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MANAGEMENT STRATEGIES OF FUSARIUM WILT DISEASE OF TOMATO INCITED BY *Fusarium oxysporum f. sp. lycopersici* (Sacc.): A REVIEW

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ABSTRACT

Tomato is a high-value dietary component, contributing to nutrition and livelihood of both rural and urban population the world over. Its production is, however, challenged by various constraints, among which are pests and diseases. Fusarium wilt, caused by *Fusarium oxysporum* f. sp. *lycopersici* (Sacc.) W.C. Snyder and H.N. Hans, is considered as one of the most important disease of tomato worldwide, which is characterized by wilted plants, yellowed leaves and minimal/reduced or even total loss/absent crop yield. This review highlights the various documented methods employed in the management of the disease, which is highly destructive in both greenhouse and field grown tomatoes. The most cost-effective and environmentally friendly strategy being the Integrated Disease Management (IDM) which are been advocated for in such a way that will not be harmful to the environment, useful microbes, plants, animals and human lives. However, efforts should be on examining and developing their efficacy, efficiency and durability on the fields and not just in the greenhouse.

KEYWORDS: Tomato, Fusarium wilt, Management, Environment, Symptom

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) belongs to the family Solanaceae and it is considered one of the world's most popular vegetables (Pritesh *et al*., 2011). It is the most important tropical vegetable crop widely used throughout the world (Hadian *et al*., 2011). It is a high-value horticultural crop for the local market and an important dietary component, contributing to improved nutrition and livelihood for both rural and urban population (Waiganjo *et al*., 2006). The fruits are used fresh in salads or cooked as a vegetable, in processed form as tomato paste (puree), tomato sauce, ketchup, juice and can also be dried. They are rich in vitamins A and C and are gaining importance because it contains lycopene, a food component known to reduce the incidence of prostate cancer, heart and age related diseases (AVRDC, 2003).

Tomato is fairly adaptable, but grows well in warm conditions with optimum temperatures of 15 ^{0}C -25 ^{0}C. High humidity and temperatures reduce fruit set and yields. Very low temperatures delay colour formation and ripening while temperatures above 30 ^{0}C inhibit fruit set, lycopene development and flavor. Tomato thrives best in low to medium rainfall with supplementary irrigation during the off season. Wet conditions increase disease attacks and affect fruit ripening. Tomatoes grow well in a wide range of soil types which are high in organic matter, well drained and a pH range of 5-7.5 (Waiganjo *et al*., 2006; Hanson *et al*., 2001). Tomato plants prefer soil that is well drained and heavily amended with organic matter. The soil should have good moisture retaining capacity. Elevation of between 1000 m to 2000 m above sea level is suitable for tomato growth (Robert, 2005).

Wikipedia (2010) documented a list of countries by tomato production based on FAOSTAT in 2008 which showed that China is the largest producer worldwide with a total production of 33,911,702 tonnes followed by United States with 13,718,171; India 10,965,355; Turkey 10,313,000 and Egypt 9,204,097. On the list, Nigeria is the 13th in the world and second largest producer in Africa after Egypt.

However, many constraints affect productivity and quality of tomato among which diseases play a salient role (Pritesh *et al*., 2011). The most common diseases of tomato include early blight, anthracnose, bacterial wilt, bacterial canker, tomato spotted wilt, *verticillium* wilt and *fusarium* wilt (Winand *et al*., 1999). The wilt diseases are caused by bacteria (*Pseudomonas* spp.) and fungi (*Verticillium* and *Fusarium* spp.) (Mardi *et al*., 2002). Tomato *Fusarium* wilt is considered as one of the most important diseases of tomato both in field and greenhouse-grown tomatoes worldwide (Abdel-Monaim, 2012; Amini *et al*., 2010; Sheu *et al*., 2006).

The disease caused by this fungus is characterized by wilted plants, yellowed leaves and minimal/reduced or even total loss/absent crop yield (Peralta *et al*., 2001). This review is an attempt to summarize the different aspect of *fusarium* wilt disease and the different management strategies developed to combat this devastating disease in tomato.

