in treatment T_5 (*T. virens*), but was significantly higher than check (38.9 q/ha).

(B) Bell pepper cv. California Wonder: An insight of the data obtained in the year 2003 presented in Table 25 clearly indicated the superiority of carbendazim + metalaxyl treatment in bell pepper. The highest yield of 142.0 q/ha was observed in carbendazim + metalaxyl followed by statistically at par 139.0 q/ha in captan + metalaxyl + *T. virens* and 138.1 q/ha in captan + metalaxyl + *T. harzianum*. The least effective fungicide treatment was carboxin + metalaxyl which recorded 125.2 q/ha yield. However, integrating antagonists with carboxin + metalaxyl showed better results. The yield of 133.2 and 132.6 q/ha was observed in carboxin + metalaxyl + *T. virens* and carboxin + metalaxyl + *T. harzianum*, respectively. The yields observed in these two treatments were statistically at par with the yield obtained in captan + metalaxyl (132.6 q/ha).

In 2004, the results indicate that all the treatments were significantly superior over check, however, fungicides were significantly better than antagonists. The highest yield of 135.2, 135.1, 133.2 q/ha was observed in carbendazim + metalaxyl, captan + metalaxyl + *T. virens* and captan + metalaxyl + *T. harzianum*, respectively. Although only 120.1 q/ha yield was observed in carboxin + metalaxyl treatment but in combination with *T. virens* or *T. harzianum* (T_8 and T_9) significantly higher yields of 128.5 and 126.5 q/ha, respectively, was obtained. Lower yields of 82.7 and 85.3 q/ha was obtained in *T. harzianum* and *T. virens*, respectively, however, these yields were significantly better than the yield of 61.4 q/ha recorded in check.

The perusal of pooled data revealed the superiority of carbendazim + metalaxyl treatment over other fungicide combinations. Carbendazim + metalaxyl recorded the yield of 138.6 q/ha which was significantly greater than the yield observed in captan + metalaxyl (130.4 q/ha) and carboxin + metalaxyl (122.6 q/ha). The two fungal antagonists recorded lesser yield compared to other treatments although in comparison to check, the yield was significantly higher. *T. harzianum* resulted in 82.1 q/ha which was statistically at par with 84.3 q/ha observed in *T. virens*. The treatment captan + metalaxyl + *T. virens* recorded 137.0 q/ha yield followed by 135.6 q/ha in captan + metalaxyl + *T. harzianum*. These two treatments were statistically at par with carbendazim + metalaxyl treatments. The yield of 130.5 and 129.5 q/ha was observed in carboxin + metalaxyl + *T. virens* and carboxin + metalaxyl + *T. harzianum*, respectively. These treatments were statistically at par with captan + metalaxyl. The data also indicates that all the treatments recorded significantly higher yield than checked (63.1 q/ha).

CHAPTER - 5

Discussion

DISCUSSION

Wilt complex disease is one of the major constraints in the successful cultivation of chilli and bell pepper crops in Jammu and Kashmir. The disease is known to be caused by a number of fungal species belonging to *Fusarium, Rhizoctonia, Phytophthora, Sclerotium* and *Verticillium* genera (Wanghiliar *et al.*, 1980; Dar and Mir, 1995a; Shali, 2000). Establishing the status of the disease is pre-requisite for determining disease management practices, and forms the basic component of decision-making in intergrated disease management. Therefore, surveys were undertaken in five districts *viz.*, Kathua, Jammu, Udhampur, Doda and Rajouri of Jammu province during the present investigation. The wilt complex was found to prevail in almost all the fields surveyed with overall average wilt incidence of 54.56 and 48.96 per cent in the year 2001 and 2002, respectively. The reduction in the incidence of disease recorded in the year 2002 as compared to 2001 seems to have occurred because of lesser precipitation received in 2002 (*Appendix II and III*) which possibly predisposes the host to disease (Verma and Sharma, 1995). During the survey it was observed that disease incidence varied in different districts as Rajouri district recorded lesser wilt incidence to the extent of 38.0 and 36.4 per cent during the year 2001 and 2002, respectively, whereas, it was maximum in Doda district, *i.e.* 69.37 and 64.22 per cent during the year 2001 and 2002, respectively. The variation in wilt incidence may be attributed to the agroclimatic conditions prevailing at different locations. The successive cultivation and monoculture of bell pepper crop in Doda may be the reason of higher wilt incidence in the district. Earlier, Shali (2000) had also recorded 33.15 to 50.33 per cent disease incidence in Jammu region. Najar (2001) recorded wilt incidence of 62.67 and 45.77

per cent in Kashmir valley during the year 1996 and 1997, respectively. The wilt complex has also attained the status of a major disease in most areas of Haryana with an incidence of 20 to 60 per cent and yield losses upto 100 per cent (Anonymous, 1987). Kaur (1993) reported the severity of chilli wilt from Punjab with 100 per cent crop loss in some genotypes.

The present studies indicated that *Fusarium oxysporum, Phytophthora capsici* and *Rhizoctonia solani* were associated with *Capsicum annuum* in all the districts surveyed, causing wilting alone and also in associations, however, *Sclerotium rolfsii* was not found causing the disease independently except in district Rajouri, where its independent occurrence was 13.0 and 7.6 per cent in the year 2001 and 2002, respectively. The studies revealed that *F. oxsporum* was the most dominant pathogen associated with *C. annuum* in all tthe five districts surveyed followed by *P. capsici* and *R. solani* Different workers have ascribed the wilt complex disease to infection by different species of *Fusarium* such as *F. annuum* (*F. oxysporum*) (Crawford, 1934), *F. oxysporum* f. sp. *vasinfectum* (Grover and Singh, 1970), *F. oxysporum* (Vidhyasakaran and Thiagrajan, 1981; Black and Rivelli, 1991), *F. pallidorosium* (Thind and Jhooty, 1985; Kaur, 1993), *F. moniliforme* (Hashmi, 1989), *F. solani* and *F. equiseti* (Koleva and Vitanov, 1990; Moens and Benaicha, 1990). Wilt disease in *C. annuum* has also been reported to be caused by *P. capsici* (Leu and Kao, 1981; Fernandez, 1983; Ahmad *et al.*, 1989; Shali, 2000), *R. solani* (Almedia *et al.*, 1980; Alavi *et al.*, 1986; Moens and Benaicha, 1990; Dar and Mir, 1995a) and *S. rolfsii* (Wanghiliar *et al.*, 1980). Mushtaq and Hashmi (1997) had also isolated *F. oxysporum* and *R. solani* from the roots of *C. annuum* showing symptoms of wilting.

Different types of wilt or wilt-like symptoms were found to be caused by different pathogens. The major characteristic symptoms caused by *F. oxysporum* were epinasty of leaves, petioles and branches, vein clearing, chlorosis of leaves, vascular browning and outright killing of plants. The symptoms incited by *R. solani* were characterised by root rot leading to wilting. The initial symptoms were the inward curling and folding of upper most young leaves. The roots were pale initially and turned brown with water soaked appearance. The symptom produced by *P. capsici* were characterised by sudden wilting of plants caused by rotting of the stem near the soil surface. The aerial parts of plants such as, leaves petioles, fruits, stems and branches become locally rotted starting with small, water soaked blackish lesions. The distinct symptoms incited by *S. rolfsii* were dark brown lesions just below the soil line, and in high moisture levels, the fungus covered the stem lesions with a cottony, white mass of mycelium and small, white, roundish sclerotia of uniform size, which turned dark brown to black on maturity. Similar wilt symptoms developed in *C. annuum* plants were also described by other workers (Alavi *et al.,* 1986; Wani,1994; Hwang and Kim, 1995; Mathur and Gurjar 2001). The production of fusaric acid (Gaumann, 1957) macro molecular polysaccarides (Dimond,1955) and the physical blockade of vascular bundles (Beckman, 1987) by hyphae of *Fusarium* spp. have been found responsible for the production of wilt symptoms in plants, whereas, the production of macerating pectolytic/cellulolytic enzymes by *R. solani, P. capsici, S. rolfsii* and other fungi have been explained to cause root rot symptoms (Bateman, 1970; Baruah *et al*., 1985)

A field study revealed that *F. oxysporum* and *R. solani* were prevalent in all the stages of crop growth. The occurrence of *P. capsici* was restricted to rainy and wet months of crop season. In the year 2001, the infection of *P. capsici* started only after

10th of June and in 2002 after 1st of July. All these pathogens are known to attack the plants in all growth stages when the environmental conditions are favourable and no specificity has been observed towards a particular growth stage. However, *P. capsici* is known to infect the plants only under high soil moisture conditions and spread rapidly during prolonged rainy weather (Hwang and Kim, 1995). Elenkov and Khrelkeva (1977) also reported that the rains and run-off water appeared to be the means of *P. capsici* spread. The correlation matrix of disease incidence with soil moisture and temperature indicated highly significant and positive correlation (correlation coefficient 0.913 in 2001 and 0.897 in 2002) between soil moisture and wilt incidence. Similarly, minimum soil temperature was also significantly and positively correlated (correlation coefficient 0.653 in 2001 and 0.752 in 2002) with wilt disease. However, maximum temperature did not showed any correlation with wilt incidence. These findings are supported by earlier workers also, who reported that soil moisture levels had been found influncing the severity of wilt and root/collar rot disease (Pontis, 1940 and Beattie *et al.*, 1944). Strong (1946) also reported that wet soils with high moisture favour Fusarium wilt of tomato. Hot weather of 30^{0}C and soil moisture of 40 per cent has proved conducive for Fusarium wilt in vegetable crops (Nelson, 1981). Schlub (1983) observed that soil moisture more positively correlated with disease incidence than temperature in *P. capsici* pathosystem. Dar and Mir (1995a) were of the same view that frequent rains which maintained high soil moisture during crop growth (chilli) aggravated Fusarium wilt disease.

Managing wilt complex disease which is seed and soil borne in nature is quite difficult. However, various measures to manage it in different parts of world aim at eliminating or at least reducing the primary inocuiam in soil or in/on seed and propagating material, besides making the hosts evade or defend the attack of the pathogens involved.

Inherent resistance or tolerance of crop plants to infection by the pathogen can most likely be a safe, most economical and eco-friendly disease management practice. While identifying the chilli and bell pepper genotypes/varieties having resistance to wilt complex pathogens *viz.*, *F. oxysporum, R. solani, P. capsici* and *S. rolfsii* in field and glasshouse conditions it was observed that out of 38 genotypes/varieties only SC-108 (01), SC-105 and Suraj Mukhi were moderately resistant. These lines could be used for hybridization programme to evolve cultivars possessing desirable traits besides resistance to wilt pathogens. Ahmad *et al.* (1994) identified 16 out of 142 chilli lines resistant to Fusarium wilt under natural epiphytotic conditions. Masalwadi cultivar of hot pepper showed immune reaction to *F. pallidoroseum* under field and controlled conditions, whereas, 20 other genotypes showed moderately to highly resistant reaction (Nayeema *et al.*, 1995). Albegbejo and Ernile (2000) found only one line, 2230, out of six pepper lines resistant to *P. capsici* in pot trials, whereas, four lines 2298, 2284, 3289 and 2227 were moderately resistant. Muhyi and Bosland (1995) identified *Capsicum annuum* accessions "long chilli" (a Korean hybrid) and "PI 167061" resistant against *R. solani.*

Most soil-borne plant diseases are being successfully managed by modifying cultural practices, to the disadvantage of the pathogens and helping to reduce the pathogen population or their contact with the host surface. Studies were carried out to observe the effect of four levels of irrigation, four levels of fertilizer and two planting methods on wilt incidence and yield of chilli and bell pepper. It was revealed that the varying irrigation frequencies had a significant influence on the wilt incidence. The application of irrigation at an interval of 11 days recorded significantly lower wilt incidence (37.0 and 44.1% in chillies and bell pepper, respectively) than observed in irrigation frequencies of 5, 7 and 9 day intervals. However, the application of irrigation at 7 day intervals, although being at par with 9 days interval recorded significantly higher yield (45.2 and 92.1 q/ha in chillies and bell pepper, respectively) than 5 and 11 days of irrigation intervals. Similar observations were also recorded by Baris *et al.* (1986) and Vitanov (1989), who also reported that restricting irrigation checked the incidence of wilts and root and crown rot diseases. Kim (1989) observed a strong relationship between soil water content and disease incidence in a green house study and reported that low level of soil water greatly suppressed the development of Phytophthora blight of peppers. The present findings were also supported by the observation made by Ristaino (1991), who reported that frequent irrigation have been found to favour bell pepper root and crown rot. The lower yields observed when the irrigation was applied at 11 day intervals, although it recorded least wilt incidence may be because of moisture stress conditions prevailed due to delayed irrigation.

