Journal of Pure and Applied Agriculture (2024) 9(2): 1-6
ISSN (Print) 2617-8672, ISSN (Online) 2617-8680
http://jpaa.aiou.edu.pk/

Tomato wilt disease (*Fusarium oxyporium* f. sp. *Lycopersici*): A threat to tomato production and humanity

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Abstract

Tomato is one of the most important vegetable crops globally. Its production is constrained by several biotic and abiotic factors. Fusarium wilt is one of the most destructive diseases in tomato plants caused by *Fusarium spp*. The disease reduces the plant fruit yield significantly, it can wipe off a whole field completely during the endemic season or when the environment is favourable for the pathogen. The infected plant shows a wilting sign at the initial stage and later dies off. Difficulty in managing the disease could be attributed to its survivability of the pathogen on different mediums for a long period and its existence in diverse pathogenic races coupled with poor understanding of its management by most tomato growers. The use of chemical fungicides are majorly relies on as an effective method in managing tomato wilt and the method is not eco-friendly. This review explained various methods that can be adopted in managing the disease without jeopardizing human health and the environment at large. The review provides diverse control methods to be integrated in managing Fusarium wilt. Understanding the biology and management of fusarium wilt in tomatoes will reduce the great loss it causes in tomato production. By integrating biological control methods, crop rotation, resistant tomato varieties, and cultural practices, farmers can significantly reduce the severity of the disease. Additionally, increasing awareness and knowledge about Fusarium wilt among tomato growers is essential for improving disease management strategies.

Keywords: Biological control, Biotic stress, Chemical control, Crop rotation, Tomato production, Tomato wilt disease

To cite this article: Falade, M. J., & Alabi, B. T. (2024). Tomato wilt disease (*Fusarium oxyporium* f. sp. *Lycopersici*): A threat to tomato production and humanity. *Journal of Pure and Applied Agriculture, 9*(2), 1-6.

Introduction

Tomato (*Solanum lycopersicum* L.) is a fruit vegetable crop that is widely cultivated globally (Shah et al., 2013; Jan et al., 2015). It could either be cultivated in the open field, protected environment, or in a container (Houssei et al., 2010). Mature tomato fruits are a major component of the human diet. The fruits can be processed into various types of products or consumed as fresh (Brookie et al., 2018; Shah et al., 2019). Ripe tomato fruit is rich in vitamins A and C which are essential in a human's daily diet (Kapsiya et al. 2015; Jan et al., 2018; Hussain et al., 2022). It is processed into different products locally and industrially and consumed in diverse ways. According to FAOSTAT (2018), tomato global production was estimated to be 182.256 million tonnes. It serves as a huge source of income for those who are involved in its production cycle ranging from agro-dealers, farmers, transporters, marketers, processors, etc. In Nigeria, the consumption rate is far beyond the production thereby resulting in the scarcity of the product to undue competition among the consumers and a price increase.

Tomato production is greatly affected by various biotic and abiotic factors (Shah et al., 2015; Shah et al., 2016; Shah et al., 2017). Of the various biotic factors affecting tomato production, diseases of various kinds are one. However Fusarium wilt caused by *Fusarium oxysporum* f. sp. *Lycopersici* (Sacc.) Snyder and Hansen are recognized as the most dangerous and destructive diseases affecting tomato production globally (Abdelaziz et al., 2022; Mostafa et al., 2022). The disease is more severe in tropical regions, especially in acidic sandy soil (Srinivas et al., 2019). The severity of any disease is a factor in the susceptibility of the variety grown, the prevailing environmental conditions of the area, the extent of infection, the inoculation load, and the timing and management approach in combating the disease (Agbowuro et al., 2020a). The long-term survival of the chlamydospore of the pathogen causing fusarium wilt in the plant debris, soil, farm equipment, and other surfaces makes the disease one of the most destructive diseases of tomatoes (Chang et al., 2018). The pathogen can cause substantial loss in tomato farms ranging from 25 to 55% (Nirmaladevi et al., 2016). The fungus can completely wipe off the whole farm under optimal infection conditions such as high moisture and humidity, poor soil drainage, compacted soil, and warm temperature (Muhammad et al., 2023).

