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The origin and current situation of *Fusarium oxysporum f.sp. lycopersici* in Pakistan

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Abstract

Tomato is famous and vital vegetable in the world and it is very beneficial to human health. Fungal pathogen reduce the production of tomato. In Pakistan, the main reason of reduction in production of tomato crop is due to diseases. *Fusarium oxysporum f.sp. lycopersici* is fungal pathogen that cause vascular wilt disease in tomato. And this pathogen is from family Ascomycota and hypocreales order. 10 to 50% and 10 to 90% tomato crop losses in the world and in Pakistan warm regions respectively. Pathogen is saprophytic in nature and is soil borne and can survive in soil for many years. Young leaves show symptoms and growth is stunted and death occur. Sindh and Northern areas of Pakistan show disease with variation in disease incidence. Acidic soil and 25 to 28°C temperature favor infection. FOL enter in root epidermis and spread in tissues of vascular system. Furthermore, clogging in vessel show wilting symptoms. Chlamydospore is dormant and is present in soil even host is not present. Contaminated soil and farm equipment's, infected transplant and irrigation water are main source of spread of this pathogen. In Pakistan that disease is managed by integrated practices such as use of resistant varieties, bio-control agents and systemic induced or acquired resistance. Use of resistant varieties and crop rotation is best way to manage this disease. Soil pH should be raised to control this disease and use of certified seed can also control this disease. Fol can control by SAR (Systemic Acquired Resistance), induced resistance, Plant resistance protein, foliar spray and Seed treatment. Fumonisin produced by pathogenic strains that infect tomato crops have mycotoxins ability.

Key words: *Fusarium oxysporum*, origin, tomato

Introduction

Tomato (*Solanum lycopersicum*) is the world's vital vegetable, belong to family Solanaceae and considered famous vegetable (Pritesh & Subramanian, 2011). It has been proved that according to the world's total annual production Tomato is ranked sixth by the Food and Agriculture Organization among famous vegetables. Annually, All over the world, 159 million tons fresh tomatoes are produced. Tomato is very common and edible in Pakistan and have economic values. In Pakistan, due to increase in population, the use and demand of tomatoes are increasing day by day. In comparison to other vegetables which have high nutritional values it is available at a lower rates. It is used in many home-cooked, many recipes, meals served in restaurant and also consumed as ketchup as well as sauces. However due to its seasonal production in the world at different locations it is available all the year (Chohan & Ahmad, 2008).

For human health, tomato is very beneficial because the risk of cancer and cardiovascular diseases associated with 2 type diabetes are reduce due to the presence of a powerful and natural antioxidant that is lycopene (Shidfar et al., 2011). Furthermore, countries with warm climate cultivate tomato more than other because it is short-duration and production cost is also low and that thing attract the tomato growers to cultivate tomato and get high yield throughout the year (Naika, de Jeude, de Goffau, & Hilmi, 2005). In Pakistan, the climatic conditions are diversified throughout the year and that favor the good quality tomato production. Area where cultivation done is about 58.2 thousand hectares and production on that area is 574.0 thousand tons. 86.3 thousand tons production is only by Punjab from area of 6.6 thousand ha and yield from each hectare is 13.1 thousand tons (Ringler & Anwar, 2013). Disease can reduce production from minor to 100% and this is major cause in reduction of crop production, it restrict the growth of crop. The pathogen like fungi, bacteria, nematodes and viruses are the causal agent which cause disease on tomato plant (G. Agrios, 2005b).

In 2009-2010, the tomato production area in Pakistan is increased and yield is also increased and tomato exported by Pakistan is 9832 tons, priced at 77 million rupees. But right now in Pakistan the production is low than other countries which are producing tomatoes and the main reason of reduction in production is diseases. The production in Baluchistan, Khyber Pakhtunkhwa, and Sindh is 18, 15.6 and 10.7 thousand hectares, respectively. The dominant sources of monetary grown cultivars which are introduced, are America and Europe (Noonari et al., 2015).