Manipulation in the levels of chemical fertilizer application so as to keep the disease at low ebb, while at the same time meeting the nutritional requirement of plant is viewed as a step towards managing the disease. Among the application of fertilizer combinations 80N + 72P + 42K kg/ha though at par with 80N + 84P + 36K kg/ha produced significantly lower wilt incidence (48.2 and 43.1% in 2002 and 2003, respectively) than 100N + 60P + 30K and 120N + 60P + 30K kg/ha in chilli cv. Pusa Jawala. In bell pepper crop, the fertilizer combination 80N + 84P + 42K produced significantly lower wilt incidence (52.9 and 45.7% in 2002 and 2003, respectively) and higher yield (89.9 and 95.8 q/ha in 2002 and 2003, respectively) than other fertilizer combinations in both the years of experimentation.The increased severity of soil-borne diseases by the application of higher doses of nitrogenous fertilizer has also been observed by other workers in celery, cabbage and maize (Schneider, 1985; Singh *et al.*, 1989; Dwivedi *et al.*, 1990). Sharma and Sohi (1983) also reported enhanced Phytophthora blight of pepper with the application of higher doses of nitrogen. Kiraly (1976) observed reduced severity and root rot caused by *Fusarium* spp. with higher dose of potassium. Increased wilt incidence by the application of higher doses of nitrogen is believed to be because of increased succulence of host tissue resulting on account of increaed collenchymatous and decreased sclerenchymatous cell proliferation (Dwivedi and Shukla, 1981). The increased levels of aminoacids and polyphenol oxidase and reduction in phenols and non-reducing and total sugars in plants applied with higher nitrogen doses have also been advocated for the increased infection by fungal pathogens (Kiraly, 1976; Ramasamy and Prasad, 1975b). The contradictory observations have been made by different workers regarding the application of higher doses of phosphorus in different crops. Woltz and Jones (1981) reported increased severity of Fusarium wilt of tomato with higher levels of phosphorus. Similarly, Sharma and Sharma (1991) have also recorded higher incience of maize Turicum blight with higher levels of phosphorus fertilization. However, it has also been reported that increased levels of phosphorus increases resistance against a number of disease in different crops and is not favouring susceptibility to disease like higher nitrogen application (Das, 1996; Patnaik, 1997). The reduced wilt incidence following increased K_2O fertilizer application, as recorded during the present study, also derives support from the findings of Kannaiyan and Prasad (1974), Schneider (1985) and Gandhi *et al.*

(1993). It is believed that the synthesis of high molecular weight compounds like proteins, starch and cellulose in K-deficient plants get impaired and low molecular weight compounds accumulated which increase susceptibility to pathogen infection (Huber, 1980). The present studies also revealed that ridge planting proved superior over flat-bed planting method in reducing wilt disease and increased the yield in both the crops. The unavailability of free flowing water on the ridges for easy dissemination and movement of pathogen propagules perhaps also checks the wilt menace in pepper crop. Phytophthora blight of chilli has been checked by similar practices (Ferreyra *et al.*, 1984; Baris *et al.*, 1986). In a field experiment conducted with varying ridge heights from 0 – 45 cm, ridge heights of 15 – 30 cm greatly reduced incidence of Phytophthora blight and increased fruit yield when compared to the non-ridges fields. These results are in conformity with those of Dar and Mir (1995b) and Verma and Sharma (1995).

The management of plant pathogens, using biocontrol agents, has assumed significance on account of ill-effects of conventional use of chemical measures for disease control and has become quite popular strategy to manage especially those diseases which are soil-borne in nature and, hence, difficult to manage by most popular method, using chemical fungicides. In the present investigation, attempts were made to identify the effective biocontrol agents against all the wilt complex pathogens *viz.*, *F. oxysporum, R. solani, P. capsici* and *S. rolfsii*. The *in vitro* bioassay of 23 isolates of fungal antagonists, using dual culture technique, revealed that five isolates *viz., Trichoderma viride* (Tv_2, Tv_5), *T. harzianum* (Th_2, Th_4) and *T. virens* (Gv_3) were most effective against all the wilt complex pathogens. The antagonist isolates Tv_2, Tv_5 and Th_2 overgrew 75 per cent of mycelial surface of *F. oxysporum, P. capsici* and *S. rolfsii* and were categorized in Class 2 as per Bell's Scale (Bell *et al.*, 1982). Tv_2 and Th_2 completely overgrew mycelial surface of *R. solani* and were categorized in Class 1. Isolate Gv_5 was effective against *S. rolfsii* and *P. capsici* but not against *F. oxysporum* or *R. solani*. Similarly, *Aspergillus flavus* overgrew 75 per cent mycelial surface of *R. solani* and *S. rolfsii* but only 50 per cent mycelial surface of *F. oxysporum* and *P. capsici*. *Trichoderma* and *Gliocladium* are known to be potential antagonists of fungal plant pathogens (Papavizas, 1985) but differences are reported in the comparative biocontrol potential of different species, as well as isolates (Lumsden and Locke, 1989). D'Souza *et al.* (2001) also reported the mycoparasitic nature of *T. harzianum* isolates on *P. capsici*, *Colletotrichum capsici*, *R. solani* and *S. rolfsii*. The mycoparasitic nature of *Trichoderma* spp. has also been reported by other workers (Prashanthi *et al.*, 2000; Girija and Umamaheshwaran, 2003).The overgrowth of *A. niger* and *A. flavus on Fusarium udum* colonies under *in-vitro* conditions was observed by Panday and Upadhyay (2000). It is a well known fact that there is sufficient selectivity of isolates of *Trichoderma* spp. in their antagonistic efficiency towards a particular pathogen (Cook and Baker, 1983). Reports (Elad *et al.*, 1980; Mukherji and Sen, 1992) showed that while some isolates of *Trichoderma* spp. were highly antagonistic to some pathogens yet there was a clear isolate variability in the degrees of parasitism. The present findings revealed that overgrowth of pathogen surface was not observed in case of Th_4, Gv_3, Tv_6, Tv_8, Gv_1, *Aspergillus niger* (An_1) and An_2 isolates, however, these isolates produced inhibition zones in dual culture against all the pathogens. The production of zone of inhibition indicate that these isolates produced some factors responsible for antibiosis in the pathogens. The present findings are also in conformity with those of Selvarajan and Jeyarajan (1996), who also reported that *T. viride* and *T.*

harzianum produced zone of inhibition against *F. solani* and *Macrophomina phaseolina*. Prashanthi *et al.* (2000) observed that *Aspergillus niger* produced zone of inhibition with *Rhizoctonia bataticola* under *in-vitro* conditions. Highley *et al.* (1996) showed that chemical substances characterized as gliotoxin and gliovirin were produced by *Gliocladium* sp., which were responsible for the formation of inhibition zone.

During the course of present study, the fungal antagonists *viz.*, *Trichoderma viride* (Tv_2, Tv_5), *T. harzianum* (Th_2, Th_4) and *T. virens* (Gv_3), which proved most effective under *in-vitro* conditions, were evaluated as seed treatment, soil treatment and seed + soil treatment against wilt complex pathogens under glasshouse conditions. Seed + soil application of fungal isolates resulted in significantly higher seedling emergence of 60.3 per cent (chillies) and 59.7 per cent (bell pepper) compared to seed (58.2% in chilli and 55.0% in bell pepper) or soil (56.8% in chilli and 56.5% in bell pepper) application alone. Soil treatment of antagonists was not as effective as seed treatment of the same antagonists in increasing seedling emergence. The maximum increase in seedling emergence (26.1%) of chilli was by seed + soil application of Gv_3, followed by Tv_2 (23.3%). However, maximum increase in seedling emergence (20.1%) of bell-pepper was observed in Th_2 followed by Gv_3 (18.2%). Since seedling emergence is the manifestation of the seed vigour and viability under the favourable edaphic, ecological and physiological conditions, absence or malfunctioning of any of these factors is likely to reduce seedling emergence. Plant pathogens are one of such biotic factors, when present in the soil or in/on seed coat hinder and/or hamper the normal process of seed germination. The antagonists seems to inhibit or restrict the growth of pathogens either by the process of antibiosis or mycoparasitism and thus tend to improve seedling emergence. *Trichoderma* induced increased growth response has been reported for various plant species, including vegetables. The production of plant hormones, vitamins, conversion of non-utilizable materials into a form that can be utilized by the plant, and increased uptake and translocation of minerals by *Trichoderma* spp. have also been suggested as a possible mechanism for increased seedling emergence (Baker,1989; Kleifeld and Chet, 1992). The present findings are supported by Bunker and Mathur (2001), who reported that seed + soil application of *Trichoderma harzianum* and *T. viride* resulted in much better seedling emergence of *Capsicum frutescens* as compared to either seed or soil application of these biocontrol agents. The release of nutrient through exudation of seeds stimulate the activity of microbes in the speromosphere, material released include large amount of sugars, amino acids, vitamins, etc. (Woodcock, 1962). The reason for effectiveness of seed treatment may be that the antagonists applied on seeds have the advantage of colonizing the spermosphere in less competition compared to antagonists applied in soil and are better placed to protect the seeds from the attack of pathogens thereby decreasing the seed mortality. Kumar and Dubey (2002) found that better seed germination was observed when *Gliocladium virens* was applied on seeds compared to soil application against *R. solani* causing web blight of winged bean. However, contradictory findings were reported by Prasad *et al.* (2002) that soil application of antagonists was found significantly better in increasing seedling emergence than applying antagonists on seed.

The glasshouse studies revealed that seed + seedling + soil application of *T. virens* (Gv_3) and *T. viride* (Tv_2) in chilli and *T. harzianum* (Th_2) in bell pepper resulted in lesser wilt incidence compared to only seed + seedling or soil treatment of these antagonists. These antagonist isolates, when used as seed + seedling + soil treatment, protected the chilli and bell pepper plants upto 100 days after transplanting and resulted in lesser wilt incidence of 41.6 per cent each in Tv_2 and Gv_3 in chilli and, 33.3 and 50.0 per cent in Gv_3 and Th_2, respectively, in bell pepper, compared to 100 per cent wilt incidence at and after 40 DAT in both the crops in check. These results are in agreement with observations made by Rao and Sitaramaiah (2000), who observed that seed + soil treatment of *Trichoderma* spp. were effective in controlling the collar rot disease of groundnut to the maximum extent, and the least success was observed when the antagonists were applied only in soil. Rhizosphere establishment and proliferation of antagonists applied on seed and soil for suppression of soil-borne plant diseases has been reported by many workers (Clique and Scheffer, 1996; Prasad *et al.*, 2002). The growth inbibition of wilt complex pathogens in presence of *Trichoderma* spp. could be attributed mainly due to competition, antibiosis or hyperparastisim. The *Trichoderma* spp. are known to produce chitinases or β (1-3) glucanases enzymes which lead to the lysis of *Rhizoctonia* and *Sclerotium* (Wu *et al.*, 1986). Some chemical substances released by *Trichoderma* spp. like non-volatile sesquiterpene antibiotic *Trichoderma* 1, 2 and 3 inhibit the growth of *Rhizoctonia* and *Sclerotium* (Godfredson and Vangedal, 1965). Similar mechanisms may be operating in the present investigations, where *Trichoderma* spp. significantly reduced wilt disease to the maximum extent when applied through seed + seedling + soil treatment. These results were in general agreement with the results of Chet *et al.* (1982), who also observed that the fungal antagonist *Trichoderma harzianum* when applied both through soil and seed treatments increased the *Trichoderma* population density in the plots by 4 to 27 times and significant reduction in *R. solani* and *S. rolfsii* was observed.