***Fusarium* Wilt Disease**

Fusarium oxysporum f. sp. *lycopersici* (Sacc.) W.C. Snyder and H.N. Hans, a soil borne plant pathogen in the class Hyphomycetes, causes *Fusarium* wilt specifically on tomato. There are more than 100 *Fusarium* vascular wilt diseases worldwide. Apart from causing diseases, they colonize outer cells of roots as harmless endophytes after the pathogen has killed the root tissues and others live as saprophytes in soil (Burgess *et al*., 2008). This disease was first described by G.E. Massee in England in 1895. The pathogen has three physiological races (1, 2, and 3, hereafter r1, r2 and r3) and are distinguished by their specific pathogenicity on tester plants carrying dominant race-specific resistance genes (Cai *et al*., 2003).

It is of worldwide importance where at least 32 countries had reported the disease, which is particularly severe in countries with warm climate (Mui-Yun, 2003). The *Fusarium* fungus is a known pathogen of tomato plant (Suarez *et al*., 2007) which is present in all important tomato growing regions of the world (Mohammed, 1990) and produces three types of asexual spores; microconidia, macroconidia and chlamydospores (Arios, 1988). Some strains of *Fusarium oxysporum* are not pathogenic and may even antagonize the growth of pathogenic strains and can be used as biological agents (Fravel *et al*., 2003).

Symptoms of *Fusarium* Wilt Disease on Tomato

Symptoms of attack first appear as slight vein clearing on the outer portion of the young leaves followed by epinasty of the older leaves (Sally *et al*., 2006). This symptom often occurs on one side of the plant or on one shoot. Successive leaves yellow wilt and die, often before the plant reaches maturity. As the disease progresses, growth is typically stunted, and little or no fruit develops. If the main stem is cut, dark brown streaks may be seen running lengthwise through the stem. The browning of the vascular system is characteristic of the disease and generally can be used for its identification (Mui-Yun, 2003). On the outside of affected stems, white, pink or orange fungal growth can be seen especially in wet conditions (Ajigbola and Babalola, 2013).

Ecology and Dissemination of the Pathogen

Fusarium oxysporum occurs, survives and grows in soils of all types, but sandy soils provide conditions that are most favourable for growth and development (Lowell, 2001). The pathogen is soil borne and remains in infested soil for up to ten years. Soil and air temperatures of 28 ^{0}C are optimum for disease. If soil temperatures are optimum but air temperatures below optimum, the pathogen will extend into the lower parts of the stem, but the plants will not exhibit external symptoms (Mui-Yun, 2003).

The pathogen is primarily spread over short distances by irrigation water and contaminated farm equipment (Stephen *et al*., 2003) but can also be spread over long distances either in infected transplant or soil (Agrios, 1988). The disease or infection can also be transmitted through infected plant material and through contaminated soil. Other means of spreading the disease is through human movement around the infected field, or the use of irrigation water and implements previously used on an infected crop (Ajilogba *et al*., 2013).

Disease Epidemiology

The pathogen enters the plant through root tips (Sally *et al*., 2006) and can remain viable in the soil for up to 30 years (Thangavelu *et al*., 2003). The mycelium grows in the xylem vessels where they cut off water supply resulting to wilting (Stephen *et al*., 2003). There is often an association of *Fusarium* wilt and nematode colonization where the nematodes provide entry route for the fungus. Enzymes may also facilitate *Fusarium* penetration into plant host (Babalola, 2010a). Infection and disease development in *Fusarium* wilt is favoured by warm soil temperature and low soil moisture (Lewis, 2003). The disease tends to be most severe in sandy soils and generally less of a problem in heavier clay soils (Larkin *et al*., 2002).

Control of Fusarium Wilt Disease

The control of *Fusarium* wilt of tomato is important in maintaining plant vigour and fruit quality and quantity. Though *Fusarium* wilt is a difficult disease to control according to Borrero *et al*. (2006), Elmer, (2006) and L'Haridon *et al*. (2011), numerous strategies have been proposed to control this fungal pathogen (Biondi *et al*., 2004; Ahmed, 2011). However, attempts to control the disease have experienced limited success due mainly to emergence of new pathogenic races (Juliano *et al*., 2005). Documented methods that are used in the control of the disease include cultural, biological, use of resistance, chemical (Pottorf, 2006) and use of natural products (Kimaru *et al*., 2004).

