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VASCULAR WILT DISEASES - A MENACE IN VEGETABLE CROPS

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Summary

Vascular wilts are the most important yield limiting diseases of vegetables and caused by both fungal and bacterial pathogens. The major wilt causing fungal pathogenic genera are *Fusarium* and *Verticillium*; while *Ralstonia solanacearum* is the bacterial wilt pathogen. These pathogens are a challenge to control because they often survive in soil for long periods and affect the crops throughout the year from across the plant families. The disease symptoms caused by each pathogenic genus are often creating confusions. For the effective plant disease management a thorough knowledge on symptoms caused by various pathogenic organisms, their detection and diagnostics techniques, mode of survival and infection, host range, and favorable conditions is needed. Similarly, to minimize the crop yield losses due to vascular wilt diseases, approaches like use of resistant varieties/cultivars, selection of suitable chemical fungicides/antibiotics, adopting different cultural practices and application of appropriate biocontrol agents, are to be included in the disease management practices. This review aims to provide comprehensive information about the vascular wilt diseases of vegetable crops, pathogen detection and disease management.

Introduction

Wilt diseases are the most widespread and destructive soil-borne diseases, which attacks a large number of vegetable species throughout the world. The symptoms expressed when the pathogens infect the roots of susceptible plants and plug the water conducting tissues (Deacon, 2004). Due to vascular wilt diseases 2-90% yield loss have been recorded in wide range of crops (Gupta *et al.*, 1987; Swamini *et al.*, 1987; Kanjilal *et al.*, 2000; Pataky *et al.*, 2000). The disease is reported to be severe both in greenhouse and field conditions. *Fusarium* and *Verticillium* are the two important wilt causing fungal pathogens while *Ralstonia* is bacterial wilt pathogen. *Fusarium* causes vascular wilt of vegetables, flowers, ornamentals and other important crops. Different host plants are attacked by special forms or races of *F. oxysporum*. Similarly, *Verticillium* also causes vascular wilt disease in many crop plants worldwide but it is most important in temperate regions. *Verticillium* attacks more than 200 species of plants, including most of the vegetables, flowers, fruits trees, field crops and forest trees (Agrios, 2004). Two species of *Verticillium* viz. *V. albo-atrom* and *V. dehliae* have been reported as phytopathogens. In the case of bacterial wilt, though there are five main genera, *Ralstonia, Ervinia, Xanthomonas, Pantoea* and *Curtobacterium* have already been reported, the wilt caused by *Ralstonia solanacearum* (formerly known as *Pseudomonas solanacearum*) is important since it is widely affecting many vegetable crops. *R. solanacearum* is known to cause severe wilt diseases in tropical and subtropical climates with high rainfall and the disease is recorded in 200 species of economically important plants (Lyons *et al.*, 2001). Chemicals especially soil fumigants *viz.*, methyl bromide and chloropicrin are effectively used to reduce the level of soil borne inoculum of wilt pathogens. However, such control measure is expensive and environmentally unsafe and hence non-chemical management strategies more importantly biocontrol agents are used as an alternative method to suppress vascular wilts. In this review, the scenario of vascular wilts of vegetable crops, pathogen detection and disease management are discussed.

Host range: All groups of wilt pathogens causes a severe damage to a wide range of vegetable crops and the major wilt diseases caused by fungal and bacterial pathogens are listed in Table 1 and Table 2 respectively.