In the present studies nine fungicides were evaluated at different concentrations under *in-vitro* conditions against the four wilt complex pathogens by poisoned food technique. It was observed that carbendazim was completely inhibitive against *Fusarium oxysporum* at all the concentrations tested (50, 100, 250 ppm) and against *R. solani* at 250 ppm. concentration. Similar observations have been recorded by Sharma *et al.* (2002) with respect to carbendazim, copper oxychloride, captan and metalaxyl against *F. oxysporum*. The authors reported that carbendazim was completely effective against *F. oxysporum* at 500 ppm concentration. The present studies revealed that metalaxyl was the most effective fungicide against *Pytophthora capsici* at all concentrations tested followed by metalaxyl + mancozeb (Ridomil MZ) which was completely inhibitive at 250 ppm concentration. Babadoost and Islam (2003) reported mefenoxam and metalaxyl were highly inhibitory to mycelial growth of *P. capsici* under *in-vitro* conditions. They found that effective dose (ED 50) of mefenoxam and metalaxyl for 50% inhibition of mycelial growth for all isolates of *P. capsici* was 0.98 and 0.99 μg a.i. / ml of culture medium, respectively. The present studies further revealed that a number of fungicides *viz.,* carboxin (50 ppm), thiophanate methyl (250 ppm) and carbendazim (250 ppm) completely inhibited the growth of *R. solani*. The efficacy of carbendazim, captan, thiophanate methyl, and carboxin against *R. solani* under *in-vitro* conditions has also been advocated by other researchers (Dubey and Patel, 2001; Upmanyu *et al.*, 2002). The most effective fungicide against *Sclerotium rolfsii* was captan, followed by metalaxyl + mancozeb. The findings were in confirmity with observations made by Chowdhary *et al.* (1998), who also reported that captan was found inhibitory to the growth of *S. rolfsii* causing wilt of bell pepper crop.

The evaluation of various seed treatments with different fungicides and their suitable combinations revealed that all the fungicides and their combinations resulted significantly superior seedling emergence of chilli and bell pepper, compared to check under glasshouse conditions. Four fungicides *viz.*, captan, carbendazim, metalaxyl and carboxin, found to be most effective under *in-vitro* conditions and four combinations of these fungicides *viz.*, captan + metalaxyl, captan + carbendazim, carbendazim + metalaxyl and carboxin + metalaxyl were tested under glasshouse conditions to observe their effectiveness on seedling emergence of chilli and bell pepper crops. In chilli, carbendazim + metalaxyl recorded maximum increase in seedling emergence over check (47.7%), followed by captan + carbendazim (45.9%). The fungicides (carbendazim + metalaxyl) recorded maximum increase in seedling emergence (56.5%) over check followed by captan + carbendazim (51.7%). The increase in germination percentage by carbendazim, captan, metalaxyl and other fungicides in tomato and pumpkin have been reported by other workers also (Wokocha, 1990; Babadoost and Islam, 2003). Sharma *et al.* (2002) also observed that highest germination percentage of linseed was obtained with Bavistin followed by Benomyl. The better efficacy of increasing the seedling emergence as exhibited by carbendazim + metalaxyl in the present study might be because of their effectiveness against *F. oxysporum, P. capsici* and *R. solani*. Besides the fungicide action against pathogens the beneficial side effects of carbendazim + metalaxyl like seed germination, promotion of seedling growth, etc. are well known (Kenerley *et al.*, 1984; Nene and Thapliyal, 1997).

In attempts to manage the disease, the fungicides were tested as seed + seedling treatment alone and in combination with spraying at 15 day intervals at crown region of the plant, under glasshouse conditions. The findings revealed that seed + seedling treatment with fungicides protected the plants only upto 40 days after transplanting (DAT), resulting in significantly lesser wilt incidence than control (100% wilting). However, in this method of treatment, 100 per cent wilting was observed at 80 DAT. Seed + seedling treatment, followed by spraying with carbendazim + metalaxyl and captan + metalaxyl resulted in significantly lesser wilt incidence of 25.0 and 29.1 per cent in chilli and 25.0 and 33.0 per cent in bell pepper, respectively, even after 100 DAT. The seed + seedling treatment + spraying with captan + carbendazim and carboxin + metalaxyl also recorded significantly lower wilt incidence (37.4 and 54.1% in chillies and 45.8 and 58.3% in bell pepper, respectively) as compared to fungicides applied only as seed + seedling dip treatment or check. These findings are supported by the observations made by Simons *et al.* (1990), who reported that spraying metalaxyl directly at the lower stem of bell pepper plants gave effective control of root rot disease caused by *Phytophthora capsici*. Mejia-Jesus *et al.* (1990), while trying to control pepper wilt caused by *P. capsici* observed that metalaxyl could give some protection to plants from the pathogen to control Phytophthora blight effectively. Sugha (2001) got significant reduction in the incidence of white rot of pea caused by *Sclerotinia sclerotium* with seed treatment of Bavistin + Thiram and three fortnightly foliar sprays of Bavistin starting with the initiation of flowering. Upmanyu *et al.* (2002) observed that the fungicidal seed treatment alone and in combination with foliar sprays reduced the incidence of root rot and severity of web blight of French bean caused by *R. solani*. They found carbendazim seed treatment and its foliar sprays given at fortnightly intervals was best treatment against root rot and web blight of French bean. Although fungicides as drench around stems of plant seems to be more effective than using sprays at crown region of plants but fungicidal drench has not been widely practiced by farmers, since it is more laborious and relatively expensive.

Managing the soil-borne disease by integrating all available methods is the need of the hour. Keeping in view the disadvantages of excessive use of chemicals, and less effectiveness of other methods it has been advocated to integrate all methods *viz.*, biological, cultural, physical and chemical tools in a way that minimize economic, health and environmental risks. *In-vitro* evaluation for compatibility of different fungicides *viz.*, carbendazim, carboxin, captan and metalaxyl with the effective antagonists like *Trichoderma viride* (Tv_2), *T. harzianum* (Th_2) and *T. virens* (Gv_3) revealed that mycelial growth of all the antagonists was completely inhibited at all tested concentrations of carbendazim. The best compatibility of tested antagonists was observed with carboxin. The growth of antagonists was slightly inhibited by metalaxyl at higher concentrations and significantly lesser growth of antagonists was observed at all tested concentrations of captan. These findings are in agreement with the findings of Mukhopadhyay *et al.* (1992), who also reported the insensitivity of *Trichoderma* and *Gliocladium* species against carboxin. The differential response of antagonistic flora to various fungicides might be due to their inherent resistance to the fungicides and their ability to degrade chemicals (Papavizas, 1985). Kumar and Dubey (2001) observed that carbendazim at 0.05 per cent concentration completely inhibit the growth of *Trichoderma herzianum* and *Gliocladium virens*, however, carboxin showed low inhibition of antagonists followed by captan. Vijayaraghavan and Abraham (2004) also observed that metalaxyl slightly inhibited the growth of *Trichoderma* spp. *in-vitro* as has also been revealed in the present findings.

In the integrated management strategies, the fungicides (captan + metalaxyl, carbendazim + metalaxyl and carboxin + metalaxyl) and bioagents (*Trichoderma viride, T. harzianum* and *T. virens*), found effective/compatible under *in-vitro* and *in-vivo* conditions, were integrated to evaluate their efficacy against wilt complex disease under glasshouse and field conditions. The seed + seedling + spraying (4 sprays started with the initiation of flowering) of carbendazim + metalaxyl and captan + metalaxyl were more effective than seed + seedling + soil treatment of antagonists under glasshouse condition. However, antagonists were superior to carboxin + metalaxyl treatment. The treatment captan + metalaxyl recorded significantly higher wilt incidence (36.0% in chilli and 38.8% in bell pepper) than observed in most effective treatment carbendazim + metalaxyl (29.1% in chilli and 31.9% in bell pepper), however, when Gv_3 or Tv_2 (chilli)/Th_2 (bell pepper) were integrated with captan + metalaxyl the treatment resulted in lesser wilt incidence which was at par with carbendazim + metalaxyl treatment. The effectiveness of carboxin + metalaxyl was also increased when used in combination with fungal antagonists. Under field conditions, similar trend in results as under glasshouse studies was observed. Superiority of carbendazim + metalaxyl, captan + metalaxyl + Gv_3 and captan + metalaxyl + Tv_2 (chilli)/Th_2 (bell pepper) was confirmed as higher disease reduction of 54.7, 53.9, 51.9% in chilli crop and 59.8, 58.6, 56.1% in bell pepper over control and maximum yield of 65.7, 64.6 and 63.9 kg/ha (in chilli) and 138.6, 137.0 and 135.6 kg/ha (bell pepper) was observed, respectively. The integration of antagonists with carboxin + metalaxyl also resulted in lesser wilt incidence and higher yield compared to the individual treatments of antagonists and fungicides. The yield observed in antagonist treatments was significantly lower than observed in fungicidal treatments but higher than control. The present findings are supported by earlier works, wherein integration of bio-control agents with fungicides gave significantly higher disease control in several crops than that obtained either by bio-control agent or by fungicide alone (Henis *et al.*, 1978; Upadhyay and Mukhopadhyay, 1983; Sawant and Mukhopadhyay, 1990; Dubey, 1997; Tiwari and Mukhopadhyay, 2003). The seed and seedling treatment with captan, metalaxyl and carboxin may eradicate the wilt causing pathogens or other microflora thereby less competition in spermosphere and rhizosphere for colonization and antagonists have better opportunity to colonize the seed and root surface and proliferate (Chet *et al.*, 1982; Ram *et al.*, 2000; Tiwari *et al.*, 2003). The subsequent application of compatible fungicides may support the growth of antagonists and may also prevent the plant from the attack of pathogens. The other workers have also observed the additive effects of compatible fungicides and antagonists (Marois *et al.*, 1981; Chattopadhyay and Sen, 1996).

CHAPTER - 6

Summary and Conclusion

SUMMARY AND CONCLUSION

Studies on the wilt complex of chilli and bell pepper were carried out during 2001-2004 at the Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu, Udheywalla, as well as on farmers' fields. Surveys of major chilli and bell pepper growing areas of Kathua, Jammu, Udhampur, Doda and Rajouri districts of Jammu division revealed that the disease was prevalent in all the districts having overall mean disease incidence ranging from 19.88 to 66.40 and 19.87 to 65.19 per cent, with an average wilt incidence of 54.56 and 48.96 per cent in the years 2001 and 2002, respectively. The maximum disease incidence of 90.53 per cent was recorded at Jathi in district Doda, in the year 2001, and the minimum of 30.23 per cent at Thandapani in Rajouri district in the year 2002. The pathogencity test of fungi isolated from diseased plants indicated that *Fusarium oxysporum, Phytophthora capsici, Rhizoctonia solani* and *Sclerotium rolfsii* were the causal organisms associated with wilt disease of chilli and bell pepper crops, independently and also in associations with each other, across the Jammu division. It was observed that the disease initiated during last week of April and the incidence increased gradually till the maturity of the crop. The maximum infection rate was observed when soil temperature was in the range of 20-30^0 C and soil moisture around 37 per cent. Soil moisture and minimum temperature were significantly and positively correlated with the wilt incidence, however, maximum temperature had non significant effect on the disease. *F. oxysporum* was observed to be present at all the stages of crop growth, however, at advanced stages, when high soil moisture prevailed because of frequent rains, it was more prevalent in associations with *P. capsici*. *P. capsici* was not observed in hot and dry months and its occurrence started only after frequent rains which increased moisture in soil. The occurrence of *R. solani* was observed throughout the cropping season, however, it was predominant during initial stages of crop growth.

Out of 38 genotypes/varieties screened against wilt complex pathogen in field and glasshouse conditions revealed that only two genotypes *viz.,* SC-108 (01), SC-105 and one variety Suraj Mukhi exhibiting moderately resistant reaction to the pathogens under both field and glasshouse conditions. Remaining germplasm was found susceptible or highly susceptible.