Biological Control

To provide an environmentally friendly *Fusarium* disease control system, the use of antagonistic microorganisms represents an alternative disease management strategy (Lugtenberg and Kamilova, 2009). The mechanisms adopted by biological control agents could be direct, indirect or mixed (Pal and Gardener, 2006). The use of bioagents was reported quite effective to control Fusarium wilt disease on tomato (Freeman *et al*., 2002). According to Momol *et al*. (2003), several isolates of non pathogenic *Fusarium* spp (*F. oxysporum* and *F. solani*) that effectively controlled *Fusarium* wilt in greenhouse test have been identified. The isolates include CS-20, CS-1, CS-24 and Fo 47 of which was consistently effective when applied at high rate. Attitala *et al*. (2001) showed that after spraying with zoospores of *Phytophthora cryptogea* followed by *Fusarium oxysporum* f. sp. *lycopersici* inoculation, tomato plants show no wilt disease.

Also, in another studies conducted by Akkopru and Demir (2005), arbuscular mycorrhizal fungi (AMF) *G. intraradices* and some Gram-negative and fluorescent rhizobacteria (RB), *P. fluorescens*, *P. putida* and *Enterobacter cloaceae*, isolated from the rhizoplane of solanaceous plants were effective against *Fusarium oxysporum* f. sp. *lycopersici*. Monda (2002) reported that bacterial biocontrol agents with promising biocontrol activities against *Fusarium oxysporum* f. sp. *lycopersici* include *Peudomonas flourescens, P. putida, P. chlororaphis, Bacillus subtilis, Streptomyces pulcher, S. corchorusii* and *S. mutabilis.* Rhizobacteria which may act directly as biofertilizer, and biostimulants through production of plant growth hormones such as indole acetic acid, gibberelin, cytokinin, ethylene, dissolved minerals, and also indirectly prevents the development of pathogenic microorganisms through siderofore, and antibiotic production (McMilan, 2007; Sarma *et al.*, 2009).

Widnyana *et al*. (2013) reported that three isolates of rhizobacteria isolated from the rhizosphere plants of the families Solanaceae and Leguminoseae namely KtS1, TrN2 and TmA1 and identified as *Pseudomonas alcaligenes* exhibited antagonistic activity against *Fusarium oxysporum* f. sp. *lycopersici* by effectively reducing the incidence of wilt disease on tomato under greenhouse experiment.

Use of Resistance

The most cost-effective and environmentally safe method of control is the use of resistant cultivars where they are available. The use of resistant varieties is the best strategy for the disease control (Sheu *et al*., 2006) and also one of the most effective alternative approaches to controlling wilt disease (Singh, 2005). But, due to breakdown of resistance in the face of high pathogenic variability in the pathogen population, the usefulness of many resistant cultivars is restricted to only a few years (Kutama *et al*., 2011; 2013).

According to Pritesh *et al*. (2011), identification and utilization of tomato plant varieties resistant to the disease represents a valid alternative to the use of chemicals. However, breeding for resistance can be very difficult when no dominant gene is known. In addition, new races of pathogens overcoming host resistance can develop (Allopru *et al*., 2005; Momol *et al*., 2003). The advantages of this method include saving the cost of chemical for control of the disease and enhancing cultivation of previously infested field.

Chemical Control

Agricultural chemicals are commonly used for management of pests and diseases. Seed treatment with synthetic fungicides considerably reduce wilt incidence in tomato. However, their use is costly as well as environmentally undesirable (Song and Goodman, 2001). Some of these chemicals include prochloraz, propiconazole, thiabendazole,carbendazim, benomyl, thiophante, fuberidazole and all of the benzimidazoles. In 2007, Nel *et al*. reported that benomyl was partly effective against *F. oxysporum* f.sp *cubense* using the root dip treatment method. This method was applied to using carbendazimal on tomato seedlings infected with *Fusarium* wilt and it led to about 24 % increase in yield (Khan and Khan, 2002).