The production of tomato is mainly reduced by fungal pathogens (Stone, Bacon, & White, 2000). Fusarium have many species and all species of Fusarium cause many diseases in tomato which cause extensive crop losses worldwide (Wang et al., 2011). Roots and crown of plants are infected by Fusarium and that pathogen live in the soil. Wilt of tomato is a disease and is caused by different species of Fusarium like *Fusarium verticillioides*, *F.oxysporum* and *F.equiseti* (Rozlianah & Sariah, 2010) . All of these infect tomatoes at any growth stage and infect through roots and crown of tomato plant. Vascular bundles of plants are infected by *Fusarium oxysporum* and due to stress, the plant infected with *Fusarium oxysporum* show an early wilting syndrome (Adisa et al., 2018; Gupta, Bochow, Dolej, & Fischer, 2000). The wilt pathogen that is Fusarium wilt, can live in infested soil for a period up to ten years and in acidic sandy soil it is very common. The development of wilt can be reduce with very hot (34ºC) or cool (17-20ºC) temperatures soil (Pietro, Madrid, Caracuel, Delgado-Jarana, & Roncero, 2003). Cultural technique, resistant cultivars, chemical control, biological control and crop rotation can manage the disease and all of these are management strategies of diseases (Abo-Elyousr & Mohamed, 2009). We can control Fusarium wilt by using resistant cultivars and this is the most efficient measure to control that disease (Amini, 2009; Beckman, 1987), but due to mutation, the pathogen's new races defeated resistance genes in currently grown cultivars (Tello-Marquina & Lacasa, 1988). The present review helps to understand the origin and alert the current situation of *Fusarium oxysporum f.*sp. *lycopersici* in Pakistan which cause wilt disease on tomato plant.

Historical perspective of Fusarium wilt of tomato

It has been reported that in the history of plant diseases, Fusarium wilt is most catastrophic disease of plant (Halila & Strange, 1996). It has been proved that the most catastrophic fungal pathogens belong to family Ascomycota and hypocreales order and to tomato crop it is serious intimidation (Mandal, Mallick, & Mitra, 2009). Worldwide, Tomato crop losses are 10 to 50% and in Pakistan, 10 to 90% tomato crop losses annually in the warm region, the causal organism of tomato wilt belong to Ascomycota family (Lagopodi et al., 2002). Root vascular system of plant is destroyed, hence affected plant system of transport is blocked which result in growth reduction and in severe cases death occur (Haware, Nene, & Rajeshwari, 1978; Malhotra & Vashistha, 1993).

For long period of time, *F. oxysporum* survive under most of the edaphic conditions and all members are saprophytic in nature. Disease like root rot and vascular are induced by some isolates on peculiar hosts (Olivain & Alabouvette, 1997, 1999; Olivain et al., 2003) and classification based on species of plants and infected cultivars and approximately 120 f.sp. and races are classified (Alabouvette et al., 2001; Gordon & Okamoto, 1992). Plant roots are penetrated by causal organisms and in this way infection is occur. In the field of tomato the losses of crop is due to causal organism *Fusarium oxysporum f.sp. lycopersici* (Fol) because it cause disease in tomato that is wilt (Benhamou, Kloepper, & Tuzun, 1998).

In 1895 it was reported firstly in England by a mycologist G.E Massee. Countries which have warm environmental conditions have this fungus and currently in 32 countries (Mui-Yun, 2003).

After the attack of F. oxysporum, plant show yellowing, leaves dropping, wilting and in the vessels of xylem show brown-black discoloration (Dubey & Singh, 2004).

It has been observed that young leaves show symptoms with one or more branches are affected and the other remaining branches being healthy. Few weeks later, with the help of knife slicing the stem and open lengthwise and we easily observe the browning of vascular system and this brownish discoloration appear from roots to the top of plant. Hence the growth of plant is stunted and death of plant may occur under warm environmental conditions. It has been reported that due to the attack of Fusarium wilt disease of tomato, the reduction in yield is from 10 to 90% (A. K. Singh & Kamal, 2012).