Sound knowledge and understanding of disease growth, development, and management are essential in preventing disease spread, grain yield loss, and unwanted expenses in disease control by the farmers (Rubab et al., 2020; Agbowuro et al., 2021; Zafarullah et al., 2021; Ullah et al., 2023). The knowledge will not only bridge the gap between tomato fruit

demand and supply by reducing the rate of fruit losses but also ensure food security sustainability. The objectives of this review are to (i) know more about fusarium wilt disease; (ii) understand the effects of fusarium wilt disease on tomato productivity; and (iii) understand the various management approaches in controlling blast disease for tomato production sustainability.

Biology of *Fusarium spp*.

This genus has more than 20 species (Wang et al., 2011). Fusarium belongs to the family-Nectriaceae, order-Hypocreales and phylum-Ascomycota. Fasarium species are very wide, ranging from non-pathogenic species to human and plant pathogens. The commonest of these species are *Fusarium solani*, *F. oxysporum*, *F. equisetti* (Chimbekujwo, 2000). Fusarium wilt disease is a major tomato disease caused by a fungus called Fusarium *oxysporum* (Borisade *et al*., 2017). *F. oxysporumare* is saprophytic and is capable of surviving in plant debris and soil (Garrett, 1970). Some strains can cause diseases on plant and animal species (Koyyappurath, 2015) and show some level of host specificity based on the plant species and variety while some strains are non-pathogenic (Wang et al., 2020).

Pathogen life cycle and epidemiology

Fusarium oxysporum is a monocyclic, soil-borne fungus that can survive in the soil or other surfaces of a material without its host for 10-15 years or more (Zhang et al., 2015). The pathogen can even last longer than 10-15 years if the soil is slightly acidic with high humidity. The pathogen is dispersed by soil, farm equipment, machinery, plant debris, seedlings, or seeds (Bahadur et al., 2022). The fungus penetrates through the root of the host plant where it blocks and colonizes the xylem tissue. The fungus is transported into a whole plant from the xylem tissue (Li et al., 2018). The blockage in the xylem makes the leaves start turning yellowish and wilting of the plant. The plant will eventually die. The development of microsclerotia in the plant tissue commences in the plant death tissue. The microsclerotia begin to spread around. The fungus can produce some resting structures called chlamydospores. The chlamydospores help the fungus survive for years. After a while, the root exudates stimulate microsclerotia germination in the soil and the fungus penetrates the roots of new plants and infects them (Chakraborty et al., 2022).

Symptoms

Fusarium oxysporum colonizes the xylem of the infected plant and extends to the vascular stem. The extent of pathogen colonization within the plant tissue dictates the rate of symptom expression. Browning of vascular tissue is the major symptom of *Fuasrium oxysporum* that results in vascular wilt. Blocking of the xylem reduces the rate of water uptake and movement causing the infected to wilt despite the presence of abundant water in the soil. The earlier symptom of fusarium wilt of tomatoes is the clearing of the ultimate veinlets in the leaflets of infected plants which results in a netted appearance (Hassan, 2020). Symptoms appear first on the lower (older) leaves, as the disease progresses, the younger leaves will also be affected (leaves start drooping, curve downwards, and turn brown-yellow) and the plant eventually dies off (Nasrin et al., 2018; Worku & Sahela, 2018). The infected plant shows symptoms of wilting during the day and recovers a little bit later in the day when the temperature is low and the environment is cool at the initial stage.

Management practices

Proper management of the fusarium wilt of tomato is imperative in raising good plant vigour with quality tomato fruits. A combination of several disease management approaches in maintaining good plant health minimizes damage caused by diseases. Excluding the pathogen on the planting material and reducing the amount and efficiency of the initial inoculum on the growing media should be the target of the farmers.