Symptoms caused by various wilt pathogens: Symptoms of root wilt and rot are often difficult to identify when the infected plants are observed at advanced stage. Wilt diseases are characterized by drying up of entire plant and browning in vascular tissues. The leaves and other green or succulent parts lose their turgidity, become flaccid and droop. This effect is usually seen first in some of the leaves. Later

Table 1. Different host range of fungal wilt pathogens

Host	Pathogen	References
Tomato	*Fusarium oxysporum* f. sp. *lycopersici*	Abdul-Wahid *et al.* (2001)
Radish	*F. o.* f. sp. *raphani*	Toit and Pelter (2003)
Cabbage and cauliflower	*F. o.* f sp. *conglutinans*	Nomura *et al.* (1979)
Pea	*F. o.* f. sp. *pisi*	Sakoda *et al.* (2004)
Bean	*F. o.* f. sp. *phaseoli*	Coelho-Netto and Dhingra (1999)
Celery	*F. o.* f. sp. *apii*	Heath-Pagliuso and Rappaport (1990)
Cucumber	*F. o.* f. sp. *cucumerinum*	Akmuradov and Sidorova (1983)
Coriander	*F. o.* f. sp. *corianderi*	Lakra and Dasgupta (2000)
Watermelon	*F. o.* f. sp. *niveum*	Zhou and Everts (2004)
Muskmelon	*F. o.* f. sp. *melonis*	Akmuradov and Sidorova (1983)
Cucumber	*Verticillium dehalie*	Costache and Tomescu (1987)
Tomato	*V. dehalie*	Costache (1977)
Cauliflower	*V. dehalie*	Debode *et al.* (2004)
Potato	*V. albo atrum and V.dehalie*	Johnston and Rowberry (1980)
Egg plant	*V. dehalie*	Costache (1977)
Beetroot	*V. dehalie*	Muller *et al.* (2004)

Table 2. Different host range of bacterial wilt pathogens

Host	Pathogen	References
Tomato, potato, capsicum, eggplant.	*Ralstonia solanacearum*	Coelho *et al.* (2001)
Watermelon, muskmelon and cucumber	*Ervinia trachiphila*	Zehnder *et al.* (2001)
Bean	*Curtobacterium flaccumfaciens*	Calzolari (2000)

the young growing tip or whole plant may suddenly or gradually dry up. Wilting may be the result of injury to the root system upon the partial plugging of water conductivity of the vessels and toxic substances secreted by the pathogen (Deacon, 2004; Singh, 1984). In contrast to wilt, rot is the process of "tissue disintegration", where the cells and tissues of host plants are separated from each other. The material binding the cells to form tissue is destroyed by the pathogen to enable it reach the host protoplasm. Such pathogens are mostly facultative parasite or saprophytes (Singh, 1984).

Wilts of *Fusarium* spp.: Initial symptoms are yellowing of the foliage, beginning with the lower leaves and progressing upward. Later, yellowing starts in only one side of a leaf midrib, one branch, or one side of the affected plant. Infected leaves later show downward curling, followed by browning and drying (Steve Bost, http/www.utextension.utk.edu). Vascular browning can be seen in infected stems and large leaf petioles. Affected plants and their root systems become stunted. The degree of stunting depends upon time of root infection, hence young plants suffered severely than the matured plants. Plants infected with *Fusarium* wilt have a brown discoloration of the vascular vessels and this discoloration can be used for diagnosis. Walker (1957) noticed some scars on the petiole apart from the dark brown vascular discoloration, *Fusarium* is reported to produce three types of asexual spores *viz.*, microconidia, macroconidia and chlamydospore. Microconidia are one or two celled while macroconidia are five celled and curved. Chlamydospores are one or two celled and thick walled round structures. Though all three types of spores of the fungus can survive in soil, the chlamydospores have the capacity to survive for long time (Agrios, 2004).

Wilts of *Verticillium* spp.: The symptoms of *Verticillium* wilt may be confused with those of *Fusarium* wilt. These two fungi produce similar field symptoms and can not be distinguished unless the pathogenic organism is cultured in the laboratory. In *Verticillium* wilt, an obvious discoloration occurred at the edges or between veins on the leaves of lower part of the plants at the beginning (Douglas, 2008). Initially the diseased leaves curls upwards under the drought conditions at noon but remains normal in the cloudy, rainy times and night times. In the later stages the entire plant leaves become wilted with green, yellow and brown discoloration. Discolored vascular tissue can be observed when stem is dissected.