To study the effect of irrigation frequencies, fertilizer levels and planting methods (ridge and flat bed planting), on wilt development and yield of chilli and bell pepper, it was observed that application of irrigation at 11 day intervals recorded significantly less wilt incidence than other irrigation frequencies tested, however, the yield at this irrigation level was significantly lower than obtained at 9 and 7 day intervals of irrigation in both the crops. Manipulation in host nutrition to manage the disease indicated an increase in wilt incidence and decrease in yield with increase in the levels of nitrogenous fertilizer, whereas, significant reduction in wilt incidence and significant increase in yield was observed when phosphorus and potassium levels were increased. The ridge planting method proved superior over flat bed method of planting in both the crops.

Keeping in view the importance of biological management, attempts were made to explore the possibility of managing the wilt complex disease by the use of fungal antagonists isolated from different locations of Jammu division and also obtained from different places. Among the 23 fungal isolates tested under *in-vitro* conditions against four wilt complex pathogens, revealed that five isolates *viz.*, Th_2 (*T. harzianum* – Kud isolate), Th_4 (*T. harzianum*- Bangalore isolate), Tv_2 (*T. viride* – Udheywalla isolate) and Gv_3 (*T. virens* – Jathi isolate) were highly effective against all the wilt complex pathogens. Th_2, Tv_2 and Tv_5 overgrew pathogen surface and did not produce any inhibition zone against any pathogen in dual culture, whereas, Gv_3 and Th_4 produced zones of inhibition against all the pathogens tested. When these fungal antagonists were evaluated under glasshouse conditions as seed treatment, soil treatment and seed treatment + soil treatment, the best results were obtained with antagonists applied as seed + soil treatment followed by seed treatment alone, increasing the seedling emergence of chillies and bell pepper. The antagonists Gv_3 and Th_2 were most effective in chillies as 26.1 and 23.3 per cent increase in seedling emergence over check was observed when applied as seed + soil treatment in the year 2001 and 2002, respectively. The same antagonists were also effective in reducing the wilt incidence of chilli and bell pepper under glasshouse conditions. Seed + seedling + soil treatment with Gv_3 and Tv_2 recorded lesser wilt incidence of 41.6 per cent each at 100 DAT, compared to 100 per cent incidence in check at 40 DAT. Similarly seed + seedling + soil treatment with Gv_3 and Th_2 proved effective and recorded lesser wilt incidence of 33.3 and 50.0 per cent in bell pepper, at 100 DAT, respectively, compared to 100 per cent in check at 40 DAT. The remaining antagonists were completely ineffective in protecting the chilli and bell pepper plants under glasshouse conditions. The studies also indicated that seed treatment with antagonists proved superior over soil treatment.

Among the nine fungicides evaluated against four wilt pathogen under *in-vitro* conditions, carbendazim was found highly effective against *F. oxysporum* and *R. solani* at 50 and 500 ppm concentration, respectively. Captan was completely effective against

P. capsici and *F. oxysporum* at 500 ppm concentration, whereas, metalaxyl was highly effective against *P. capsici* and recorded 100 per cent growth inhibition at 50 ppm concentration, followed by mancozeb + metalaxyl which also completely inhibited the mycelial growth at 500 ppm concentration. Carboxin also completely inhibited the radial growth of *R. solani* at 50 ppm concentration. The highly effective fungicides, found under *in-vitro* conditions, were further tested alone and in suitable combinations to observe their effectiveness on seedling emergence and wilt incidence under glasshouse conditions. Seed treatment with carbendazim + metalaxyl increased 47.7 and 56.5 per cent seedling emergence over check in chillies and bell pepper, respectively. The next best treatment was captan + carbendazim and captan + metalaxyl which increased 45.9 and 44.9 per cent seedling emergence over check, respectively, in chillies and 51.7 and 41.8 per cent in bell pepper, respectively. Treating seed and seedlings with fungicides only could not prevent the plants from wilt complex pathogens, although some effectiveness was observed up to 40 DAT compared to check. Seed treatment + seedling dip + spraying at crown region of plant at 15 days interval of carbendazim + metalaxyl and captan + metalaxyl resulted in only 25.0 and 29.1 per cent wilt incidence at 100 DAT in chillies and 25.0 and 33.3 per cent, in bell pepper, respectively, compared to 100 per cent wilt incidence in check at 40 DAT of crop. Seed treatment + seedling dip + spraying with captan + carbendazim and carboxin + metalaxyl also recorded lesser wilt incidence of 37.4 and 54.1 in chilli and 45.8 and 58.3 per cent in bell pepper, respectively, compared to fungicides applied only to seeds, seedlings as well as check.

For successful integrated disease management compatibility of fungicides *viz.*, carbendazim, carboxin, metalaxyl and captan (effective under *in-vitro* and glasshouse conditions) with antagonists *viz.* Th_2, Tv_2 and Gv_3 (effective under *in-vitro* and glasshouse conditions) was tested under *in-vitro* conditions. Carboxin was found compatible with all the three antagonists; however, at 250 ppm concentration the mycelial growth in Th_2 and Tv_2 was significantly lower than check. Captan and metalaxyl had also shown compatibility with antagonists, although mycelial growth observed in antagonists at all concentrations was lower than check. However, carbendazim was not found compatible with any of the antagonists as 100 per cent mycelial growth inhibition was observed. The glasshouse studies indicated that in general the fungicides were more effective than antagonists in controlling wilt disease. The maximum disease reduction over control was observed in seed + seedling + spraying of carbendazim + metalaxyl at crown region at 15 day intervals. However, integration of captan + metalaxyl with Gv_3 or Tv_2 resulted in higher disease reduction over control (70.9% in each) in chilli. These treatments were at par with the best treatment carbendazim + metalaxyl. Similarly, in bell pepper crop the maximum disease reduction over control was observed when captan + metalaxyl was integrated with Th_2 or Gv_3. Carboxin + metalaxyl also recorded higher disease reduction over control when integrated with antagonists compared to their individual treatment. Under field conditions the fungal antagonists were not as much effective as in glasshouse experiments, although superior to check in minimizing wilt incidence and increasing yield of both chilli and bell pepper crops. The treatments carbendazim + metalaxyl, captan + metalaxyl + Gv_3 and captan + metalaxyl + Th_2 (bell pepper) / Tv_2 (chillies) resulted in wilt incidence of 27.6, 28.1, 29.3 per cent and 26.1, 26.9, 28.5 per cent in chilli and bell pepper, respectively. The similar trend in results as in wilt incidence was observed in yield of both the crops. In chilli, carbendazim + metalaxyl recorded maximum yield of 65.7 q/ha, which was followed by captan + metalaxyl + Gv_3 (64.6 q/ha) and captan + metalaxyl + Tv_2 (63.9). The minimum yield of 46.1 q/ha was observed in Tv_2, although in comparison to check it was significantly higher. Carboxin + metalaxyl recorded yield of 57.5 q/ha, however, when integrated with Gv_3 or Tv_2 higher yield of 61.6/61.4 q/ha was observed. Similarly, in bell pepper crop also carbendazim + metalaxyl recorded 138.6 q/ha yield which was statistically at par with yield observed in captan + metalaxyl + Gv_3 (137.0 q/ha) and captan + metalaxyl + Th_2 (135.6 q/ha).

To sum up, the following conclusions are drawn from the present investigations:

1. The survey of different districts of Jammu division revealed that the wilt complex was a major disease encountered in the chilli and bell pepper crops, the disease incidence varied from district to district, the maximum incidence being observed in Doda district.

2. *Fusarium oxysporum*, *Phytophthora capsici, Rhizoctonia solani* and *Sclerotium rolfsii* were found to be the causal agents responsible for the wilt complex disease.

3. *F. oxysporum* was the most predominant pathogen in all the districts causing disease independently and also in combination with other pathogens, followed by *P. capsici*, *R. solani* and *S. rolfsii.*

4. *F. oxysporum* remained associated with the disease throughout the cropping season infecting at all stages of crop growth, however, *P. capsici* was predominant at flowering stage during rainy season when high soil moisture

prevailed. Whereas, *R. solani* was more prevalent during initial stages of crop growth.

5. Soil moisture and minimum soil temperature were significantly and positively correlated with wilt diease, however, no correlation was observed between maximum temperature and disease incidence.

6. Moderately rsistant reaction was observed in the variety Suraj Mukhi and genotypes SC-103 and SC-108 (Shalimar Collections) against all the pathogens causing wilt complex in *Capsicum annuum*, under both field and glasshouse condition, hence, could be used in further breeding programmes.

7. Application of irrigation at 11 day intervals resulted into lesser wilt incidence compared to 5, 7 and 9 day irrigation intervals. However, application of irrigation at 9 day intervals resulted in superior yield than 5 and 11 day intervals in chilli and bell pepper. The fertilize dose 80N + 84P + 42K recorded minimum wilt incidence and maximum yield in both the crops. The ridge planting proved superior to flat bed planting.

8. The *in-vitro* evaluation of fungal antagonists revealed that *Trichoderma harzianum* (isolate Th_2 and Th_4), *T. viride* (isolate Tv_2 and Tv_5) and *T. virens* (Gv_5) were most effective against all the four pathogens.

9. Most of the antagonists applied as seed treatment, soil treatment and seed + soil treatment resulted in higher seedling emergence than check. However, application of antagonists as seed + soil treatment was superior over the individual seed and soil treatments. Seed treatment proved superior over soil treatment in increasing the seedling emergence in both the crops.

10. Seed + seedling + soil treatment with Tv_2 and Gv_3 recorded minimum wilt incidence in chilli, whereas, in bell pepper, Th_2 and Gv_3 were superior over other antagonists in reducing wilt disease under glasshouse conditions.

11. The *in-vitro* evaluation of fungicides indicated that carbendazim, metalaxyl and carboxin were completely inhibitive against *F. oxysporum*, *P. capsici* and *R. solani*, respectively, at all the concentrations tested. However, captan was effective at higher concentrations against all the pathogens.

12. Seed treatment with all the nine fungicides resulted in higher seedling emergence in both the crops.

13. Seed treatment + seedling dip + spraying with carbendazim + metalaxyl and captan + metalaxyl resulted in minimum wilt incidence in both the crops under glasshouse conditions.

14. The fungicide carboxin was found most compatible with the antagonists (Th_2, Tv_2 and Gv_3), although captan and metalaxyl also exhibited compatibility, however, the radial growth of antagonists with these fungicides were significantly lower than check at all the concentrations tested.

14. The integration of Gv_3, Tv_2 and Th_2 with captan + metalaxyl resulted in lesser wilt incidence and higher yield compared to their individual treatments and these treatments were statistically at par with the best treatment carbendazim + metalaxyl in both the crops under glasshouse and field conditions.

Bibliography

BIBLIOGRAPHY

Ahmad, N., Tanki, M.I. and Mir, N.M. 1994. Screening of advanced breeding lines of chilli, sweet and hot pepper cultivars against Fusarium wilt. *Plant Disease Research* **9** : 153-154.

Ahmed, S., Ansar, M. and Azmat, I. 1989. Root and collar rot of chillies caused by *Phytophthora capsici*. *Journal of Agricultural Research* **27** : 155-156.

*Ahmed, S., Hamid, K., Tariq, A.H. and Jamil, F.F. 2000. Chemical control of root and collar rot of chillies. *Pakistan Journal of Phytopathology* **12** : 1-5.

*Alavi, A., Saber, M. and Akhavizadigan, M.D. 1986. Rhizoctonia crown and root rot of pepper in Iran. *Iranian Journal of Plant Pathology* **22** : 9-12.

*Alois, A.B. and Mace, M.E. 1981. Biochemistry and physiology of resistance. In : *Fungal Wilt Disease of Plants*. Mace, M.E., Bell, A.A. and Beckman, C.H. (Eds.), Academic Press, New York, pp 447-449.

Albegbejo, M.D. and Ernile, I.D. 2000. Screening of advanced breeding pepper lines for resistance to basal stem rot and wilt. *Capsicum and Eggplant Newsletter* **19** : 109-110.