Chemical control

Chemical control involves the use of chemicals in managing diseases. The chemical method of controlling disease includes:

Disinfectants

The long-time survival of *Fusarium oxysporum* on tomato seeds, farm equipment, and irrigation water makes it necessary to disinfect the seeds and other equipment before planting. Sodium hypochlorite (NaOCl), hydrogen peroxide (H_2O_2), ozone (O_3), alcohols (ethanol, isopropyl alcohol), and quaternary ammonium salts are disinfectants that are commonly used in agriculture. The chemicals inactivate the pathogens through protein and nucleic acid disruption or function impairment (McDonnell and Russell, 1999). However, the disinfectants should be used appropriately as recommended so that the viability of the seeds will not be affected. According to Menzies and Jarvis (1994), the treatment of tomato seeds with NaOCl does not eliminate *Fusarium oxysporum* on tomato seeds but greatly reduces the pathogen load. The use of Formaldehyde will eliminate dry macroconidia of *Fusarium oxysporum* on farm equipment. Farm workers and visitors should disinfect their hands and shoes regularly, especially during the transplanting period.

Fungicides and fumigant

Different fungicides have shown activity against *Fusarium oxysporum*. Some synthetic fungicides inhibit the growth, reproduction, and development of fungi while some kill them depending on their active ingredient. The use of fungicides seems to be the most adopted control measure by the farmers. The disease severity and incidence history in a particular area

will dictate the kind of fungicide to buy, the dosage to use, the time of application, and the method and frequency of its application (Agbowuro et al., 2020a). Fumigation of the environment in the case of closed systems like greenhouse or hydroponics systems and equipment has been another strategy in managing the disease. This method has helped manage Fusarium wilt.

Biological control

The use of biological agents in managing diseases causing pathogens is called biological control. The use of biological agents as a biocontrol is gaining more popularity over chemical methods in societies especially where environmental degradation and human and animal health are of greater concern (Agbowuro et al., 2020a). Abusive use of chemical fungicides in agricultural activities has adverse effects on human health and the ecosystem at large.

Some microbial have been discovered to inhibit the growth and development of *Fusarium oxyporium*. The beneficial microorganisms include both bacteria and fungi. The use of *Pseudomonads, Bacillus Amyloliquefaciens, Chaetomium globsum, Rhizophagus intraradices, Trichoderma harzianum* has been reported to be effective against *Fusarium oxyporium* in tomato plants under greenhouse and field conditions as been reported by several researchers (Datnoff et al., 1995; Chin-A-Woeng et al., 1998; Charoenporn et al., 2010; Cepeda, 2012; El-Mohamedy et al., 2014; Loganathan et al., 2014). The combination of these innocunant has been reported to be effective. The combination of these inoculants has been reported to be effective. However, for the effectiveness of the microbial inoculant, the inoculant should be applied when the environmental factor is favourable, and complete information about the proper usage and dosage of the microbial by the manufacturer should be followed (Agbowuro et al., 2021). The storage and handling of the inoculant is vital.

The use of plant extract that contains antifungal properties has been reported to inhibit the growth and development of plant pathogens (Agbowuro et al., 2020b). 115 reported that the use of plants with antifungal properties in controlling diseases is highly valuable. Neem cake powder contained phytochemicals that had fungistatic effects against *Fusarium oxyporium* (Kimaru et al., 2004). The study of Qasem and Abu-Blan (1996) on aqueous extract of *Ranunculus* sp. Against *F. oxysporum* f.sp.*lycopersici in vitro* shows a high level of mycelia growth inhibition on the pathogen.