Verticillial wilt is caused by two closely related soil borne fungi, *Verticillium dahliae* and *V. albo-atrum* (Douglas, 2008). Both *V. albo-atrum* and *V. dahliae* produce one-celled, colorless conidia that are short-lived. *V. dahliae* capable of producing minute, black, resting structures-called microsclerotia, while *V. albo-atrum* produce microsclerotial-like dark, thick-walled mycelium but not exactly microsclerotia. The microsclerotia of *V. dahliae* can survive in soil up to 15 years (Agrios, 2004). In general, agricultural soils may contain up to 100 or more microsclerotia per gram, but six to 50 microsclerotia per gram are sufficient to generate 100 per cent infection in susceptible crops such as eggplants, potato and tomato (Anon, 1997).

Wilts of *Ralstonia solanacearum*: In case of bacterial wilt, the root appears healthy and often is well developed. Pathogen is mostly confined to vascular region. In advance stage, it may invade the cortex and pith and cause yellow brown discoloration in the tissues (Verma & Sharma, 1999). It also produces kind of polysaccharide which blocks the vascular system mechanically (Balasubramaniam & Nilkantan, 1976). There after the translocation of water and minerals is checked resulting in the affected plants becomes wilted. Bacterial wilt is similar to fungal wilt in observations but in later one, the fungi remain almost exclusively in the intact vascular system until the death of plant, but in bacterial wilt the bacteria often destroyed part of cell wall of xylem vessels or cause them to rapture quite early in the disease development. An oozing in the cut end of the stem is a typical symptom of bacterial wilt disease.

Detection and diagnostics of wilt pathogens

Fungal wilt pathogens: Conventionally, *Fusarium* genus is detected based on symptoms it produce on the host and presence of fungal colonies in the affected tissues (Baayen, 2000). However, the traditional method has following problems; (i) it is difficult to identify if more than one *forma specialis* occur on a given host, (ii) unable to distinguish common non-pathogenic strains in soil and rhizosphere inhabitants (Edel *et al*., 2000). Alternatively, identification of plant pathogens using molecular tools will eliminate the problems of conventional methods. Earlier, polymerase chain reaction (PCR) has been used as a major tool for the diagnosis and study of phytopathogenic fungi (Henson and French, 1993; Martin *et al*., 2000; Ghignone and Migheli, 2005). Later, for identification at family, genus, or species level, nuclear rDNA, including the small and large subunits, 5.8S, 28S and the internal transcribed spacer (ITS) region were successfully utilized (White *et al*., 1990). Based on differences in nucleotides in ITS sequences of 18S, 5.8S and 28S ribosomal DNAs, a PCR technique was developed for the detection of *F. oxysporum* f.sp. *lycopersici* (Moricca *et al*., 1998). Race level identification was also made using specific primers in PCR assays (Jimenez & Jimenez, 2003). A powerful technique, real-time quantitative PCR was used to detect nucleic acid of many phytopathogenic fungi (Abd-Elsalam, 2003; Okubara *et al*., 2005). Real-time PCR technique using the SYBR Green dye was used to detect *F. solani* f.sp. *phaseoli* propagules (Filion *et al*., 2003). Similarly, the Taq Man-based real-time assay was used to detect *F. culmorum* (Strausbaugh *et al*., 2005). It indicates the detection and diagnosis of *Fusarium* spp. at species and race level is possible through PCR based molecular approaches.