*Almedia, O.C., Robbs, C.F., Akiba, F. and Kimura, O. 1980. A new pepper disease caused by *Rhizoctonia solani* Kuhn in Brazil. *Fitopathologia Brasileira* **5** : 7-10.

*Anonymous. 1987. Note on stem rot and wilt of chilli in Haryana (India). *Plant Protection Bulletin* **39** : 35.

Anonymous, 1989. *Annual Progress Report,* Division of Plant Pathology, Sher-e-Kashmir University of Agricultural Sciences and Technology, Kashmir, Shalimar, Srinagar, p 30.

Anonymous, 1993. *Annual Progress Report,* Division of Plant Pathology, Sher-e-Kashmir University of Agricultural Sciences and Technology, Kashmir, Shalimar, Srinagar, p 44.

Anonymous, 2004. *Area and Production Data of Vegetables in Jammu Division of Jammu and Kashmir State*, Directorate of Horticulture, Talab Tillo, Jammu, p 6.

Babadoost, M. and Islam, S.Z. 2003. Fungicide seed treatment effects on seedling damping-off of pumpkin caused by *Phytophthora capsici. Plant Disease* **87** : 65-68.

*Babayan, D.N. and Shakhnubaryan, S.T. 1969. Presence of infection by fungal wilt in the seeds of tomato, pepper and eggplant under conditions of the Ararat plain, Armenia. *Uchen-Zap Erevan Univ* **1** : 136-147.

*Baker, R. 1989. Improved *Trichoderma* spp. for promoting crop productivity. *Trends in Biotechnology* **7** : 34-38.

Balaji, A. and Vaitheswaran, M. 1988. Effect of potassium stress on *Hibiscus cannabinus* infected by the root knot nematode, *Meliodogyne incognita. Indian Journal of Nematology* **18** : 216-218.

*Baris, M., Gulsoy, E., Guneu, M., Maden, S., Sagir, A., Senyurek, M., Ulukus, I., Yalcin, O. and Zengin, H. 1986. Investigations on sources of primary inoculum of crown blight (*Phytophthora capsici* L.) of capsicum and control measures against the disease. *Bilki Koruma Bullteni* **26** : 59-95.

Baruah, H.K., Baruah, P. and Baruah, A. 1985. *A Text Book of Plant Pathology*. Oxford and IBH Publishing Company, New Delhi (India), p 498.

Bateman, D.F. 1970. Pathogenesis and diseases. In : *Rhizoctonia solani, Biology and Pathology*. Parmeter, J.R. (Ed.), University of California Press, Berkeley, USA, pp 160-170.

*Beattie, J.H., Doolittle, S.P., Beattie, W.R., Magruder, R. and Webster, R.E. 1944. *Production of Peppers*, Leaf Literature USDA **140** : 7.

Beckman, C.H. 1987. *Nature of Wilt Diseases*, American Phytopathological Society, St. Paul, p 174.

*Behera, B., Narian, A. and Swain, N.C. 1989. Physiology and chemical control of *Fusarium pallidoroseum* affecting ground nut. *Orissa Journal of Agriculture Research* **2** : 29-34.

Bell, D.K., Wells, H.D. and Markham, C.R. 1982. *In-vitro* antagonism of *Trichoderma* species against six fungal plant pathogens. *Phytopathology* **72** : 379-382.

*Benlloch, M. and Dominguez, F. 1934. Laenfermedad de Los Pimentales en Aldeanueva del Camino. *Agriculture Research* 7 : 1-20.

*Black, L.L. and Rivelli, V. 1991. *Fusarium oxysporum* f.sp. *capsici* identified as the causal agent of wilt in pepper. In : *Pepper diseases, A Field Guide*, Academic Press, London, pp 24-25.

*Booth, C. and Sutton, B.C. 1984. *Fusarium pallidoroseum*, the correct name for *F. semitectum*. *Transactions of the British Mycological Society* **83** : 702-704.

Bowers, J.H. and Mitchell, D.J. 1990. Effect of soil water potential and periodic flooding on mortality of pepper caused by *Phytophthora capsici*. *Phytopathology* **80** : 1447-1450.

*Brain, P.W., McGowan, J.C. 1945. Viridin : A highly fungistatic substance produced by *Trichoderma viride*. *Nature* **156** : 144-145.

Brayford, D. 1993. *The Identification of Fusarium Species*, International Mycological Institute, Kew, Surrey, England, p. 27.

*Brown, J.G. and Gibson, F. 1926. *Plant Pathology. 34th Annual Report*, Arizona Agriculture Experimentation Station for the year ending June 30th 1923, pp 448-506.

Bunker, R.N. and Mathur, K. 2001. Integration of biocontrol agents and fungicides for suppression of dry root rot of *Capsicum frutescens*. *Journal of Mycology and Plant Pathology* **31** : 330-334.

Camino, V., Despestre, T. and Espinosa, J. 1987. Search for *Capsicum annuum* susceptibility to *Fusarium*. *Capsicum Newsletter* **6** : 70.

*Chatterjee, S., Mukherjee, N. and Katua, D.C. 1997. Status of bacterial wilt disease in West Bengal. *Journal of Interacademica* **1** : 97-99.

Chattopadhyay, C. and Sen, B. 1996. Integrated management of Fusarium wilt of muskmelon caused by *Fusarium oxysporum*. *Indian Journal of Mycology and Plant Pathology* **26** : 162-170.

*Chaves, B.A. 1947. Principais doencas das plantas en nordeste. *Brazil Bollettino Agriculture Pernambuco* **14** : 5-46.

*Chet, I., Elad, Y, Koflan, A., Hadar, Y. and Katan, J. 1982. Integrated control of soil-borne and bulb-borne pathogen in Iris. *Phytoparasitica* **10** : 229-231.

Chowdary, K.A., Reddy, D.R. and Rao, K.C. 1998. Efficacy of systemic (Triazoles) and non-systemic fungicides against sclerotial wilt of bell pepper caused by *Sclerotium rolfsii* Sacc. *Indian Journal of Plant Protection* **26** : 125-130.

*Chupp, C. and Sherf, A.F. 1960. *Vegetable Diseases and Their Control*, John Wiley and Sons, New York, USA, p 693.

*Ciferri, R. 1926. Primer Informe, Annual de la Estacion Agron. U. Col. De. Agric. de Haina. *Republica Dominicana* **1** : 27-36.

*Clique, S. and Scheffer, R.T. 1996. Biological control of damping-off caused by *Pythium ultimum* and *Rhizoctonia solani* using *Trichoderma* spp. applied as industrial film coating on seeds. *European Journal of Plant Pathology* **102** : 247-255.

Cook, R.J. and Baker, K.F. 1983. *The Nature and Practice of Biological Control of Plant Pathogens*, American Phytopathological Society, St. Paul, Minnesota, USA, p 539.

*Copcu, M. and Saydam, C. 1974. A preliminary study on the cross-inoculation of isolates of *Verticillium dahliae* obtained from various hosts. *Journal of Turkish Phytopathology* **3** : 39-49.

*Crawford, R.F. 1934. The etiology and control of chilli wilt produced by *Fusarium annuum*. *Technical Bulletin*, New Mexico Agriculture Experimental Station **223** : 1-20.

D'Souza, V., Javanta, K.R., Bibekananda, M. and Dasgupta, B. 2001. Screening of *Trichoderma harzianum* against major fungal pathogens of betelvine. *Indian Phytopathology* **54** : 340-345.

*Dar, G.M. and Mir, N.A. 1995a. Pepper wilt causes and prevalence in Kashmir. *Proceedings of National Symposium on Recent Trends in the Management of Biotic and Abiotic Stresses in Plants*, November 2-3, held at HPKVV, Palampur (India).

*Dar, G.M. and Mir, N.A. 1995b. Studies on the management of chilli wilt in Kashmir. *Proceedings of National Symposium on Recent Trends in the Management of Bioticand Abiotic Stresses in Plants*. November 2-3, held at HPKVV, Palampur (India).

*Das, C.R. and Chattopadhyay, S.B. 1955. Bacterial wilt of brinjal. *Indian Phytopathology* **8** : 130-135.

Das, P.C. 1996. *Manures and Fertilizers*, Kalyani Publishers, Ludhiana, India pp 6-8.

*Davey, C.B. and Papavizas, G.C. 1960. Effect of dry mature plant materials and nitrogen on *Rhizoctonia solani* in soil. *Phytopathology* **50** : 522-525.

Dimond, A.E. 1955. Pathogenesis in wilt diseases *Annual Review of Plant Physiology* **6** : 329-350.

Dimond, A.E. 1970. Biophysics and biochemistry of the vascular wilt syndrome. *Annual Review of Phytopathology* **8** : 301-322.

Domsch, K.H., Gams, W., Anderson, T.H. 1980. *Compendium of Soil Fungi* (Vol. 1, 2), Academic Press, London, p 1250.

*Doolittle, S.P. 1953. Disease of pepper. In : *Year Book of Agriculture*, Oxford and IBH Publishing Company, N. Delhi, pp 465-469.

Dubey, S.C. 1997. Biological control of web blight of groundnut caused by *Thanatephorus cucumeris. Proceedings of Golden Jubilee International Conference of IPS*, November 10-15, held at IARI, New Delhi, p 194.

Dubey, S.C. 1998. Evaluation of fungal antagonist of *Thanatephorus cucumeris* causing web blight of horsegram. *Indian Journal of Mycology and Plant Pathology* **28** : 15-18.

Dubey, S.C. 2002. Bioagent based integrated management of collar rot of frenchbean. *Indian Phytopathology* **55** : 230-231.

Dubey, S.C. and Patel, B. 2001. Determination of tolerance in *Thanatephorus cucumeris, Trichoderma viride, Gliocladium virens* and *Rhizobium* sp. to fungicides. *Indian Phytopathology* **54** : 98-101.

Dukes, P.D. and Fery, R.L. 1984. Southern blight (*Sclerotium rolfsii* Sacc.) of pepper : Identification of resistance. *Hortscience* **19** : 1984.

Duniway, J.M. 1975. Limiting influence of low water potential on the formation of sporangia of *Phytophthora drechsleri* in soil. *Phytopathology* **65** : 1089-1093.

*Dwivedi, K. and Shukla, P. 1981. Effect of interaction of nitrogen, phosphorus and potassium on Dreschlera leaf spot of mung. *Indian Phytopathology* **34** : 200-202.

Dwivedi, R.R., Sangam, L. and Saxena, S.C. 1990. Effect of NPK fertilizers on the severity of black bundle, late wilt and pink stalk rot of maize. *Plant Disease Research* **5** : 49-51.

Elad, Y., Chet, I. and Katan, J. 1980. *Trichoderma harzianum*, a biocontrol agent effective against *Sclerotium rolfsii* and *Rhizoctonia solani*. *Phytopathology* **70** : 119-121.

*Elenkov, E. and Khrelkova, E. 1977. *Phytophthora capsici* po pipera (*Phytophthora capsici* on peppers). *Rastitelna Zashchita* **25** : 25-30.

*Fernandez, M.C. 1983. *Phytophthora capsici*, causal agent of wilt of *Capsicum annuum* in Chile. *Agricultura Technica* **43** : 91-93.

Ferreyra, E.R., Tosso, T.J. and Fernandaz, M.F. 1984. Effect of irrigation water management on *Phytophthora capsici* causal agent of *Capsicum annuum* blight. *Agricultura Technica* **44** : 319-324.

Gandhi, S.K., Sangwan, M.S. and Dang, J.K. 1993. Influence of NPK fertilizers on the development of purple blotch of onion. *Plant Disease Research* **8** : 184.

*Garcia, F. 1933. Reduction of chilli wilt by cultural methods. *Technical Bulletin*, New Mexico Agriculture Experimental Station **216** : 1-15

*Garofalo, F. 1957. Preliminary experiments on soil sterilization with steam and vapam in plantings of eggplant and capsicum. *Fitopatholgia* **20** : 59-78.

*Gaumann, E. 1957. Fusaric acid; a wilt toxin. *Phytopathology* **47** : 342-357.