Physical method and good agronomic practices

The physical methods of disease management include sanitation, soil solarization, and flooding. These methods have been adopted in the management of *Fusarium* wilt diseases (Mihajlović et al., 2017; Muhammad et al., 2020). Sanitation is a practice of preventing inoculum sources from entering the farm or a way of eliminating the inoculum on the field before planting. This exercise could be carried out by destroying affected plants or infested debris. Flaming the field with affected plants will help in killing the pathogen resting structure (Mihajlović et al., 2017). Soil solarization is a hydrothermal process in the soil during high temperatures and intense solar radiation reduces the inoculum load of fusarium spp. (Mishra et al., 2014; Singh et al., 2015). Flooding is a method of managing soil-borne diseases. Flooding reduces oxygen in the soil and increases carbon dioxide, leading to various microbial interactions that result in toxic substances to pathogens upon anaerobic processes (Kogan, 1999).

Use of resistant varieties

The use of cultivars that are resistant to disease has offered a better chance of managing fusarium wilt in terms of cost, environmental sustainability, and labour compared to other methods (Agbowuro et al., 2020a). The use of cultivars that are resistant to diseases is eco-friendly and reduces the cost of production but cuts the cost inquired by other disease control measures Development of disease resistant varieties may be a bit difficult for plant breeders because the fungus can evolve and mutate to overcome resistance genes (Zhou et al., 2007). Screening of tomato accessions with potential for fusarium wilt resistance is essential in developing tomato accessions that are resistant to the pathogen. Tomato accessions that are resistant to the *Fusarium oxyporium* are the sources of introgression of new resistance genes into some elite tomato varieties in a breeding program. The resistant varieties can resist the pathogen and still yield optimally.

Nutrition management

The biological and physio-chemical properties of the medium where the crop is grown determine the ability of the crop to resist diseases (Luong et al., 2003). Appropriate plant nutrient supply boasts plant immunity that is essential for better growth and development in plants and gives a high yield in return. Nitrogen is a macronutrient that is essential for the growth and development of plants. However, the nutrient is low in most tropical soil (Salami & Agbowuro, 2016). Application of nitrogenous fertilizer controlled *Fusarium* wilt by boosting its immune system (Kimaru, 1998). Agrios (1988) reported that maintaining soil pH at 6 – 7.5 will make the environment unfavourable for the development of the disease. Owino et al. (1995) reported that soil amendment is more promising than the use of fungicides in controlling *Fusarium wilt*. Soil amendment helps in reducing *Fusarium oxyporium* load in the soil. However, soil amendment is eco-friendly and improves soil properties. The application of fly ash obtained from coal contains reasonable amounts of silicon dioxide and calcium dioxide reducing fusarium wilt (Khan & Singh, 2001). Huang et al. (2011) reported that the application of silicon reduces fusarium symptoms.

Integrated disease management (IDM)

Integrated disease management involves the use of more than one disease control approach for effective disease management. A combination of different approaches is more effective than using a single approach (Kogan, 1999). During endemic season or when the environmental variable highly favoured the pathogen growth and development, the pathogen may crack down the resistant potential of a resistant variety grown but the use of another control approach with this will assist in controlling the disease.

Conclusion

Fusarium wilt is one of the most destructive diseases of tomatoes globally. The disease widens the gap between its production and supply. Understanding the biology, epidemiology, and management of the disease will help in managing it appropriately. Adopting more than one management approach has been reported to be the most effective control measure by minimizing disease incidence and increasing fruit yield. Chemical fungicides is the most widely method in managing fusarium wilt. However, the method harms the environment and human's and livestock's health. The combination of another control measure should be adopted for better tomato fruit yield and to ensure food security and sustainability.

References

Abdelaziz, A. M., Kalaba, M. H., Hashem, A. H., Sharaf, M. H. & Attia, M. S. (2022). Biostimulation of tomato growth and biocontrol of Fusarium wilt disease using certain endophytic fungi. *Botanical Studies, 63,* 34. https://doi.org/10.1186/s40529-022-00364-7

Agbowuro G. O., Aluko M., Salami A. E. & Awoyemi S. O. (2020b). Evaluation of different aqueous plant extracts against rice blast disease fungus (*Magnaporthe oryzae*). *Ife Journal of Science, 22*(3), 193-202.