In general identification of *Verticillium* wilt diseases through symptomology is very difficult unless bioassay or pathogenecity tests are being carried out (Clarkson and Heale, 1985; Sewell and Wilson, 1984) and these bioassays are laborious and time-consuming, rather through molecular approach, for an instance *V. dahliae* was successfully detected using PCR from fungus culture (Li *et al*, 1994; Li *et al*, 1999) and naturally infested soil (Volossiouk *et al*., 1995). However, still it is a problem to detect the pathogen both in the plant and soil (Garcia-Pedrajas, 1999; Mascarello *et al*., 2001; Volossiouk *et al*., 1995). Therefore, a precise and more rapid method is required for the characterization and detection of *Verticillium* spp. By utilization of differences in ITS regions of nuclear rDNA, identifications using specific primers were made in *V. albo-atrum, V. dahliae,* and *V. tricorpus* (Morton *et al*., 1995; Nazar *et al*., 1991; Robb *et al*., 1993). A considerable progress has been made to detect and quantify the *Verticillium* biomass in different host plants and in soil samples using specific primers in PCR assays (Hainz and Platt, 2000; Hu *et al*., 1993; Mercado-Blanco *et al*., 2002; Moukhamedov *et al*., 1994; Robb *et al*., 1994). Similarly, an amplified fragment length polymorphism (AFLP) marker linked to the virulence of *V. albo-atrum isolates* have been identified (Radisek *et al*., 2003) and sequence-characterized amplified region (SCAR) marker was developed and utilized in multiplex and nested PCR assays for distinguishing the pathotypes of *V. albo-atrum*.

Bacterial wilt pathogen

Isolation and culture observation on differential medium: Normally, tetrazolium medium (Kelmans, 1954) is used to identify the colonies of *R. solanacearum,* where it produces typical fluidal, smooth and white colonies with pink internal whirling patterns. Anitha et al. (2004) standardized the methodology for detecting bacterial wilt infection *(R. solanacearum)* in seed and seedlings of introduced

groundnut germ-plasm by direct seed plating method on tetrazolium chloride agar (TZCA) medium. Hitherto, several other media supplemented with different antibiotic have been used to isolate this pathogen (Karganilla and Buddenhagen, 1972; Nesmith and Jenkins, 1979; Granada and Sequeira, 1983). However, a semi selective medium proposed by Granada and Sequeira (1983) gave rigorous growth of *R. solanacearum* isolates within a 48 h of incubation. Aggarwal and Sood (2005) used a simple plating technique to detect the presence of *R. solanacearum* from capsicum seeds.

Protein based detection techniques

Serological techniques: For identification of *R. solanacearum* at race/biovar/pathovar level serological techniques are mostly used. These techniques are mainly based on reaction between antigen and antibody. Different parts of the bacterial cells *viz.*, exopolysaccharide (EPS), cell wall structural (somatic) components ("0" antigens), extra cellular glycoprotein, and flagella components ("H" antigens) (Digat and Cambra, 1976) were used as antigen to develop polyclonal antibody. Among which, only glycoproteins were found as strain-specific (Coleno *et al.*, 1976; Digat and Cambra, 1976; Eden-Green and Adhi, 1986), where as other proteins showed cross reaction with the related bacteria or their races. Hence, to avoid cross reaction, monoclonal antibodies need to be developed. Glycoproteins based monoclonal antibodies were produced and have been used to distinguish the different strains (serovars) of *R. solanacearum* (Schaad *et al.*, 1978). Similarly strain specific antibodies have been developed and used worldwide to detect strain variation in *R. solanacearum* (He, 1986; Alvarez *et al.*, 1993; Robinson, 1993).

Latex agglutination test: In this experiment, latex beads were allowed to bind with purified gamma globulin extract (IgG) of polyclonal antiserum. Then, sensitized latex beads and homogenate from diseased plant samples were mixed at equal proportion to get agglutinated. This technique was adopted to detect a race 3 strain of *R. solanacearum* (Nakashima & Nydegger, 1986). Though this technique is simple and reliable, it has no long- term stability.