District Mirpurkhas, district Tando Allahyar and district Hyderabad are the locations where tomato is growing in sufficient amount and for the estimation of disease incidence of fusarium wilt disease these places was surveyed. The observed disease incidence was between 8.3 to 47.0% in all places which was surveyed. In Hyderabad district the observed disease incidence % that was maximum at Bodani was 47.0 followed by neonshehar that was 43.0, Further more at Jeay Shah was 38.667 and at Bhitae was 36.3 so variation in incidence is occur. However in Tnado Allahyar district the recorded maximum incidence was 25.3 at DhiganoBazdar, at Darya Khan Nahiyon was 12%, at Ilyas Khanzad was 10% and at Javed Khanzad was 8.3%. At Kachhelo farm in Mirpurkhas district the recoded disease incidence was 22%. All the results show that in district Hyderabad the disease is more frequent in comparison to district Tando Allahyar and district Mirpurkhas (Jiskani, Pathan, Wagan, Imran, & Abro, 2007).

District Swat and district Mansehra in Northern region have high disease incidence and severity of the disease and in Southern region, District Peshawar and district Bannu have also higher incidence and severity of the disease and in district Malakand, district Charsadda and district Swabi in central region have low disease incidence and severity (Akbar, Hussain, Ullah, Fahim, & Ali, 2018).

Now it is clear that the disease incidence in the central region is lower as compare to disease incidence in the province of northern and southern regions. During growth season of tomato in northern areas, the sandy clay loam soil has pH 5 to 6 that is acidic and 25-28°C range of temperature which suit the infection and survival of pathogen Fusraium (Sherwood, 1920; Srivastava et al., 2012).

Incidence of disease in the central region of the province was low as well as low severity in disease because nitrate fertilizer is used by growers in these areas and with this application of applying nitrate fertilizer, pH of soil become raised that limit the growth of pathogen Fusarium (Woltz & Jones, 1984).

Fusarium wilt of Tomato by FOL

FOL *(Fusarium oxysporum f.sp. lycopersici)* is causing wilt disease on tomato crop and it's a chief disease of tomato (Borisade, Uwaidem, & Salami, 2017). The entry site of FOL is root epidermis and after entering it spread in tissues of vascular system, and plant xylem vessel are inhibit due to this entry and spread of pathogen in tissues of vascular system. Hence showing clogging in vessel and stress of water occur then showing symptoms of wilt (V. K. Singh, Singh, & Upadhyay, 2017).

Crop yield reduce or stop and have yellow color leaves which show wilted disease on crop and this is morphological identification of that disease. In infested soil, the chlamydospore of FOL which are dormant can survive even in the absence of host (Cha et al., 2016; Khan, Maymon, & Hirsch, 2017).

In the process of infection, following steps are involved: 1- With the help of host-pathogen signals, root is cognizance, 2- Hairs of root and hyphal propagation are the surfaces where pathogen attach 3- Encroachment of root cortex, and vascular tissue and distinction within xylem vessels, 4- Finally toxins and virulence factors are oozed. Disease is developed and vessels are colonized and host plant is wilted (Di, Takken, & Tintor, 2016).

Three types of spores are produced by FOL during its life cycle with different potential of infection and these spores are microconidia, macroconidia and chlamydospores (De Cal, Pascual, & Melgarejo, 1997). For long period of time, FOL can survive in soil and in plant debris in the form of mycelium and chlamydospores and naturally FOL is saprophyte and soil borne pathogen (Partridge, 1997).

Symptoms

Attack symptoms include minor vein clearing on the outer portion of young leaves, followed by epinasty on older leaves (Sally, Randal, & Richard, 2006). This condition usually only affects one side of the plant or one branch. Before the plant reaches maturity, successive leaves become yellow, wilt, and die. Growth is usually slowed as the disease proceeds, and little or no fruit develops. Dark brown streaks can be seen going longitudinally across the main stem if it is cut. The browning of the vascular system is a symptom of the disease and can be used to identify it in most cases (Mui-Yun, 2003). White, pink, or orange fungal growth can be noticed on the outside of diseased stems, especially under moist situations (Ajilogba & Babalola, 2013).