The high frequency of chemical use, non-target effects, development of resistance to many chemicals, pathogens which remain viable for many years and risks to human health and the surrounding environment have stimulated development of alternative methods for disease management. Moreover, pesticides generally are more effective against aerial plant pathogens than their soil-borne counterparts (Recycled Organics Unit, 2006). It is also technically difficult to treat large amount of soil, and the range of approved chemicals is declining as active compounds are withdrawn for toxicological and environmental reasons, for example, methyl bromide has been phased out due to its extremely high ozone depleting potential.

The current trend to near zero-market tolerance for pesticide residues in fresh leafy vegetables provides an additional motivation to search for non-chemical means to control pests and diseases (Reuveni *et al*., 2002). *Fusarium* wilt is controlled by disinfecting the soil with methyl bromide, chloropicrin or metham sodium. Systemic fungicides such as benomyl, thiabendazole and thiophanate have been used to control *Fusarium* wilt.

However, sustainable use of fungicides in *Fusarium* wilt management is difficult due to development of resistant isolates and damaging effects on the natural environment, the agro ecosystem and human beings (Pritesh *et al*., 2011; Dewaard *et al*., 1993). The excessive misuse of a wide range of fungicides has resulted this to be harmful to the environment and increased the resistant pathogen populations (Ogzonen *et al*., 2001).

Use of Natural Products

Though many research efforts have been carried out to find alternative and environmentally safe methods to control plant diseases (Agbenin *et al*., 2004), the use of plant products for the control of *Fusarium* wilt in crops is limited (Agbenin and Marley, 2006). Tests done by Kimaru *et al*. 2004 revealed that neem cake powder contains ingredients that have fungistatic effects against *Fusarium* wilt of tomatoes. Similar findings were also reported by Coventry *et al.* 2001 as the neem extracts were found to possess antimicrobial activity with notable effects on some fungal pathogens. Hanaa *et al*. (2011) investigated the effect of *Azadirachta indica* (Neem) and *Salix babylonica* (Willow) 10 % aqueous extracts on *Fusarium* wilt disease in tomato and revealed that the percentage of disease incidence was reduced to the level of 25.5 % and 27.8 % after 6 weeks of infection respectively.

Also, Agbenin and Marley (2006) reported that crude extracts of neem (*Azadirachta indica*) and garlic (*Allium sativum*) at concentrations ranging from 5 % to 30 % of the material in 100 ml of potato Dextrose Agar inhibited mycelial growth of *Fusarium oxysporum* f. sp. *lycopersici* at various levels. Dry neem seed extract gave 100 % inhibition. Fresh neem leaf extract reduced mycelial growth with increasing concentration while in garlic, there is no difference in growth inhibition among the various concentrations used. Umar *et al.* (2013) studied the influence of different quantities (0.0, 25, 50, 75 and 100 g/ha) of farmyard manure (FYM) on the growth and disease incidence of *Fusarium* wilt on tomato and reported that there was consistently significant reduction in the incidences and severities of tomato wilt due to *Fusarium*, which suggest that it could be beneficial to farmers in the reduction of wilt caused by *Fusarium* for higher yield tomato production in northern Nigeria.

Cultural Control

Cultural control involves practices and farming techniques that will help to increase the quality and quantity of the yield and also reduce the influence of pests and diseases. It involves manipulation of the environment in non- mechanical ways to control plants pests and diseases. It includes altering farming practices to make the environment unfavourable for the growth of disease pathogens and pests (Islam, 2001).

It is also the purposeful manipulation of a garden or farm in the growing, planting and cultivation of plants to reduce plant disease, pest damage and numbers of pests. It has been shown that the correct implementation of cultural methods to control soilborne pathogens yields improved soil structure and consequently decreases incidence (Neshev, 2008).