Enzyme-linked immunosorbent assay (ELISA): In general ELISA is widely accepted technique to quarantine the pathogenic infection in plant samples and it is much reliable, speedy and easy to handle. Robinson (1993) reported that indirect ELISA system to detect bacterial infection and this system was found to be reliable to detect even at 10^4 cfu/ml of the sample. Post-enrichment NCM-ELISA was used to detect *R. solanacearum* from ginger rhizomes (Kumar *et al* 2002). Dot-blot ELISA is an alternative method to ELISA and this system was used in International Potato Center to detect potato tuber infection with *R. solanacearum*. Initially, the bacterial cells are allowed to trap on nitroellulose membrane and the remaining procedure will be followed as in ELISA. The advantage here is to analyse large volume of sample compare to ELISA.

Immune-Fluorescence assays: In this method, the bacterial cells will be coated with polyclonal antibody followed by secondary antibody (swine antirabbit antibody conjugated with the fluorescent dye fluorescein isothiocyanate) and resultant product is finally observed under fluorescent microscope. This technique is practiced in European quarantine services to detect the *R. solanacearum* infection in imported potato tubers (Janse, 1988).

DNA based techniques

Hybridization with DNA (pathogen specific) probe: In the present technique, a non radioactive DNA probes specific to the pathogens will be developed by labeling with horseradish peroxidase enzyme or digoxygenin and used to hybridize with DNA sequence (single stranded) of the pathogenic organisms. Seal *et al*. (1992) developed a DNA probe (P52096) specific to *R. solanacearum*. Similarly, Cook and Sequeira (1991) reported a probe specific to race 3 strains of *R. solanacearum*.

PCR technique: In PCR, DNA of pathogenic organisms will be amplified using pathogen specific forward and reverse primers. Two primers PS96-H and P896-I corresponding to the DNA probe PS2D96 were developed and used to detect *R. solanacearum* (Seal *et al.*, 1992). Kumar and Anandaraj (2006) reported PCR-based detection of *R. solanacearum* ginger isolate from soil. Ramesh *et al.* (2008) reported the PCR based method to detect *R. solanacearum* from soil, eggplant and weeds. James *et al.* (2003) reported the possibility of using Random amplified polymorphic DNA (RAPD) analysis for detection of *R. solanacearum* race 3.

Favourable conditions for wilt disease development

Disease intensity is highly dependant on favorable environmental conditions such as temperature and soil pH, moisture and nature. Normally, Fusarial wilt occurs in high temperature (78-90°F) and poorly drained soil where as *Verticillium* wilt noticed in low temperature (70-80°F) (Anon, 1997). Apart from this, application of high amount of nitrogenous fertilizers, deficiency in potassium and soil acidic conditions (pH 5-6) also favors the wilt development (Raj & Kapoor, 1995). Bacterial wilt disease incidence is more in warm and humid conditions with high temperature. Also, it is severe in soils with high moisture content and sandy loam nature (Yuan *et al.*, 1992).

Mode of infection

By fungal pathogens: Generally, the pathogens which cause wilt diseases are soil inhabitant and the main mode of infection is via infected soil (Hashimoto, 1989). When healthy plants are grown in contaminated soil, the germ tube of spores or the mycelium penetrates the root tips directly or enters the root system through wounds or at the point of formation of lateral roots. The mycelium advances through the root cortex intercellularly, and when it reaches the xylem vessels it enters through the piths. Then the mycelium remain exclusively in the vessels and travels through them, mostly towards the stem and crown of the plant. While, spores or conidia germinate and penetrate the wall of vessels and enters into the vessels, due to this the host plant fails to uptake water and nutrition from soil, resulting process is called "vessel clogging" (Agrios, 2004). The leaves of infected plant transpire water more than the water transport by root and stem. Finally, stomata in the leaves will be closed and wilted, and soon followed the death of whole plant.

By bacterial pathogen: The bacterial pathogens survive in the soil, seed and some cases in the insect vector, when they comes in contact with host plant they enters into the plant system through wounds and multiply in the vascular system (xylem) and causes blocking of the vessels. Normally, the bacterium confined to vascular region alone and in advance stages, it may enter into the cortex as well as pith and produces yellow discolorations in the tissues.