Epidemiology

FOL is a fungi and a soil saprophyte. Warm temperature that is 28°C favor Fusarium wilt of tomato (Bawa, 2016; Debbi, Boureghda, Monte, & Hermosa, 2018). Yield loss of wilted plants approximately 60 to 70% and have yellowed leaves (R. Singh et al., 2015). Irrigation water and farm equipment's that are contaminated with FOL are the main source of spread of this pathogen on short distance and at long distance this pathogen that cause wilt disease on tomato plant can spread through contaminated soil, infected transplant etc., (G. Agrios, 2005a).When FOL infect a region then that region contaminated with FOL and this fungus remains there forever (Animashaun, Popoola, Enikuomehin, Aiyelaagbe, & Imonmion, 2017; Prihatna, Barbetti, & Barker, 2018).

Management

The pathogen of fusarium wilt of tomato can survive in the soil in the form of chlamydospore and in infected plant debris in the form of mycelium for a long period of time so that's why the control of this pathogen infection in the field is not easy(Haware, Nene, & Natarajan, 1996).

For the management of that disease in Pakistan, integrated practices are used by farmers like resistant varieties are cultivated, use of bio-control agents and systemic induced resistance or systemic acquired resistance (Fatima & Anjum, 2017; Hussain, Abid, Farzana, Akbar, & Shaukat, 2013; Shafique, Asif, & Shafique, 2015; Sultana & Ghaffar, 2013).

Pathogen of fusarium wilt of tomato is both soil and seed-borne so their control by chemicals not effective. Application of botanical pesticides and employing of antagonistic microbes are management measures against this pathogen (Djatnika & Hermanto, 2003; Pietro et al., 2003). Antagonistic microbes have ability to control FOL is indicated by some studies but in the field their influence has not been proven yet (Bastasa & Baliad, 2005).

It has been considered that in tomato germplasm the genetic resistance against fusarium wilt of tomato is effectual mean of controlling that disease (Medina-Filho & Tanksley, 1983).

To control this fungus in the field we have to apply different strategies of management like rotation of crop, control by cultural practices, chemical control, use of resistance varieties and control by biological method and in this way we can manage disease cause by this fungus (Abo-Elyousr & Mohamed, 2009). As we know very well that the pathogen of Fusarium wilt of tomato is saprophytic in nature and the ordinary practices potency is limited. To handle this pathogen we have to cultivate resistant varieties because this is a good source but the serious question is that it's long term performance and their wide-scale availability (Tello-Marquina & Lacasa, 1988). It has been reported that to control this pathogen in developing countries the applications of chemical are used (Rojo, Reynoso, Ferez, Chulze, & Torres, 2007). However, the unwise use of fungicides cause many problems like pollution in environment and pesticides remain on the food or in the food as well as chemical antifungal property failure (Waard et al., 1993).

The farmers of district swat doesn't practice crop rotation and grow only few varieties of tomato so that's why break down in resistance is occur. Same in the southern regions the farmers get seed from local sources that is not certified and infected with pathogen which cause disease in crop when grown and lack of crop rotation practices as well as growing a few tomato varieties. However, the soil of this region is not only in dried condition but also have low content of moisture and it has been reported, that type of soil favor the attack of fusarium to plant (Foster, 1946). The farmer doesn't know the value and benefit of seed that is free from disease and crop rotation and this is due to extension education lack. When infected seeds are grown by farmer, seedling become infected after emergence because this pathogen is both seed and soil borne. To reduce inoculum in soil and increase suppressive conditions of disease, the best practice is crop rotation (Jones & Overman, 1971; LeBlanc, Kinkel, & Kistler, 2017).

