Chapter

Fusarium Soilborne Pathogen

Leonce Dusengemungu

Abstract

Fusarium species are among the most persistent species of soilborne fungal pathogens. They cause severe economic damage in different agricultural production (potato, wheat, rice, etc.) due to the mycelia and chlamydospores that play a role during the infection of host plants. Our review has explored various studies on *Fusarium* species. The mechanisms involved in enhancing the protective ability of the *Fusarium* strain have been discussed. Furthermore, the current chemical and biological control methods to minimize Fusarium species' impact on crops were highlighted. Future directions in the attempt to improve the control of *Fusarium* soilborne pathogens have been discussed.

Keywords: fusarium, crops, soilborne, fungal pathogens, chemical methods

1. Introduction

Soilborne fungal pathogens are ubiquitous, and they can be found in soil, water, and air; when in contact with crops, they can trigger root rots, wilts, stunting, and other plant diseases [1]. The *Fusarium* species are classified among the most diverse soilborne pathogens [2]. Several research have pointed out that fungus from the genus Fusarium can grow on both live and dead plants and any other organic materials, including animal debris [3]. Furthermore, there is evidence that *Fusarium* conidia are waterborne and can transform into airborne when dehydrated or dried; their chlamydospores are predominantly soilborne [4]. The genetic structure of Fusarium and its sexual stages have allowed its ascospore to survive in extreme conditions like high temperature and high altitudes. Various *Fusarium* spp. have been isolated from humans and animals. In some instances, Fusarium species identified in the corneas of diseased eyes of humans have been linked with the loss of vision ability and more complications in immunocompromised personnel [5]. More findings have associated *Fusarium* spp. with different plant diseases such as head blight, vascular wilt in various crops, scab on cereal grains, and crown rot [5, 6].

Fusarium soilborne pathogens can resist harsh conditions and persist in soil due to the production of chlamydospores, which help them to survive without the host's support. Researches have shown that once the soil is colonized by *Fusarium oxysporum* f.sp.*cubense* (FOC), it is better to wait or use the plants that can resist *F.oxysporum*; otherwise, the susceptible varieties cannot survive [6, 7].

A biological method of soil disinfestation reported by (2012) was found efficient in controlling various soilborne pathogens, such as *F. redolens*, *F. Oxysporum f.spp. lycopersici*, *F. spinaciae*, *and radices-lycopersici*. The methods are accomplished by using labile carbon-activated microbial systems by creating anaerobic soil conditions in moist soils covered with polyethylene mulch. Furthermore, this reported method was also found effective in controlling some nematodes species such as *Pratylenchus* and *Meloidogyne incognita* sp. [6]. Biological methods have been reported to ameliorate soil health by regulating the number of soil and plant pathogens due to their effect on agricultural residue accumulation [8].

2. The mechanisms involved in enhancing the protective ability of Fusarium strain

The biological management of Fusarium wilt diseases in soil and crops has been fulfilled by the use of nonpathogenic *Fusarium* spp. and other antagonistic organisms such as *Trichoderma* spp. (*Trichoderma harzianum*, *T. asperellum*, *and T. virens*) (**Figure 1**) [9]. The mechanisms involved in this process are still ill-defined. However, a few hypotheses involved in suppressing the occurrence of pathogenic Fusarium have been made through molecular mechanism elucidation and Fusarium species genome sequencing. Nutrient competition between pathogenic and nonpathogenic fungi has been noticed during the investigation of conducive and suppressive soils as well as population dynamics of soil supplemented with Fusarium spp., and it was revealed that the increase or decrease of Fusarium root colonization and chlamydospore germination were due to the nutrient competition [9, 10].

Competition of infection sites to the root surface was also described as a mode of action between pathogenic Fusarium and saprophytic fungi [11]. Larkin and Fravel investigated the effect of higher glucose concentration (0.2 mg/g of soil) on the germination of chlamydospores of nonpathogenic Fusarium (F047); it was noticed that the higher concentration of glucose suppressed the germ tube elongation of wilt Fusarium pathogen while inhibiting chlamydospore germination [12]. More research has correctly observed that nonpathogenic and pathogenic isolates