Management

Disease management requires a thorough knowledge on three main components such as host, pathogen and environment. The disease development and progress depends on the interaction of all three factors and the reaction must be positive when host become susceptible, pathogen develops virulence and environmental conditions are favorable. When disease management practices are imposed, the value of the crop must exceed the cost of control practices. Hence the possible approaches like resistant varieties, cultural, chemical and biological methods must be integrated in wilt disease management.

Cultural practices: Control of plant diseases through cultural practices involves the principles of avoidance, exclusion and eradication. Under cultural control method the use of resistance cultivar or hybrids offers the best possibility of control of *Fusarium* wilt. Cultural control was found better than biological and chemical control (Gomez-Caicedo *et al.*, 2001). Sharma and Kumar (2000) suggested that soil amelioration by karanj cake (*Pongamia glabra*), bleaching powder and lime to manage the bacterial wilt of tomato. Keshwal and Khare (2000) showed that long-term fallowing of artificially infected soil for one or two summers provided 100% control of bacterial wilt in tomato. Kumar and Sood (2003) showed that bioagent treated tomato seedlings grown in soil amended with sodium nitrate and potassium nitrate resulted in the complete control of wilt incidence. Ramesh and Manjunath (2002) observed that farm yard manure, poultry manure and mushroom spent substrate plus paddy straw when applied with recommended NPK dose to eggplant resulted lowest wilt incidence. Dubey (2005) reported that the interactions of Karanj cake, bleaching powder and seedling root dip in streptocycline was the most effective treatment in managing bacterial wilt in tomato. Soil solarization by mulching with polyethelene film resulted in 96.3% of healthy plant in comparison to control 32%. The temperature of solarized soil reached upto 52°C at depth of 10-15 cm (Abdul-Wahid *et al.*, 2001). Similarly at 15 and 25-cm depth, solarization caused an increase in soil temperature of 15.4 $\pm$ 2.7°C and 14.7 $\pm$ 1.84°C respectively. Soil solarization delayed the appearance of all the wilt diseases tested and reduced the incidence of *Verticillium* wilt by 89 -96 % and *Fusarium* wilt by 59-94.6% (Tamietti & Valentino,

2000). In case of bacterial wilt diseases, practices like destruction of diseased plant, prevention of leaf cutting or animal browsing in infested plots, disinfection of pruning knives, selection of planting materials from diseased free field and crop rotation with non host crops for two years reported be effective (Yirgou & Bradbury, 1974). The use of resistant cultivars or hybrids (Table 3), application of soil amendments and soil solarization offers the best possibilities of the disease control (Couteaudier & Alabouvette, 1982; Sood, 2005).

Table 3. Resistant cultivars or hybrids against wilt diseases in vegetables

Crop	Resistance variety	References
Potato	Campbell 14 , Mainestay, Nor King Russet , Rideau (V)	Reeves *et al.* (1985), Reeves *et al.* (1997), Johansen *et al.* (1985), Johnston *et al.* (1980)
Pea	Kamelot (F)	Kreuzman (2001)
Bean	CO-59196 and CO-33142 (F)	Rodolfo-Velasquez and Schwartz (2000)
Cucumber	Jinyou No.5(F)	Li *et al.* (2000)
Muskmelon	Longtianxueguan (F)	Wang (2000)
Watermelon	Qingfa 8 (F), Summit(F)	Zhang *et al.* (1999), Schenck (1961)
Tomato	Taichung Asveg 4(F),BT-10(B), LE 79-5(B), BWR-5(B), Sunrise, Cascade, Mountain spring, Sunbeam, (V,F)	Lin and Hong (1989), Kalloo *et al.* (2002), Lori Bushway (2008).
Brinjal	SM 6-7(B), PPC(B), BWR-12(B), BB-77, BB-44(B), ARU-2C(B)	Kalloo *et al.* (2002)

V = *Verticillium* resistance, F = *Fusarium* resistance and B = Bacterial resistance

Chaudhary and Sharma (1999) recommended the incorporation of resistance to bacterial wilt, into susceptible brinjal cultivars through back cross pedigree method. Sharma *et al.* (2005) reported some Fl crosses of brinjal were resistant to wilt caused by *R. solanacearum*. Gopalakrishnan (2000) showed that the F1 hybrids of brinjal showed high yield potential with resistance to bacterial wilt. Thakur *et al.* (2004) confirmed that the resistance to bacterial wilt in tomato is governed by a single recessive gene.