Girija, V.K. and Umamaheshwaran, K. 2003. Basal rot of balsam and its management through bioagents. *Plant Disease Research* **18** : 52-55.

*Godfredsen, W.O. and Vengedal, S. 1965. *Trichoderma*, a new sesquiterpene antibiotic. *Acta Chem Scan* **19** : 1088-1102.

Gonzalez-Salan, M.M., Bosland, P.W. 1993. Enhanced *Capsicum* germplasm resistant to Verticillium wilt. *Capsicum and Eggplant Newsletter* **12** : 85-87.

Grover, R.K. and Singh, G. 1970. Pathology of wilt of okra (*Abelmoschus esculentus* L.) caused by *Fusarium oxysporum* f. sp. *vasinfectum* (Atk.) Snyder and Hansen, its host range and histopathology. *Indian Journal of Agricultural Sciences* **40** : 989-996.

*Hansford, C.G. 1940. *Report of the Senior Plant Pathologist*, Department of Agriculture, Uganda, 1938-39, pp 28-29.

*Hartman, G.L. and Hwang, T.C. 1992. *Phytophthora* blight of pepper, screening for disease resistance. *Tropical Pest Management* **38** : 319-322.

*Hashmi, M.H. 1989. Seed-borne mycoflora of *Capsicum annuum* L. *Pakistan Journal of Botany* **21** : 302-308.

Hazarika, D.K. and Das, K.K. 1998. Biological management of frenchbean caused by *Rhizoctonia solani*. *Plant Disease Research* **13** : 101-105.

*Henis, Y., Ghaffar, A. and Baker, R. 1978. Integrated control of *Rhizoctonia solani* damping-off of radish : Effect of successive planting, PCNB and *Trichoderma harzianum* on pathogen and disease. *Phytopathology* **68** : 900-909.

*Highley, T.L., Padmanabhan, H.S.A. and Howell, C.R. 1996. *Antagonistic Properties of Gliocladium virens Against Wood Attacking Fungi*, International Research Group on Wood Presentation, p 9.

*Huber, D.M. 1980. The role of mineral nutrition in defence. In : *Plant Disease, An Advanced Treatise* (Vol. V.). Horsfall, J. and Cowling, E. (Eds.), Academic Press, New York, USA, pp 381-406.

*Huber, D.M. 1981. The use of fertilizers and organic amendments in the control of plant diseases. In : *Handbook of Pest Management in Agriculture* (Vol. I). Pimental, D. (Ed.), CRC Press Boca Raton, Florida, pp 357-394.

Huber, D.M. and Watson, R.D. 1974. Nitrogen form and plant disease. *Annual Review of Phytopathology* **12** : 139-165.

Hwang, B.K. and Kim, C.H. 1995. Phytophthora blight of pepper and its control in Korea. *Plant Disease* **3** : 221-227.

*Jia, J.S. 1992. Studies on the chilli pepper Phytophthora blight and its control in Xingjiang. *Acta-Phytopathologica Sinica* **22** : 257-263.

Jyothi, A.R., Koshy, A., Mathew, J. and Abrahim, K. 1993. Bacterial wilt of chillies in Kerala and reaction of certain chilli accessions to *Pseudomonas solanacearum*. *Bacterial Wilt Newsletter* **9** : 6.

Kannaiyan, S. and Prasad, N.N. 1974. Effect of potassium fertilizer on muskmelon wilt development. *Indian Phytopathology* **27** : 527-531.

*Kanniayan, S. and Prasad, N.N. 1975. Effect of soil moisture on the survival of *Fusarium oxysporum* f. sp. *melonis*. *Laboratory Development Bulletin* **12** : 11-12.

Kapoor, K.S. and Sharma, S.R. 1988. Soil application of fungicides against wilt of eggplant. *Capsicum Newsletter* **7** : 90-91.

Kapoor, K.S. and Thakur. P.C. 1987. Control of seed bed loses of *Capsicum*. *Capsicum Newsletter* **6** : 79-80.

Kaufman, D.D. and Williams, L.E. 1964. Effect of mineral fertilization and soil reaction on soil fungi. *Phytopathology* **54** : 134-139.

Kaur, S. 1993. *Fusarium* wilt – a cause of chilli crop failure in Punjab. *Plant Disease Research* **8** : 181-183.

Kenerley, C.M., Brucks, R.I. and Grand, L.F. 1984. Effects of metalaxyl on growth and ectomycorrhizae of fraser fir seedlings. *Plant Disease* **68** : 32-35.

Khan, A.N.A., Shetty, K.S. and Patil, R.B. 1979. Occurrence of bacterial wilt of chilli in Karnataka and its relationship to the wilts of other solanaceous crops. *Indian Phytopathology* **32** : 507-512.

*Kim, C.H. 1989. Soil-borne diseases : Phytophthora blight and other diseases of red pepper in Korea. *Republic Extension Bulletin. ASPAC – Food and Fertilizer Technology Center* **302** : 10-17.

*Kim, C.H., Cho, W.D. and Kim, S.C. 1982. An investigation of the control of red pepper fruit rot caused by *Phytophthora capsici* Leonin. *Research Reporter* **24** : 46-50.

*Kiraly, Z. 1976. Plant disease resistance as influenced by biochemical effect of nutrient fertilizers. *Phytopathologische Zeitschrift* **34** : 33-46.

Kleifeld, O. and Chet, I. 1992. *Trichoderma* plant interaction and its effects on increased growth response. *Plant and Soil* **144** : 267-272.

*Koleva, K. and Vitanov, M. 1990. *Fusarium* species related to root rot of pepper. *Rasteniev dni Nauki* **27** (6) : 61-63.

*Kozlowska, C. 1964. Investigation on the biology of *Fusarium oxysporum* and attempts to control it. *Prace Inst Badaw. Lesn* **246** : 3-91.

Kumar, D. and Dubey, S.C. 2001. Management of collar rot of pea by the integration of biological and chemical methods. *Indian Phytopathology* **54** : 62-66.

Kumar, M. and Dubey, S.C. 2002. Relationship of disease intensity with weather and management of web blight of winged bean. *Indian Phytopathology* **55** (2) : 152-157.

Larkin, R.P. and Fravel, D.R. 1998. Efficacy of various fungal and bacterial biocontrol organisms for control of Fusarium wilt of tomato. *Plant Diseases* **82** : 1022-1028.

*Leonian, L.H. 1922. Stem and fruit blight of peppers caused by *Phytophthora capsici*. *Phytopathology* **12** : 401-408.

*Leu, L.S. and Kao, C.W. 1981. Pepper blight induced by *Phytophthora capsici*. *Plant Protection Bulletin* **23** : 59-66.

*Lu, J.Y., Yu, C.F. and Ju, L.H. 1984. Studies on differentiation of the virulence of *Verticillium dahliae* on pepper. *Acta Phytopathologica Sinica* **14** : 213-218.

*Lukacs, J.and Sjarka, J. 1988. Fusarium wilt of capsicum. *Zoldse Gtermeszlesi Kutato Interzet Bulletine* **21** : 95-99.

Lumesden, R.D. and Locke, J.C. 1989. Biological control of damping-off caused by *Pythium ultimum* and *Rhizoctonia solani* with *Gliocladium virens* in soil-less mix. *Phytopathology* **79** : 301-305.

Manoranjitham, S.K., Prakasam, V. and Rajappan, K. 2000. Control of chilli damping-off using bioagents. *Journal of Mycology and Plant Pathology* **30** : 225-228.

*Marchionatto, J.B. 1935. Species of *Fusarium* existing in Argentina. *International Bulletin of Plant Protection* **9** : 125-138.

*Marois, J.J., Mitchell, D.J. and Sonoda, R.M. 1981. Biological control of Fusarium crown rot of tomato under field conditions. *Phytopathology* **77** : 1257-1260.

Martin, J.P. 1950. Use of acid, rose bengal and streptomycin in the plate method for estimating soil fungi. *Soil Science* **69** : 215-232.

Mathur, K. and Gurjar, R.B.S. 2001. *Sclerotium rolfsii* – a new threat to chilli in Rajasthan. *Journal of Mycology and Plant Pathology* **31** : 261.

*Mayee, C.D. and Datar, V.V. 1986. *Phytopathometry Technical Bulletin-1* (Special Bulletin-3). Marathwada Agricultural University, p 146.

*McRae, N. 1932. *Science Report for 1930-31*. Imperial Institution of Agriculture, Research, Pusa, p 84.

*Mejia-Jesus, A. 1990. Controlling attempts in fading chili caused by *Phytophthora capsici* L. fungus at Valsequillo, Mexico. *Serie Protection Vegetables* **1** : 93-108.

Mihutta, G.L. and Rowe, R.C. 1986. *Trichoderma* spp. as biocontrol agents of *Rhizoctonia* damping-off of radish in organic soil as comparison to four delivery system. *Phytopathology* **76** : 306-312.

*Moens, M. and Benaicha, B. 1990. Control of pepper wilt in Tunisia. *Parasitica* **46** : 103-109.

*Morten, D.T. and Sproube, W.H. 1955. Antagonistic and stimulatory effects of soil microorganism upon *Sclerotium*. *Phytopathology* **45** : 417-420.

Muhyi, R. and Bosland, P.W. 1995. Evaluation of *Capsicum* germplasm for source of resistance to *Rhizoctonia solani*. *Hortscience* **30** : 341-342.

Mukherjee, B. and Sen, C. 1992. *Aspergillus* and *Penicillium* spp. : Potential agents for biocontrol of *Macrophomina phaseolina*. *Indian Phytopathology* **45** : 39-43.

*Mukhopadhyay, A.N., Shreshtha, S.M. and Mukherjee, P.K. 1992 Biological seed treatment for control of soil-borne plant pathogens. *F.A.O Plant Protection Bulletin* **40** : 1-10.

*Mushtaq, M. and Hashmi, M.H. 1997. Fungi associated with wilt disease of *Capsicum* in Sindh Pakistan. *Pakistan Journal of Botany* **29** : 217-222.

Najar, A.G. 2001. *Cause and Management of Chilli Wilt in Kashmir*. Ph.D. Thesis submitted to SKUAST-K, Shalimar Campus, Srinagar, p 143.

*Narain, A., Behera, B. and Swain, N.C. 1989. Seed-borne nature of ***Fusarium pallidoroseum*** in groundnut and its management. *Crop Research* **2** : 200-204.

Nayeema, J., Ahmad, N., Tanki, M.I. and Dar, G.M. 1995. Screening of hot pepper germplasm for resistance to Fusarium wilt [*Fusarium pallidoroseum* (Cooke) Sacc.]. *Capsicum and Eggplant Newsletter* **14** : 68-71.

*Nedumaran, S. and Vidhyasakaran, P. 1981. Control of *Fusarium semitectum* infection in tomato seed. *Seed Research* **9** : 28-31.

*Nelson, P.E. 1981. Life-cycle and epidemiology of *Fusarium oxysporum*. In : *Fungal Wilt Diseases of Plants*. Mace, M.E., Bell, A.A. and Beckman, C.H. (Eds.), Academic Press, New York, pp 51-78.

Nene, Y.L. and Thapliyal, P.N. 1997. *Fungicides in Plant Disease Control*, Oxford and IBH Publishing Company, New Delhi, p 507.

*Nirwanto, H. and Djajati, 1994. Study on the use of soil amendment with leguminous foliage and liming in effort to control Fusarium wilt disease of tomato. *Acta Horticulturae* **36** : 155-162.

*Palloix, A. 1986. *The resistance of pepper (Capsicum annuum) to Phytophthora capsici*. Thesis submitted to the Universite Lyoni, France, p. 134.

Panday, K.K. and Upadhyay, J.P. 2000. Microbial population from rhizosphere and non-rhizosphere soil of pigeonpea. Screening for resident antagonist and mode of mycoparasitism. *Journal of Mycology and Plant Pathology* **30** : 7-10.

Papavizas, G.C. 1985. *Trichoderma* and *Gliocladium* : Biology, ecology and potential for biocontrol. *Annual Review of Phytopathology* **23** : 23-54.