Agbowuro, G. O., Afolabi, M. S., Olamiriki, E. F. & Awoyemi, S. O. (2020a). Rice blast disease (*Magnaporthe oryzae*): A menace to rice production and humanity. *International Journal of Pathogen Research, 4*(3), 32-39.

Agbowuro, G. O., Ayeyo M. E. & Emecho, T. S. (2021). The Use of Microbial Inoculants in Crop Production for Food Security Sustainability. *Advanced Journal of Graduate Research, 10*(1), 33-40.

Agrios, G. N. (1988). Plant pathology, Third edition. Academic Press Inc. New York; 1988.

Bahadur, A. (2022). Current status of Fusarium and their management strategies. IntechOpen. doi: 10.5772/intechopen.100608.

Borisade, O. A., Uwaidem, Y. I., & Salami, A. E. (2017). Preliminary report on *Fusarium oxysporum* f. sp. *Lycopersici (Sensu lato)* from some tomato producing agroecological areas in Southwestern Nigeria and susceptibility of F1-resistant tomato hybrid (F1-Lindo) to infection. *ARRB*, *18*(2), 1–9.

Brookie, K. L., Best, G. L., & Conner, T. S. (2018). Intake of raw fruits and vegetables is associated with better mental health than intake of processed fruits and vegetables. *Frontier Psychology*, *9*, 487.

Cepeda, M. V. (2012). Effects of Microbial Inoculants on Biocontrol and Plant Growth Promotion [Master's thesis, Ohio State University]. OhioLINK Electronic Theses and Dissertations Center. http://rave.ohiolink.edu/etdc/view?acc_num=osu1345239027

Chakraborty, A. B., Roy, A., & Kumar, P. A. D. (2022). Fusarium wilt of tomato. *The Pharma Innovation Journal*, *SP-11*(6), 744-748.

Chang Y, DU B, Wang G. L., Ji. P., XIE, Y., Li, X., Li, Z., & Wang, J. A (2018). Study on the pathogen species and physiological races of tomato Fusarium wilt in Shanxi. *China Journal of Integrative Agriculture, 17*(6), 1380–1390.

Charoenporn, C., Kanokmedhakul, S., Lin, F.C., Poeaim, S., & Soytong, K. (2010). Evaluation of bio-agent formulations to control Fusarium wilt of tomato. *African Journal of Biotechnology*, *9*(36), 5836-5844.

Chimbekujwo, I. B. (2000). Frequency and pathogenicity of Fusarium wilts (*Fusarium solani* and *Fusarium equiseti*) of cotton (*Gossypium hirsutum*) in Adamawa. Nigeria. *Revista de Biología Tropical*, *48*(1), 1-5

Chin-A-Woeng, T. F. C., Bloemberg, G. V., van der Bij, A. J., van der Drift, K. M. G. M., Schripsema, J., Kroon, B., Scheffer, R. J., Keel, C., Bakker, P. A.H. M., Tichy, H.-V., de Bruijn, F. J., Thomas-Oates, J. E., & Lugtenberg, B. J. J. (1998). Biocontrol by phenazine-1- carboxamide-producing Pseudomonas chlororaphis PCL1391 of tomato root rot caused by *Fusarium oxysporum* f. sp. radicis-lycopersici. *MPMI*, *11*, 1069-1077.

Datnoff, L. E., Nemec, S. A. & Pernezy, K. (1995). Biological control of Fusarium crownand root rot of tomato in Florida using *Trichoderma harzianum* and *Glomus intraradices*. *Biological Control*, *5*(3), 427-431.

El-Mohamedy, R. S. R., Abdel-Kareem, F., Jabnoun-Khiareddine, H. & Daami- Remadi, M., (2014). Chitosan and Trichoderma harzianum as fungicide alternatives for controlling Fusarium crown and root rot of tomato. *Tunisian Journal of Plant Protection*, *9*, 31-43.