Biological control: Biological control of pathogen involves the management through non-chemicals mainly using microorganisms and antagonists. Biological control helps the establishment of some microorganisms which are beneficial to plant environment and harmful for pathogen by their antagonistic activity. Numerous microorganisms such as non-pathogenic strain of *F. oxysporum* MT 0062., *Bradyrhizobium japonicum*, *Pseudomonas* like *P. putida* 89B-27, *P. fluorescens* CHA-0 and *P. fluresence*-WCS, *Serratia marcescens* 90-166, *Talaremyces flavus* and *Streptomyces* spp. were isolated and used to control *Fusarium* and *Verticillium* wilt of vegetables (Liu *et al.*, 1995; Fravel *et al.*, 1995; El-Abyad *et al.*, 1993; Yamaguchi *et al.*, 1992). In watermelon field, infection by *F. oxysporum* was reduced by 44.4% using *Trichoderma* spp. (Dula *et al.*, 1987). The nonpathogenic *F. oxysporum* MT0062 was effective as a biological control agent against wilt diseases in solanaceous crops (Yamaguchi *et al.*, 1992). Specific non-pathogenic strains of *Fusarium* spp., isolated from wilt-suppressive soils, were the most effective antagonists for the reduction (50-80%) of *Fusarium* wilt diseases of tomatoes, watermelons and muskmelons. The microorganisms, including isolates of *Gliocladium virens*, *T. hamatum*, *P. fluorescens* and *Bacillus cepacia*, were also significantly reduced *Fusarium* wilt (30 to 65% reduction) disease (Larkin & Fravel, 1998). *T. flavus* has shown greater biocontrol potentiality against *Verticillium* wilt diseases through production of the extra cellular enzyme glucose oxidase and the subsequent release of hydrogen peroxide (Larkin *et al.*, 1998). The antagonistic *P. fluorescens* strain DSMZ 12501 and the chitinolytic *S. plymuthica* strain DSMZ 12502 were also reported against *V. dahliae* (Kurze *et al.*, 2001). *B. subtilis* was found effective against *Fusarium* wilt of tomato and other vegetables (Sarhan *et al.*, 2001). Several antagonistic bacteria like *Lysobactor enzymogenes* (OH 11), *P. fluorescens* (BOH 3), and *Bacillus* spp., were reported to control both fungal and bacterial wilt pathogens (Jiang *et al.*, 2005). Similarly, *Penicillium oxalicum* also reported to have reduced 22%-64% of wilt disease in tomato (Sabuquillo *et al.*, 2006).

Six bacterial strains *viz. Corynebacterium sp.* BT6, *Bacillus* spp. FH17 and BB11, *Escherichia* sp. BT4, *Serratia* sp. J2 and *Pseudomonas* sp. J3. were found most effective against bacterial wilt disease (Guo *et al.*, 2001). Jagadeesh *et al.* (2001) evaluated the role of a fluorescent siderophore using Tn5 mutants of