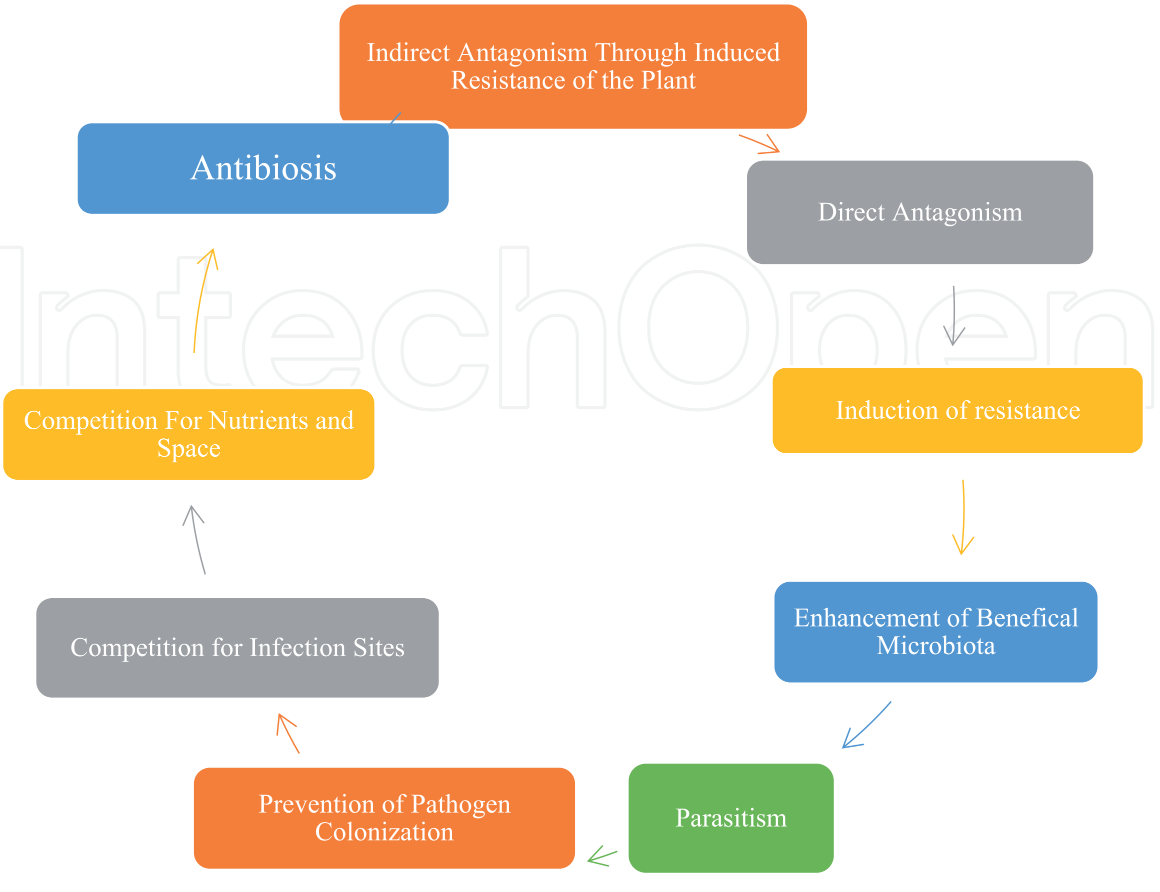

Figure 1.
The modes of action of the protective strains of F. oxysporum and many other beneficial microorganisms.

of Fusarium generally colonize root zones (emergency site of secondary roots, root apex, and elongation zone); these sites have higher nutrient oxidation [2, 10]. There is evidence that nonpathogenic *F. oxysporum*, which is characterized among endophytic fungi, can stimulate the defense response of host plants when plant pathogens attach them; furthermore, it has been found to increase resistance to environmental stress and enhance the production of essential hormones such as auxins and gibberellins, which are known to activate the plant growth [11, 13, 14].

The inoculation of nonpathogenic Fusarium strains into the roots of plants was found to inhibit the disease expression through a systemic resistance induction [15]. Nonpathogenic *F. oxysporum* were inoculated into watermelon plants to test their resistance against pathogenic Fusarium strains, and it was found to cause local and systemic resistance. In addition, the occurrence of both pathogenic and non-pathogenic strains on the root stimulated resistance mechanism in plants, therefore demonstrating their importance in the induction of local resistance [11].

3. Microbiological control of Fusarium soilborne pathogens

Current findings have shown that plant diseases resulting from soilborne plant pathogens' contamination are complicated to manage. However, various investigations have recognized the renowned biological control of soilborne pathogens using antagonistic microorganisms [16]. Previous studies have demonstrated that besides the most popular *Penicillium* spp., *Pseudomonas* spp., *Streptomyces* spp. (*Streptomyces griseoviridis*), and *Trichoderma* spp. (*T. harzianum*, *T. asperellum*, *T. koningii*), which represent the most broadly investigated groups of biological control agents, the Fusarium *species* can also be used to control plant diseases [2]. Among *Fusarium* species that cause soilborne pathogens, there is *F. emeriti*, *F. avenaceum*, *F. solani*, *F. sulphureum*, *F. tabacinum*, and *Fusarium oxysporum (F. oxysporum)*, which is also commonly known to cause vascular wilt in economically important crops. Among *F. oxysporum* include pathogenic and nonpathogenic strains. Research findings have pointed out that *F. oxysporum* as a biological agent can only control wilt originated from diverse pathogenic strains from similar species. However, more research is required to investigate if they cannot control wilt from other pathogenic species. Moreover, the mechanism involved in inducing the protective capacity of *F. oxysporum* is still not well understood [17].