Parmeter, J.R. and Whitney, H.S. 1970. Taxonomy and nomenclature of the imperfect state. In : *Rhizoctonia solani, Biology and Pathology*. Parmeter, J.R. (Ed.), University of California Press, Berkeley, USA, pp 7-19.

*Parveen, S., Haque, S.E. and Ghaffar, A. 1998. Efficacy of *Pseudomonas acruginosa* and *Paecilomyces lilacinus* in the control of root rot, root knot disease complex on some vegetables. *Nematologia-Mediterranea* **26** : 209-212.

Patnaik, N. 1997. Soil fertility and fertilizer use. In : *Handbook of Agriculture*, Indian Council of Agricultural Research, New Delhi, pp 207-208.

*Pontis, R.E. 1940. El 'marchitonatto' del Pimiento (*Capsicum annuum*) en la provincia de Mendoza. *Review of Argentina Agronomy* **7** : 113-127.

Prasad, C.S., Gupta, V., Tyagi, A. and Pathak, S. 2003. Biological control of *Sclerotium rolfsii* Sacc., the incidence of cauliflower collar rot. *Annals of Plant Protection Science* **11** : 61-63.

Prasad, R.D., Rangeshwaran, R. and Kumar, S.P. 1999. Biologial control of root and collar rot of sunflower. *Journal of Mycology and Plant Pathology* **29** : 184-188.

Prasad, R.D., Rangeshwaran, R., Anuroop, C.P. and Rashmi, H.J. 2002. Biological control of wilt and root rot of chickpea under field conditions. *Annals of Plant Protection Science* **10** : 72-75.

Prashanthi, S.K., Srikant, K. and Anahosur, K.H. 2000. Management of safflower root rot caused by *Rhizoctonia bataticola* by antagonistic microorganism. *Plant Disease Research* **15** : 146-150.

Pratap, H.R.S., Philip, T. and Sharma, D.D. 1996. *In-vitro* antagonism of *Trichoderma* species against mulberry leaf spot pathogens, *Cercospora moricola*. *Indian Journal of Sericulture* **35** : 107-110.

Ram, D., Mathur, K., Lodha, B.C. and Webster, J. 2000. Evaluation of resident biocontrol agents as seed treatments against ginger rhizome rot. *Indian Phytopathology* **53** : 450-454.

*Ramasamy, K. and Prasad, N.N. 1975a. Effect of potassium nutrition on phenol metabolism of melon wilt. *Madras Agriculture Journal* **62** : 313-317.

*Ramasamy, K. and Prasad, N.N. 1975b. Potassium and melon wilt. III. Influence of potassium on *in-vitro* fusaric acid and pathogen propagules. *Science and Culture* **41** : 525-526.

Rao, T.S.K. and Sitaramaiah, K. 2000. Management of collar root disease (*Aspergillus niger*) in groundnut with *Trichoderma* spp. *Journal of Mycology and Plant Pathology* **30** : 221-224.

Rifai, M.A. 1969. A revision of genus *Trichoderma*. *Mycological Papers* **116** : 1-56.

Ristaino, J.B. 1991. Influence of rainfall, drip irrigation and inoculum density on development of phytophthora root and crown rot epidemics and yield in bell pepper. *Phytopathology* **81** : 922-929.

*Sanford, G.B. 1926. Some factors affecting pathogenicity of *Actinomyces scabies*. *Phytopathology* **16** : 525-527.

*Sarhan, A.R.T. and Hegazi, A.M.A. 1986. Effect of nitrogen, phosphorus and potassium on sensitivity of pepper plants to Fusarium wilt toxin. *Acta Phytopathological Et Entomological Hungarica* **21** : 251-254.

*Sarhan, A.R.T. and Sharif, F.M. 1986. Integrated control of *Fusarium* wilt of pepper. *Acta Phytopathologica et Entomologica Hungarica* **21** : 123-126.

*Sarhan, A.R.T., Barna, B. and Kiraly, Z. 1982. Effect of nitrogen nutrition on *Fusarium* wilt of tomato plants. *Annals of Applied Biology* **101** : 245-250.

Satour, M.M. and Butler, E.E. 1968. Comparative morphological and physiological studies of the progenies from intra specific mating of *Phytophthora capsici*. *Phytopathology* **58** : 183-192.

Sawant, I.S. and Mukhopadhyay, A.N. 1990. Integration of metalaxyl with *Trichoderma harzianum* for the control of Pythium damping-off in sugar beet. *Indian Phytopathology* **43** : 535-541.

*Schlub, Y.A. 1983. Epidemiology of *Phytophthora capsici* on bell pepper. *Journal of Agricultural Sciences* **100** : 7-11.

*Schmitz, H. 1930. Poisoned food technique. *Indust. Engin. Chem. Analyst.* 2nd edition, pp 361-363.

Schneider, R.W. 1985. Suppression of Fusarium yellows of celery with potassium chloride and nitrate. *Phytopathology* **75** : 40-48.

Selvarajan, R. and Jeyarajan, R. 1996. Inhibition of chickpea root rot pathogens *Fusarium solani* and *Macrophomina phaseolina* by antagonists. *Indian Journal of Mycology and Plant Pathology* **26** : 248-251.

Shali, S.K. 2000. *Studies on Chilli Wilt*. M.Sc. thesis submitted to the Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu, p 55.

*Shannon, E. and Cotter, D. 1986. *Chilli Disease Control*, Cooperative Extension Service, New Mexico State University, p 400.

Sharma, J.P. and Sharma, U.C. 1991. Effect of N and P on the yield and severity of Turcicum blight of maize in Nagaland. *Indian Phytopathology* **44** : 383-385.

*Sharma, R.L., Singh, B.P., Thakur, M.P. and Verma, K.P. 2002. Chemical management of linseed wilt caused by *Fusarium oxysporum* f. sp. *lini*. *Annals of Plant Protection Science* **10** : 365-410.

*Sharma, S.R. and Sohi, H.S. 1983. Study regarding N, P and K. *Journal of Turkish Phytopathology* **12** : 19-26.

*Sheela, J., Sivaprakasam, K. and Seetharaman, K. 1995. Biological control of Fusarium wilt of eggplant. *Madras Agriculture Journal* **82** : 201-204.

*Shin, Y.A. and Tezuka, N. 1992. Effects of soil moisture and inoculam density on the incidence of Phytophthora blight of red pepper. *Proceedings of Kanto-Tosan Plant Protection Society* **39** : 81-83.

*Shrestha, S.M. 1992. *Biocontrol Potential of Trichoderma harzianum and Gliocladium virens on Lentil Wilt Complex*. Ph.D. thesis submitted to G. B. Pant University of Agriculture and Technology, Pantnagar, p 210.

*Simons, J.N., Simons, J.E., Simons, J.L. and Winsberg, T. 1990. Control of Phytophthora crown rot in bell pepper with direct sprays of metalaxyl. *Proceedings of the Florida State Horticultural Society* **103** : 120-121.

Singh, A. and Singh, A.K. 1998. Screening of chilli germplasm against Fusarium wilt. *Crop Research* **15** : 132-133.

Singh, R.S., Jindal, A., Singh, D. and Singh, T. 1995. Selection of *Trichoderma* isolates against common fungicides for their use in integrated plant disease management. *Indian Journal of Mycology and Plant Pathology* **25** : 127.

Singh, S.P. 1989. *Production Technology of Vegetable Crops*, Agriculture Research Communication Centre, Karnal, India, p 2.

Singh, S.P., Abu-Mohammad and Sinha, P.P. 1989. Effect of nitrogen, phosphorus and potash on the development of Alternaria leaf spot of cabbage. *Indian Phytopathology* **42** : 245-247.

Singh, Y. 1998. Management of *Sclerotinia* rot of rapeseed and mustard through chemicals. *Plant Disease Research* **13** : 149-150.

Smith, P.G., Vilualon, B. and Villa, P.L. 1987. Horticultural classification of peppers grown in the United States. *Hortsciences* **22** : 11-13.

*Srivastava, V.K. and Diwakar, M.C. 1987. Note on stem rot and wilt of chillies in Haryana. *Plant Protection Bulletin* **39** : 35.

*Strong, M.C. 1946. The effects of soil moisture and temperature on Fusarium wilt of tomato. *Phytopathology* **36** : 218-225.

Subramanian, G.V. 1971. Hyphomycetes : An account of Indian species. Indian Council of Agricultural Research, New Delhi p 613.

Sugha, S.K. 2001. Management of white rot of pea by fungicides. *Journal of Mycology and Plant Pathology* **31** : 335-338.

*Sumitha, R.and Gaikward, S.J. 1995. Checking Fusarium wilt of pigeon pea by biological means. *Journal of Soils and Crops* **5** : 163-165.

*Sung, N.K. and Hwang, B.K. 1988. Comparative efficacy and *in-vitro* activity of metalaxyl and metalaxyl copper oxychloride mixture for control of Phytophthora blight of pepper plants. *Korean Journal of Plant Pathology* **4** : 185-196.

Taya, R.S., Tripathi, N.N. and Parwar, M.S. 1988. Influence of soil type, soil moisture and fertilizers on the severity of chickpea dry root rot caused by *Rhizoctonia bataticola* (Taub.) Butler. *Indian Journal of Mycology and Plant Pathology* **18** : 133-136.

Tewari, A.K. and Mukhopadhyay, A.N. 2003. Management of chickpea rot rot and collar rot by integration of biological and chemical seed treatment. *Indian Phytopathology* **56** : 39-42.

Tewari, A.K., Mukhopadhyay, A.N. and Agarwal, R. 2003. Colonization of *Gliocladium virens* on biologically treated chickpea seed for biocontrol of chickpea wilt complex. *Acta Phytopathologica Et Entomologica Hungarica* **38** : 79-85.

Thind, T.S. and Jhooty, J.S. 1985. Relative prevalence of fungal diseases of chilli fruits in Punjab. *Indian Journal of Mycology and Plant Pathology* **15** : 305-307.

*Thomas, K.M. 1938. *Detailed Administration Report of the Government Mycologist, Madras, for the year ending 1937*, p 27.

*Tomkins, C.M. and Tuckar, C.M. 1942. Root rot of pepper and pumpkin caused by *Phytophthora capsici*. *Journal of Agricultural Research* **13** : 417-426.

*Tsao, P.H. and Gilberto, O. 1969. Selective isolation of species of *Phytophthora* from natural soil on an improved antibiotic medium. *Nature* **223** : 636-638.

Upadhyay, J.P. and Mukhopadhyay, A.N. 1983. Effect of non-volatile and volatile antibiotics of *Trichoderma harzianum* on growth of *Sclerotium rolfsii*. *Indian Journal of Mycology and Plant Pathology* **13** : 232-233.

Upmanyu, S., Gupta, S.K. and Shyam, R.K. 2002. Innovative approaches for the management of root rot and web blight (*Rhizoctonia solani*) of frenchbean. *Journal of Mycology and Plant Pathology* **32**: 317-331.

*Verma, B.R. and Sharma, B.K. 1995. Management of chilli wilt. *Proceedings of the National Symposium on Recent Trends in the Management of Biotic and Abiotic Stresses in Plants*, November 2-3, held at HPKVV, Palampur (India).

Verma, S. 1997. *Epidemiology and Management of Leaf Blight and Fruit Rot of Bell Pepper*. M.Sc. thesis submitted to Dr. Y.S. Parmar U.H.F., Solan, HP, p 82.

Vidhyasakaran, P. and Thiagarajan, C.P. 1981. Seed-borne transmission of *Fusarium oxysporum* in chilli. *Indian Phytopathology* **34** : 211-213.

Vijayaraghavan, R. and Abraham, K. 2004. Compatibility of biocontrol agents with pesticides and fertilizers used in black pepper gardens. *Journal of Mycology and Plant Pathology* **34** : 500-508.

*Vincent, J.M. 1927. Distribution of fungal hyphae in the presence of certain inhibitors. *Nature* **159** : 850.

*Vitanov, M. 1989. Movement of *Phytophthora capsici* in soil and infection of pepper. *Rasteniev' dni Nauki* **26** : 60-66.