FAOSTAT. (2018). Food and Agriculture Organisation of the United Nations. [accessed 2020 June 13]. http://www.fao.org/faostat/en/#data/QC.

Garrett, S. D. (1970). Pathogenic root infection fungi. London, UK: Cambridge University Press; 1970.

Hassan, H. A. (2020) Biology and integrated control of tomato wilt caused by *Fusarium oxysporum lycopersici*: A Comprehensive review under the light of recent advancements. *Journal of Botany Research*, 3(1), 84-99.

Houssei, A. A., Ahmed, S. M. & Ismail, A. A. (2010). Activation of tomato plant defense response against

Fusarium wilt disease using *Trichoderma harzianum* and salicyclic acid under greenhouse conditions. *Research Journal of Agriculture and Biological Sciences, 6*(3), 328–338.

Huang, C. H., Roberts, P. A., & Datnoff, L. E. (2011). Silicon suppresses Fusarium crown and root rot of tomato. *Journal of Phytopatho*logy, *159*, 546-554.

Hussain, Z., Khan, H., Imran, M., Naeem, M. K., Shah, S. H., Iqbal, A., Ali, S. S., Rizwan, M., Ali, S., Muneer, M. A., Widemann, E., & Shafiq, S. (2022). Cation/proton antiporter genes in tomato: Genomic characterization, expression profiling, and co-localization with salt stress-related QTLs. *Agronomy, 12*, 245. https://doi.org/10.3390/agronomy12020245

Jan, S. A., Ali, G. M., Ali, S., Shah, S. H., & Ahmad, N. (2018). Genetic improvement in tomato (*Solanum lycopersicum*) against salt stress. *Indian Journal of Biotechnology, 17*, 459-465.

Jan, S. A., Shah, S. H., Ali, S., & Ali, G. M. (2015). The effect of plant growth regulators on callus induction and somatic embryogenesis of hybrid tomato. *Pakistan Journal of Botany, 47*(5), 1671-1677.

Kapsiya. J., Gungula, D. T., Tame, V. T. & Bukar N. (2015). Effects of storage chemicals and packaging systems on physicochemical characteristics of tomato (*Solanum lycopersicum* L.) fruits. *AASCIT Journal of Bioscience, 1*(3), 41–46.

Khan, M. R., & Singh, W. N. (2001). Effects of soil application of fly ash on the fusarium wilt on tomato cultivars. *International Journal of Pest Management, 47*, 293–297.

Kimaru, S. K. (1998). Efficacy of neem kernel cake powder against Fusarium wilt of tomato (Unpublished master's thesis). Kenyatta University, Kenya.

Kimaru, S. K., Waudo, S. W., Monda, E., Seif, A. A., & Birgen, J. K. (2004). Effect of neem kernel cake powder (NKCP) on Fusarium wilt of tomato when used as a soil amendment. *Journal of Agriculture and Rural Development in the Tropics and Subtropics, 105*(1), 63–69.

Kogan, M. (1999). Integrated pest management: Constructive criticism or revisionism? Phytoparasitica, 27, 93–96.

Koyyappurath, S. (2015). Histological and molecular approaches for resistance to *Fusarium oxysporum* f.sp. radicis-vanillae, causal agent of root and stem rot in Vanilla spp. (Orchidaceae) (Doctoral dissertation). Université de la Réunion, France.

Li, Y. T., Hwang, S. G., Huang, Y. M., & Huang, C. H. (2018). Effects of Trichoderma asperellum on nutrient uptake and Fusarium wilt of tomato. *Crop Protection, 110*, 275–282.

Loganathan, M., Garg, R., Venkataravanappa, V., Saha, S., & Rai, A. B. (2014). Plant growth promoting rhizobacteria (PGPR) induces resistance against Fusarium wilt and improves lycopene content and texture in tomato. *African Journal of Microbiology Research, 8*(11), 1105–1111.