The growers in Malakand, Charsadda and Swabi practices crop rotation and it is reported that in these areas tomato crop is rotating with leguminous crops like peas and beans and by this practice Fusarium wilt is restricted. Furthermore, Nitrogen fixing bacteria like Rhizobia is allowed by crop rotation with leguminous crops to fix nitrogen of atmosphere to nitrates and nitrites and by this the pH of soil is enhance which stop Fusarium specie growth and incidence of Fusarium wilt of tomato become low (G. N. Agrios, 2005; Jones & Overman, 1971).

Biological control

The Greek Streptomyces microflora was screened for strains capable of controlling the phytopathogenic fungus *Fusarium oxysporum*. *Streptomyces rochei* ACTA1551, the best antifungal producer, was found to be capable of protecting tomato plants from Fusarium wilting in lab conditions while also promoting plant development. The same streptomycete strain was found to be a promising generator of antibiotic metabolites with a wide range of action. *Streptomyces rochei* ACTA1551 is an advanced potential biocontrol agent that has been shown to be effective against the pathogenic fungus *Fusarium oxysporum* (Kanini, Katsifas, Savvides, & Karagouni, 2013).

In an attempt to reduce tomato wilt induced by *Fusarium oxysporum f. sp. lycopersici*, fungi known to produce lytic enzymes were utilised. In vitro, certain fungal species (*Penicillium oxalicum, Aspergillus nidulans* and *Penicillium purpurogenum*) destroyed FOL hyphae and reduced microconidia populations in the soil. Fungi treatments had no effect on the number of FOL chlamydospores in the soil or the number of FOL populations in the tomato rhizosphere. The most effective biocontrol agent was *P. oxalicum,* which reduced disease severity in both non-autoclaved (20 percent reduction) and sterile soil. *P. oxalicum* reduced disease severity in sterile soil to varying degrees (27 percent decrease at high levels and 50 percent decrease at low levels). Disease control by *A. nidulans* and *P. purpurogenum* was only possible in sterile soil when disease severity was minimal (55 percent and 45 percent, respectively) (De Cal, Pascual, Larena, & Melgarejo, 1995).

The ability of *B. brevis* to limit the development of *F. oxysporum f.sp. lycopersici* (Fol) in pot-grown tomato plants in the glasshouse was strongly correlated with antagonism reported in microcosms. Many crops have been found to benefit from the introduction of rhizobacteria, such as *Paenibacillus spp., Bacillus spp., Burkholderia spp.*, and *Pseudomonas spp.*, as to stop fusarium wilt disease (Hervas, Landa, Datnoff, & Jimenez-Diaz, 1998; Leeman et al., 1995; Lemanceau & Alabouvette, 1993). *B. brevis* is a probable biological control agent for *F. oxysporum f.sp. lycopersici* on tomato plants (Chandel, Allan, & Woodward, 2010).

Systemic Acquired Resistance

Resistance to *Fusarium oxysporum f. sp. Lycopersici* (Fol) in tomato could be induced by exogenous treatment of 200mM salicylic acid (SA) via root feeding and foliar spray. HPLC was used to detect endogenous increase of free SA in tomato roots, and LC–MS/MS analysis was used to validate identification. The endogenous SA level in the roots increased to 1477 $ngg^{-1}FW$ after 168 hours of SA administration through roots, which was 10 times greater than control plants. Similarly, after 168 hours of foliar spray treatment, the salicylic acid level was 1001 $ngg^{-1}FW$, which was 8.7 times greater than control plants. At 168 hours of SA feeding through the roots, the activity of peroxidase POD (EC 1.11.1.7) was 4.7 times and phenylalanine ammonia lyase PAL (EC4.3.1.5) was 5.9 times greater, than in control plants. At 168 hours after foliar spraying with SA, the rise in PAL and POD activities was 3.7 and 3.3 times higher, respectively, than in control plants. Fol treatment dramatically reduced vascular browning and leaf yellowing wilting in tomato plants treated with salicylic acid. Salicylic acid had no discernible effect on Fol mycelial growth. The ability of the tomato root system to absorb and distribute salicylic acid throughout the plant was demonstrated by a significant increase in the basal level of salicylic acid in non-inoculated plants. It's possible that the tomato produced resistance to Fol is an instance of salicylic acid-dependent SAR (Systemic Acquired Resistance) (Mandal et al., 2009).