*Wangiliar, P.D., Somani, R.B. and Bobade, K.P. 1988. Sclerotium collar rot – a new menace to chilli in Vidharbha. *PKV Research Journal* **12** : 88-89.

Wani, M.A. 1994. *Studies on fungal wilt of chilli* (*Capsicum annuum* L.). M.Sc. (Agri.) Thesis, submitted to Sher-e-Kashmir University of Agricultural Sciences and Technology, Kashmir, Srinagar, p. 74.

*Weindling, R. 1932. *Trichoderma lingorum* as a parasite of other soil fungi. *Phytopathology* **22** : 837-845.

*Wokocha, R.C. 1990. Integration of *Sclerotium rolfsii* infection of tomato in the Nigerial Savana : Effect of *Trichoderma viride* and some fungicides. *Crop Protection* **9** : 231-234.

*Woltz, S.S. and Engelhard, A.W. 1973. *Fusarium* wilt of chrysanthemum : Effect of nitrogen source and lime on disease development. *Phytopathology* **63** : 155-157.

*Woltz, S.S. and Jones, J.P. 1981. Nutritional requirements of *Fusarium oxysporum* : Basis for disease control system. In : *Fusarium : Diseases, Biology and Taxonomy.* Nelson, P.E., Toussoum, T.A. and Cook, R.J. (Eds.), Pennsylvania State University Press, Pennsylvania, USA, pp 340-349.

*Woltz, S.S. and Jones, J.P. 1984. Effects of aluminium, lime and phosphate combinations on Fusarium wilt of tomato. *Phytopathology* **74** : 629.

*Woodcock, W.P. 1962. Influence of aeration of exudation from seeds on growth of root rot fungi. *Phytopathology* **52** : 927.

*Woolliams, G.E., Denby, L.G. and Hansen, A.S.F. 1962. Screening sweet and hot peppers for *Verticillium* wilt resistance. *Canadian Journal of Plant Science* **42** : 515-520.

*Wu, W.S., Liu, S.D., Chang, Y.C. and Tschen, S. 1986. Hyperparasitic relationship between antagonists and *Rhizoctonia solani. Plant Protection Bulletin* **28** : 91-100.

*Xie, J.H., Cardenas, E.S., Sammis, T.W. and Lindsay, D.L. 1999. Effect of irrigation method on chilli pepper yield and *Phytophthora* root rot incidence. *Elseviu Science* **42** : 127-142.

*Zakharova, I.I. 1971. Role of *Fusarium* spp. in hallow ear formation of spring wheat. *Zashch Rast* **29** : 92-99.

***Original not seen**

Appendices

RECIPES OF MEDIA USED

a) Potato-Dextrose Agar

Agar	:	20.0 g
Potato (peeled and sliced)	:	200.0 g
Dextrose	:	20.0 g
Distilled water	:	1000.0 ml
pH	:	6.0 - 6.5

b) P_{10}VP Medium (Tsao and Gilberto, 1969)

Agar	:	20.0 g
Potato (peeled and sliced)	:	200.0 g
Dextrose	:	20.0 g
Distilled water	:	1000.0 ml
Pimaricin	:	10.0 ppm
Veneomycin	:	200.0 ppm
PCNB	:	100.0 ppm

c) Peptone-Dextrose-Rose Bengal Agar (Martin, 1950)

Agar	:	20.0 g
KH_2PO_4	:	1.0 g
$MgSO_4.7H_2O$	:	0.5 g
Peptone	:	5.0 g
Dextrose	:	10.0 g
Rose Bengal (1%)	:	3.3 ml
Distilled water	:	1000.0 ml
Streptomycin sulphate	:	30.0 mg

d) Trichoderma Selective Media (Shreshta, 1992)

Agar	:	20.0 g
$MgSO_4$ $7H_2O$	:	0.2 g
K_2HPO_4	:	0.9 g
KCl	:	0.15 g
NH_4NO_3	:	1.0 g
Glucose	:	3.0 g
Distilled water	:	100.0 ml
Dicrysticine	:	0.5 g
Apron	:	0.05 g
Captan	:	0.05 g
Vitavax	:	0.02 g
Rose Bengal	:	0.15 g

e) Oatmeal Agar

Agar	:	20.0 g
Oatmeal	:	15.0 g
Distilled water	:	1000.0 ml

RECIPES OF MEDIA USED

a) Potato-Dextrose Agar

Agar	:	20.0 g
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Distilled water	:	1000.0 ml
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KCl	:	0.15 g
NH_4NO_3	:	1.0 g
Glucose	:	3.0 g
Distilled water	:	100.0 ml
Dicrysticine	:	0.5 g
Apron	:	0.05 g
Captan	:	0.05 g
Vitavax	:	0.02 g
Rose Bengal	:	0.15 g

e) Oatmeal Agar

Agar	:	20.0 g
Oatmeal	:	15.0 g
Distilled water	:	1000.0 ml

WEATHER DATA RECORDED AT PONICHAK, JAMMU

(February, 2001 to October, 2001)

Standard week	Dates	Rainfall (mm/wk)	Relative humidity (%)		Temperature (^0C)	
			Max.	Min.	Max.	Min.
5	29 – 04 Feb	–	72.6	44.9	22.0	3.8
6	05 – 11 Feb	–	74.5	45.1	23.9	3.8
7	12 – 18 Feb	2.0	60.7	46.1	24.9	8.9
8	19 – 25 Feb	0.9	76.8	50.6	23.9	10.9
9	26 – 04 Mar	4.7	75.4	44.4	25.2	7.6
10	05 – 11 Mar	–	71.9	52.4	27.4	9.4
11	12 – 18 Mar	–	76.6	52.1	28.9	10.8
12	19 – 25 Mar	24.6	78.9	48.6	28.4	12.4
13	26 – 01 Apr	5.4	83.2	46.3	28.9	13.4
14	02 – 08 Apr	1.2	81.3	45.3	32.6	13.1
15	09 – 15 Apr	3.9	64.4	41.6	33.3	18.9
16	16 – 22 Apr	29.2	82.2	49.8	28.3	15.9
17	23 – 29 Apr	–	71.3	34.7	37.3	18.6
18	30 – 06 May	–	62.9	36.4	39.6	20.9
19	07 – 13 May	1.0	65.6	30.4	41.0	23.5
20	14 – 20 May	30.7	68.0	37.4	36.2	22.1
21	21 – 27 May	1.4	77.5	37.1	3.2	22.7
22	28 – 03 Jun	38.3	77.3	44.0	38.0	22.7
23	04 – 10 Jun	39.7	76.9	48.9	34.7	23.5
24	11 – 17 Jun	184.1	82.9	55.1	34.4	23.0
25	18 – 24 Jun	25.9	88.1	57.1	35.1	23.2
26	25 – 01 Jul	34.1	85.9	58.5	34.8	25.6
27	02 – 08 Jul	65.7	92.0	62.4	34.8	25.6
28	09 – 15 Jul	70.4	93.7	69.9	34.1	25.4
29	16 – 22 Jul	104.9	93.6	72.9	33.9	25.4
30	23 – 29 Jul	52.1	94.2	74.2	33.3	25.4
31	30 – 05 Aug	131.8	93.0	73.6	34.5	24.9
32	06 – 12 Aug	113.9	92.3	71.4	34.1	24.7
33	13 – 19 Aug	79.7	93.7	69.9	34.2	25.4
34	20 – 26 Aug	146.8	93.0	72.5	34.1	24.8
35	27 – 02 Sep	41.5	91.6	66.6	34.9	24.7
36	03 – 09 Sep	14.3	90.0	69.6	34.3	22.7
37	10 – 16 Sep	33.4	91.5	68.6	31.5	20.6
38	17 – 23 Sep	–	91.0	63.5	33.7	20.9
39	24 – 30 Sep	–	90.0	58.4	34.2	19.1
40	01 – 07 Oct	–	88.1	58.6	33.0	19.5
41	08 – 14 Oct	–	85.6	53.6	32.8	17.4
42	15 – 21 Oct	–	85.3	53.7	31.6	14.0
43	22 – 28 Oct	–	85.9	58.8	31.4	15.7

Appendix - III

WEATHER DATA RECORDED AT PONICHAK, JAMMU

(February, 2002 to October, 2002)

Standard week	Dates	Rainfall (mm/wk)	Relative humidity (%)		Temperature (^0C)	
			Max.	Min.	Max.	Min.
5	29 – 04 Feb	–	83.7	61.5	19.8	4.3
6	05 – 11 Feb	0.8	88.7	67.0	20.1	5.0
7	12 – 18 Feb	–	85.5	63.0	23.5	7.3
8	19 – 25 Feb	3.6	83.1	60.2	24.8	9.8
9	26 – 04 Mar	8.3	83.3	65.6	22.6	8.8
10	05 – 11 Mar	26.3	85.4	69.4	25.2	11.1
11	12 – 18 Mar	–	88.4	70.4	28.8	12.0
12	19 – 25 Mar	7.6	83.2	62.7	31.1	16.8
13	26 – 01 Apr	0.9	84.8	58.9	31.2	14.0
14	02 – 08 Apr	0.8	80.8	58.1	31.1	16.1
15	09 – 15 Apr	–	81.4	57.3	39.6	14.8
16	16 – 22 Apr	–	81.4	40.4	38.8	17.0
17	23 – 29 Apr	15.1	74.0	47.0	34.4	19.1
18	30 – 06 May	–	70.6	40.0	39.0	19.2
19	07 – 13 May	–	66.7	43.1	42.5	21.3
20	14 – 20 May	–	63.0	37.1	42.8	23.3
21	21 – 27 May	–	58.8	37.0	41.7	23.8
22	28 – 03 Jun	3.9	69.3	42.3	37.8	22.6
23	04 – 10 Jun	6.7	70.3	37.4	40.4	24.0
24	11 – 17 Jun	23.7	78.9	39.3	38.4	22.7
25	18 – 24 Jun	16.4	66.0	40.1	32.8	23.3
26	25 – 01 Jul	16.6	85.0	48.3	38.0	24.6
27	02 – 08 Jul	49.3	90.4	48.6	37.6	24.1
28	09 – 15 Jul	19.7	81.1	47.0	39.7	25.9
29	16 – 22 Jul	23.7	87.3	51.1	33.1	27.1
30	23 – 29 Jul	78.9	91.1	43.8	36.4	23.4
31	30 – 05 Aug	35.9	93.5	46.5	38.8	24.7
32	06 – 12 Aug	19.7	93.7	63.8	35.9	27.0
33	13 – 19 Aug	57.6	90.5	68.1	31.5	25.1
34	20 – 26 Aug	176.9	90.1	76.9	31.0	26.1
35	27 – 02 Sep	157.6	91.6	73.5	30.3	25.6
36	03 – 09 Sep	13.2	98.7	61.3	31.6	23.0
37	10 – 16 Sep	68.2	94.7	56.6	31.1	22.8
38	17 – 23 Sep	19.7	93.7	56.7	31.4	21.8
39	24 – 30 Sep	–	97.3	53.4	31.7	19.5
40	01 – 07 Oct	–	94.3	45.8	33.4	17.8
41	08 – 14 Oct	29.9	98.6	58.6	30.5	17.2
42	15 – 21 Oct	–	98.6	52.8	30.8	16.1
43	22 – 28 Oct	1.7	96.0	45.7	29.5	13.9

VITA

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Bachelor's Degree	:	B.Sc. Agriculture (Hons.)
University	:	CCSU, Meerut
Year of Award	:	1998
Per cent marks	:	54.0
Master's Degree	:	M.Sc. Agriculture (Plant Pathology)
University	:	AAIDU, Allahabad
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Title of Master's Thesis	:	"Studies on the effect of seed treatment with different fungicides on the rhizosphere microflora, growth, nodulation and yield of *Pisum sativum* L."
Ph.D.	:	Ph.D. Agriculture (Plant Pathology)
OGPA	:	3.34 / 4.00
Title of Ph.D. Thesis	:	"Studies on the wilt complex disease of *Capsicum annuum* L."

Awards / Distinctions / Fellowship / Scholarships :

- ❖ Qualified NET.