Luong, M. C., Hoang, D. C., Phan, T. B., Luong, T. P., Jiaan, C., & Heong, K. L. (2003). Impacts of nutrition management on insect pests and diseases of rice. *Omon Rice, 11*, 93-102.

McDonnell, G., & Russell, A. D. (1999). Antiseptics and disinfectants: Activity, action and resistance. *Clinical Microbiology Reviews, 12*(1), 147-179.

Menzies, J. G., & Jarvis, W. R. (1994). The infestation of tomato seed by Fusarium oxysporum f. sp. radicis-lycopersici. *Plant Pathology, 43*(2), 378-386.

Mihajlović, M., Rekanović, E., & Hrustić, J. (2017). Methods for management of soil-borne plant pathogens. *Journal of Pesticides and Phytomedicine, 32*, 9-24.

Mishra, P., Singh, P., & Tripathi, N. N. (2014). Evaluation of plant extracts against Fusarium oxysporum sp. lycopersici, wilt pathogen of tomato. *International Journal of Food, Agriculture and Veterinary Sciences, 4*, 163-167.

Mostafa, Y. S., Alamri, S. A., Alrumman, S. A., Hashem, M., Taher, M. A., & Baka, Z. A. (2022). In vitro and in vivo biocontrol of tomato Fusarium wilt by extracts from brown, red, and green macroalgae. *Agriculture, 12*, 345. https://doi.org/10.3390/agriculture12030345

Muhammad Rafiq, C. H., Mahmood, M. T., & Mushtaq Ahmad, M. (2020). Fusarium wilt's pathogenic studies and disease management: A review. *Genetics and Molecular Research, 19*, gmr16039974.

Muhammad, E. H., Muhammad, A. G. K., Khairy, A. M. A., & Hala, A. M. E. (2023). Recent approaches for management of tomato Fusarium wilt. *Pakistan Journal of Phytopathology, 35*(2), 421-438. https://doi.org/10.33866/phytopathol.035.02.0839

Nasrin, L., Podder, P., & Mahmud, M. R. (2018). Investigation of potential biological control of Fusarium oxysporum f.sp. lycopersici by plant extracts, antagonistic species, and chemical elicitors in vitro. *Fungal Genomics and Biology, 8*, 155.

Nirmaladevi, D., Venkataramana, M., Srivastava, R. K., Uppalapati, S. R., Gupta, V. K., & Yli-Mattila, T. (2016). Molecular phylogeny, pathogenicity and toxigenicity of Fusarium oxysporum f. sp. lycopersici. *Scientific Reports, 6*, 21367. https://doi.org/10.1038/srep21367

Owino, P. O., Waudo, S. W., & Kuria, M. (1995). Control of Fusarium wilt of tomatoes using soil amendments. *East African Agricultural Journal, 60*(4), 235-245.

Qasem, J. R., & Abu-Balan, H. A. (1996). Fungicidal activity of some common weed extracts against different plant pathogenic fungi. *Journal of Phytopathology, 144*, 157–161.

Rubab, S., Fayyaz, S., & Asmatullah. (2020). Plant parasitic nematodes associated with wheat and maize. *Advances in Agriculture and Biology, 3*(1), 8-17.

Salami, A. E., & Agbowuro, G. O. (2016). Gene action and heritability estimates of grain yield and disease incidence traits of low-N maize (*Zea mays* L.) inbred lines.

Agriculture and Biology Journal of North America, *7*(2), 50-54. https://doi.org/10.5251/abjna.2016.7.2.50.54

Shah, S. H., Ali, S., & Ali, G. M. (2019). Morphological analysis of cold-tolerant tomato (*Solanum lycopersicum* Mill.) plants expressing *CBF3* gene. *Advances in Agriculture and Biology, 2*(1), 14-24.

Shah, S. H., Ali, S., Hussain, Z., Jan, S. A., Jalal-ud–Din, & Ali, G. M. (2016). Genetic improvement of tomato (*Solanum lycopersicum* Mill.) with *AtDREB1A* gene for cold stress tolerance using optimized Agrobacterium-mediated transformation system. *International Journal of Agriculture & Biology*, *18*(3), 471-482.