fluorescent *Pseudomonas* sp. in biological control of bacterial wilt in tomato. Das and Bora (2000) examined the role of biological control agents, *P. fluorescens, B. subtilis, T. harzianum, T. viride, T. koningii, Aspergillus terreus* and *Gliocladium virens,* their inhibitory action and their efficacy in suppression of *R. solanacearum*. Kumar and Sood (2002) reported bacterial wilt management by use of *P. fluorescens* in combination of *G. mosseae*. Ramesh and Korikanthimath (2004) reported the use of *P. fluorescens* as a potential biocontrol agent for the management of *R. solanacearum* in aubergine. Kumar and Sood (2005) observed no bacterial wilt incidence in tomato when biological control agents (*P. fluorescens* and *B. cereus*) were combined with 10 weeks soil solarization. Biswas and Singh (2007) proved that soil disinfection with lime one month before transplanting and the use of *Pseudomonas fluorescens* as biological control agent were effective to minimize the bacterial wilt incidence in brinjal field. Bora and Bora (2008) reported that *P. fluorescens* and *T. viride* significantly reduced the bacterial wilt disease incidence in brinjal and also increased the recovery of antagonists from rhizosphere. Ramesh *et al.* (2009) reported that *Pseudomonas* is the major antagonistic endophytic bacterium from eggplant which has potential to be used as a biocontrol agent against *R. solanacearum* in eggplant.

Plant extracts: Aggarwal *et al.* (2005) suggested wilt management in tomato by using plant refuge or root extract of *Tagetes erecta*. Khan *et al.* (2007a) reported that methanol extract of palmarosa (1.0 %), *M. arvensis,* and *M. longifolia* were effective against *R. solanacearum*. Khan *et al.* (2007b) screened botanicals (1.0%) for their antibacterial activity against *R. solanacearum* and observed that Harar *(Terminalia bellirica)* and Euphorbia *(Euphorbia pulcherrima)* were the most effective to inhibit the growth of the pathogen.

Chemical control: Chemical control offers direct protection by forming barrier between host and pathogen artificially. Chemical can be used by several means like spraying, dusting, seed treatment and soil treatment. *In vitro* experiment with many fungicides against *F. oxysporum* Klotz indicated that prochloraz and carbendazim were found the most effective fungicides (Song *et al.*, 2004). In a field study, the seed treatments with captan (Orthocide) at 75 g a.i./kg and RP5 (0.267% triticonazole + 0.33% iprodione), in potato (cv. Kennebec) tubers showed greater efficacy in controlling the diseases caused by *Fusarium spp.*, *Rhizoctonia solani*, *Streptomyces scabies* and *Verticillium spp*. (Platt & MacLean, 1997). Among the 8 fungicides bavistin [carbendazim], opus [cis-1-[3-(2-chlorophenyl)-2-(4-fluorophenyl)oxiranyl]methyl]1-H-1,2,4-triazole, tilt [propiconazole], antracol [propineb], atemi [cyproconazole], contaf, vitavax [carboxin] and indofil M-45 (mancozeb) + thiophanate-methyl evaluated, antracol was most effective against the beans wilt pathogens (Mukherjee & Tripathi, 2000). Several antibiotics were tested against *R. solanacearum* in which streptomycin and streptopenicillin recorded less bacterial infection (Singh *et al.*, 2000). Mondal *et al.* (2005) reported the efficacy of different antibiotics *viz.*, streptomycin, chloramphenicol, oxytetracy-cline hydrochloride, norfloxacin, amoxicillin + cloxacillin, chloro-quine phosphate and dichlorophen on tomato seedlings by root dipping before planting against bacterial wilt disease and found that the incidence of bacterial wilt was reduced to a great extent. Rai *et al.* (2008) reported minimum wilt incidence and highest yield of bell pepper when seeds were treated with streptomycin.

Conclusion

Wilt diseases are very severe form of soil borne diseases, caused by of both fungi and bacteria. Identification of causative organisms based on the diseases symptoms is very difficult unless the organisms are cultured on the specific media, but it is not possible to identify at pathotypes. By the advent of biotechnology and several molecular approaches, serological and nucleic acid based diagnosis and detection techniques have been developed and used to detect the pathogens at species, pathotypes and race levels. Further, management of vascular wilt diseases with different practices was discussed and it is very important to integrate these practices for successful disease management and to increase the vegetable production.

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