Induced Resistance

Bacillus thuringiensis strain 199 confers systemic resistance to Fusarium wilt in tomato. A bacterial strain was used to stimulate the roots of two-week-old tomato seedlings. Following the experimental design, some pots of tomato seedlings were inoculated with *Fusarium oxysporum lycopersici* inoculum after 10 days of transplantation to cause disease. Plants challenged with *F. oxysporum f.sp lycopersici* alone showed obvious indications of Fusarium wilt after 15 days of incubation. Disease severity was significantly reduced in plants treated with *B. thuringiensis* 199 *F. oxysporum f.sp lycopersici.* When bacterially treated plants were compared to non-treated plants, the amount of total phenolic increased 1.7-fold. Likewise, in case of defense-related enzymes, a significant increase of 1.3-, 1.8-, and 1.4-fold in polyphenol oxidase (PPO), phenyl ammonia lyase (PAL), and peroxidase (PO) was observed in comparison with untreated control. As a result of these findings, this bacterial strain has the potential to be used as a plant protection agent. *F. oxysporum* is a fungus that lives in the soil. It's possible that this will spread through irrigation water. Internally, this fungus infects a plant's vascular system. Rather than modifying the entire soil mycoflora, it is preferable to protect the fungus's entry point in the plant. Some microorganisms can be employed to develop resistance in plants in order to counteract this destructive infection. The host plant can also give the food that these microbes require to survive. The efficacy of bacterial strains for this purpose has been documented by a number of researchers. All of these investigations suggest that these bacteria have a favourable impact on the amounts of defense-related biochemicals in their hosts. According to the findings, *B. thuringiensis* strain 199 can protect plants from Fusarium wilt. The only thing left to do is create an inoculum for commercial use in the field (Akram, Mahboob, & Javed, 2013).

In several sets of tests, chitosan, chitosan hydrolysates, and menadione sodium bisulphite (MSB) were added to soil and sprayed on tomato plants to assess their combined impact on disease development in tomato plants. The three products were effective in protecting young plants against the disease, with foliage sprays showing the best results with chitosan hydrolysates and MSB (0.25 + 0.05 $g.L^{-1}$, respectively), implying that systemic resistance induction plays a major role in tomato defence against *Fusarium oxysporum f.sp lycopersici* (FOL) attack. In plants inoculated with FOL and treated with elicitors as disease resistance indicators, several enzymatic pathways related to host defense were evaluated. The induced resistance of tomato plants was found to be associated with increase in peroxidase and β 1,3 glucanase activities (Paz-Lago et al., 2000).

Plant Resistance Protein

Plant resistance proteins recognize pathogen effectors and offer race-specific protection. To impart resistance against *Fusarium oxysporum f. sp. lycopersici* (Fol) races 1, 2 and 3, the resistance genes I, I-2, and I-3 have been transferred into cultivated tomato (*Solanum lycopersicum)* from wild tomato species. Only the I-2 resistance gene has been extracted from tomato, despite the fact that the Fol effectors corresponding to these resistance genes have all been identified. The discovery that I-3 encodes an S-receptor-like kinase (SRLK) genes discloses a new mechanism for Fol resistance as well as a new family of resistance genes, which includes Pi-d2 from rice. The discovery of I-3 also opens up the possibility of studying the complicated effector–resistance protein relationship in tomato that involves Avr1-mediated repression of I-2 and I-3-dependent resistance (Catanzariti, Lim, & Jones, 2015).

Foliar Spray

After seedlings were transplanted into contaminated field soil, a foliar spray of VMA (validamycin A) or VAA (validoxylamine A) on tomato seedlings in a nursery may be useful in controlling Fusarium wilt. A few extra sprays in the field may be required for disease control throughout the tomato production cycle, or VMA could be used in conjunction with other disease control strategies in an integrated pest management programme. VMA and VAA foliar sprays unique, easy, and ecologically friendly way to control soil-borne diseases. It may be possible to reduce the use of more toxic pesticides by using VMA and VAA (Ishikawa et al., 2005).