These methods are mainly preventive and a good knowledge of the nature, behavior and environmental conditions of the growth of the disease agent is very important to controlling the disease development. However, management of seedborne and soilborne diseases such as wilt caused by *Fusarium* species has always been problematic (Rao and Balachadran, 2002). Crop rotation with non-solanaceous crops for four to six years is usually recommended to avoid pest problems common to this group of vegetables by reducing the populations of these fungi. The crop should be rotated with grasses and cereals whenever possible (Sally *et al*., 2006).

Mulching, which is the addition of a thick layer of mulch on the soil surface help control weed, optimize soil moisture and keep the soil cool. This helps create unfavourable conditions for soilborne pathogens thereby controlling diseases (Raid, 2011). Mulching also avoid splashing of soilborne diseases on tomato leaves during watering (Francis, 2012).

Intercropping of tomato and maize should be encouraged as the tomato gets shade from the maize and is produced out of season, thereby increasing the farmer’s yield and income. In Cuba this method increased annual yield by 5-6 tonnes/ha (Wolfswinkel, 2010).

Weed control by destroying susceptible diseased weeds helps to reduce the incidence of transfer of pathogens like *Fusarium* spp. to plants. Excessive handling of plants, which includes tying, thinning and pruning, result to wounds and increase their susceptibility to *Fusarium* wilt pathogen (Ajigbola and Babalola, 2013).

Soil Solarization

This is done by spreading a clear plastic sheet over the soil for several weeks. This helps to trap solar energy which in turn inhibits soilborne diseases, nematodes, insects and many weed seeds. This is usually done during the summer when the air temperature is high and there is intense radiation (Ploeg and Stapleton, 2001). Combination of soil solarization and two layers of mulching decrease the rate of fungal infection in plants (Garibaldi and Gullino, 1991).

Soil Disinfection Using Heating and Steam

This is usually done as a preplanting method. Hot water can be used according to Tetaya (2001) and can keep the soil sterilized for up to three years. Steam can also be used especially in greenhouse conditions (Gullino, 2001). Soil disinfection helps to keep the soil sterile and free from disease causing pathogens.

Integrated Disease Management

Integrated Disease Management (IDM) is recognized as an effective approach for increasing agricultural productivity and combating environmental degradation in developing countries (Waiganjo *et al.*, 2006). Practices that can help to build healthy soils include crop rotation, organic matter additions or using high-residue tillage implements. A significant amount of research has been conducted on the suppression of pests and diseases through the application of compost products worldwide. The results have shown that composts can provide natural biological control of soil borne diseases affecting collar and roots as well as plant foliage (Recycled Organics Unit, 2006).

The inclusion of green manures and cover crops in a rotation is an excellent way to sponsor fertility, suppress weeds and provide a break in pest cycles (Jeff, 2009). Incorporating several different species of crops in a rotation, along with manures and/or compost, ensures a diversity of organic matter sources. This diversity leads to a more minerally balanced soil and a pool of nutrients which become available slowly over time, reducing leaching, waste and toxicity that can result from immediately-available inorganic fertilizer additions (Jeff, 2009; Recycled Organics Unit, 2006).

Crop rotation with non-similar crops such as cabbage and cauliflower for at least 4-5 years, use of disease resistant cultivars, use of natural antagonistic organisms especially bacillus based biological control agents (BCAs), farm hygiene and the use of chemicals such as prochloraz and methyl bromide are some of the integrated control strategies for the control of fusarium wilt of tomato (Ajilogba *et al*., 2013). Ultimately, managing for good soil fertility is extremely important because the soil environment and the surrounding air environment are in reality virtually inseparable, and the establishment of a functional and stable system in one environment can have far-reaching impacts in the other (Dishon, 2012).

CONCLUSION

In conclusion, apart from looking at the fact that these methods are working in different ways, efforts should be on examining and developing their efficacy, efficiency and durability on the fields and not just in the greenhouse. The different formulations of microbial products that will give the most efficient result should also be considered very important in biological control. Area of interest should therefore be on educating farmers on the appropriate use of cultural practices and their integration into other strategies for a better and a safer result.

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