Shah, S. H., Ali, S., Jan, S. A., & Ali, G. M. (2013). A novel approach for rapid *in vitro* morphogenesis in tomato (*Solanum lycopersicum* Mill.) with the application of cobalt chloride. *European Academic Research*, *1*(9), 2702–2721.

Shah, S. H., Ali, S., Jan, S. A., Jalal-ud-Din, & Ali, G. M. (2015). Piercing and incubation method of *in planta* transformation producing stable transgenic plants by overexpressing *DREB1A* gene in tomato (*Solanum lycopersicum* Mill.). *Plant Cell, Tissue and Organ Culture, 120*(3), 1139-1157.

Shah, S. H., Ali, S., Qureshi, A. A., Zia, M. A., Jalal-ud–Din, & Ali, G. M. (2017). Chilling tolerance in three tomato transgenic lines overexpressing *CBF3* gene controlled by a stress-inducible promoter. *Environmental Science and Pollution Research, 24*, 18536–18553.

Singh, R., Biswas, S. K., & Nagar, D. (2015). Sustainable integrated approach for management of Fusarium wilt of tomato caused by Fusarium oxysporum f. sp. lycopersici (Sacc.) Snyder and Hansen. *Sustainable Agriculture Research, 4*(2), 138-147.

Srinivas, C. N., Devib, K., Narasimha, M., Chakrabhavi, D., Mohan, T. R., Lakshmeesha, C., Bhim Pratap, S., Naveen, K., Kalagatur, S. R., Niranjana, A. H., Abdulaziz, A., Alqarawi, B. T., Elsayed, F. A., Chandra Nayaka, S., & Srivastava, R. K. (2019). Fusarium oxysporum f. sp. lycopersici causal agent of vascular wilt disease of tomato: Biology to diversity – A review. *Saudi Journal of Biological Sciences, 26*, 1315-1324.

Ullah, A., Hamid, A., Shah, S. M., & Khan, A. (2023). Assessment of nematode-induced diseases in chili fields of Karachi: Implications for sustainable crop management. *Advances in Agriculture and Biology, 6*(1), 54-60.

Wang, B., Yu, H., Jia, Y., Dong, Q. S., Alabouvette, C., Edel-Hermann, V., Kistler, H. C., Ye, K., & Ma, L. A. (2020). Chromosome-scale genome assembly of Fusarium oxysporum strain Fo47, a fungal endophyte and biocontrol agent. *Molecular Plant-Microbe Interactions, 33*, 1108-1111.

Wang, H., Xiao, M., Kong, F., Chen, S., Dou, H., & Sorrell, T. (2011). Accurate and practical identification of 20 Fusarium species by seven-locus sequence analysis and reverse line blot hybridization, and an in vitro antifungal susceptibility study. *Journal of Clinical Microbiology, 49*(5), 1890-1898.

Worku, M., & Sahela, S. (2018). Review on disease management practice of tomato wilt caused by Fusarium oxysporum in case of Ethiopia. Journal of Plant Pathology and Microbiology, 9, Article 472.

Zafarullah, Hussain, Z., & Mehmood, K. (2021). Micropropagation of disease-free banana genotype 8818-William for field cultivation. *Advances in Agriculture and Biology, 4*(1), 41-47.

Zhang, M., Xu, J. H., Liu, G., Yao, X. F., Li, P. F., & Yang, X. P. (2015). Characterization of the watermelon seedling infection process by Fusarium oxysporum f. sp. niveum. *Plant Pathology, 64*, 1076-1084.

Zhou, E., Jia, Y., Singh, P., Correll, J., & Lee, F. (2007). Instability of the Magnaporthe oryzae virulence gene AVR-Pita alters virulence. *Fungal Genetics and Biology, 44*, 1024-1034. https://doi.org/10.1016/j.fgb.2007.02.003