Seed Treatment

The efficacy of methyl jasmonate (MeJA) to protect tomato seedlings from fusarium wilt caused by the soil-borne fungal pathogen *Fusarium oxysporum f.sp. lycopersici* (Fol) was investigated via seed treatment. Isolated from seeds of *Solanum lycopersicon* L. cv. Phytopathological and molecular approaches were used to identify the beta fungus as Fol Race 3 fungus. In vitro, MeJA at concentrations of 0.01, 0.1, and 1 mM inhibited spore germination and mycelial growth. Soaking tomato seeds in 0.1 mM MeJA solution for 1 hour increased the level of resistance to the tested fungus in tomato seedlings 4 weeks after inoculation. In vitro spore germination of the investigated fungus was inhibited by extracts from the leaves of 15-day-old seedlings derived from previously MeJA soaked seeds. The amounts of phenolic substances such salicylic acid (SA), kaempferol, and quercetin increased significantly in these seedlings. In response to exogenous MeJA application, up-regulation of the phenylalanine ammonia-lyase (PAL5) and benzoic acid/salicylic acid carboxyl methyltransferase (BSMT) genes and down-regulation of the isochorysmate synthase (ICS) gene indicate that the phenylalanine ammonia-lyase (PAL) pathway, not the isochorismate (IC) pathway, is the most common pathway for SA production. Furthermore, the rise in PAL5, chalcone synthase (CHS), and flavonol synthase/flavanone 3-hydroxylase-like (FLS) genes appears to be linked to the increased accumulation of the flavonols quercetin and kaempferol. Increased salicylic acid levels were accompanied by a decrease in jasmonic acid, the precursor of MeJA, and an increase in 12-oxo-phytodienoic acid (OPDA), the precursor of jasmonic acid, in seedlings produced from MeJA-soaked seeds. The current findings show that priming tomato seeds with 0.1 mM MeJA before sowing reduces the assault of the soil-borne fungal pathogen *F. oxysporum f.sp. lycopersici* on seedlings developed from these seeds, so it can be used in practice (Krol, Igielski, Pollmann, & Kepczynska, 2015).

Pathogenic and Non-Pathogenic FOL Morphological and Molecular Investigations

Pathogenic and nonpathogenic *F. oxysporum f. sp. lycopersici* strains obtained from tomato were characterised molecularly. Based on morphological and molecular investigations, the causative pathogen isolated from sick plants and soil samples was identified. Pathogenicity tests on five tomato cultivars revealed that 45 percent of the isolates were very virulent and 30 percent were moderately virulent. The presence of substantial genetic variation among the strains was revealed by a molecular analysis based on fingerprints generated using ISSR. The pathogen has at least four evolutionary branches, according to phylogenetic analyses based on ITS sequences. The polyphyletic origin of *F. oxysporum f. sp. lycopersici* was indicated by its clustering with nonpathogenic isolates and members of other formae speciales. Further investigation demonstrated intra-species variability as well as nucleotide insertions or deletions in the ITS region among the strains studied, with the observed alterations being clade specific. The pathogen population's considerable genetic diversity necessitates the creation of successful tomato resistance breeding programs. Toxigenic strains were found to have the Fum1 gene, indicating that the pathogenic strains infecting tomato crops have the ability to manufacture Fumonisin (Nirmaladevi et al., 2016).

Conclusion

It is concluded that Fusraium wilt of tomato is developed on warm temperature and on all tomato growing areas with different range and by delivering contaminated farm equipment's and irrigation water from one field to the other field, So there is need for sanitation practices. Pathogen can survive in acidic soil for many years so soil pH should be raised. Chemical use to control the disease cause pollution in environment and also effect on human health by eating that sfood. There is need to ban chemical control application. Extension education information deliver to illiterate farmer and there is need to tell him the benefit of crop rotation to control that disease. Government should make policies and regulations to sale the only certified seed to farmers so that this disease can be avoided.

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