Ortoneda et al. [18] investigated *Fusarium oxysporum* virulence mechanisms in plant and mammalian species. It was found that a single strain of *Fusarium* infection can induce vascular wilt disease in the plant. While the inoculation of microconidia of the tomato pathogenic isolates in the lateral tail vein of immunocompromised, mice can cause extensive complications such as the dissemination of infection in all organs and the death of the mice. More findings from the same study established that removing the mutant genes regulating a mitogen-induced protein kinase, a class V chitin synthase, and a pH response transcription factor affect diverse virulence factors important in both the tomato plants and mouse pathogenicity. Supportive studies have confirmed that *F. oxysporum* can suppress Fusarium wilts, and therefore, the utilization of this Fusarium strain to reduce the virulence capacity of other diseases due to Fusarium is recommended (**Figure 1**) [19, 20].

Relatively, little is understood about the interactions of plant pathogens, soil microbiome, and myxobacteria strains to reduce soilborne phytopathogens. Ye et al. [16] indicated that a predatory myxobacterium *Corallococcus* sp. strain EGB can be used to minimize cucumber Fusarium wilt through its capacity to colonize plant roots, thereby influencing the ability of the soil microbial community. The research findings done in two-year field experiment has shown that the inoculation of the solid-state fermented *Corallococcus* sp. strain EGB controlled the cucumber Fusarium wilt by 79.6% in the greenhouses, 66.0% in the field in 2016, and 53.9% in the field in 2016, and the analysis of the capacity of strain EGB showed that it could improve the soil microbial community while reducing effectively the soilborne (*Fusarium oxysporum f.sp. cucumerinum*). Therefore, it was concluded that *Corallococcus* sp. has significant potential as a new biological control agent of soilborne pathogens, in particular Fusarium wilt. Due to the inefficient current techniques used to reduce vascular wilt pathogens in various important crops, more research is needed to explore and develop novel biological control agents and the currently available strains such as nonpathogenic *Fusarium*, *Pseudomonas*, *Streptomyces*, *Trichoderma*, *Gliocladium*, *and Coniothyrium* [21].

More research findings have confirmed that diverse bacterial and fungal strains can control Fusarium wilt in soil. A comparative analysis of meta-barcoding of taxonomic diversity of bacterial and fungal organisms from non-suppressive and suppressive soils concerning the control of Fusarium wilt has shown that bacterial and fungal strains recognized for their antagonistic activity against *F. oxysporum* was detected in suppressive and non-suppressive soils [22].

Fusarium wilt of banana (FWB), in particular, *Fusarium oxysporum* f.sp. cubense (Foc) race one has caused a considerable loss of banana plantations due to its distribution in tropical areas. However, researches show that FWB has been reduced up to 79% by employing *Pseudomonas* spp. and approximately up to 70% by various endophytes and *Trichoderma* spp. The use of another biological agent to control FWB is recommended to support the currently available techniques [22].

Actinomycetes obtained from soil have been found to inhibit Fusarium *Solani f.sp. pisi* that causes black root rot in Chickpea. A hundred actinomycetes were tested for their antifungal activities against *F. solani in vitro* and *in vivo*. The identifications result of actinomycetes used in the experiment showed that the isolates S3 of actinomycetes were highly similar to *Streptomyces* antibiotics, while the isolates s40 have similarities with *Streptomyces peruviensis*. From these results, it can be concluded that the actinomycetes and bacteria can minimize the effect of fungi. More studies should be conducted to produce these biocontrol en masse to confirm their biocontrol capacity and potential for commercialization as biocontrol agents [23].

4. Chemical control methods of Fusarium soilborne pathogens

Soilborne diseases can be reduced by spraying and fumigating with chemicals such as fungicides or biocontrol agents. Song et al. [24] investigated the capacity of seven fungicides, carboxin, azoxystrobin, hymexazol, tolclofos-methyl, thiram, carbendazim, and prochloraz, against *Fusarium oxysporum* Klotz on the Tomato (*Lycopersicon esculentum* Mill) plant grown in a hydroponic system. The inhibitory activities of these fungicides against the *F. oxysporum* findings showed that the median concentration (EC_{50}) was 154.03, 144.58, 69.961, 53.606, 26.292, 0.235, and 0.019 $\mu g.ml^{-1}$, respectively. Among all the fungicides used, prochloraz and carbendazim were found very efficient in controlling the mycelial growth of *F. oxysporum*. These results confirmed that wild tomato disease due to the infection of Fusarium pathogens could be inhibited by minimum toxicity of fungicides, using measured concentrations.

A similar study by Chauhan et al. [25] established the use of chemical fungicides, carboxin, carbendazim, quintozene, and thiram for seed management, pre- and post-sowing soil drench, and seed treatment of cotton can potentially reduce the occurrence of soil pathogens: *Fusarium oxysporum sp. Vasinfectum* (Atk.) Snyder and Hansen, *Macrophomina phaseolina* (Tassi) Goid = *Rhizoctonia bataticola*

(TAUB.) Butler, *Rhizoctonia solani* (Kuhn) and *Fusarium solani* (Mart.) Sacce. However, the use of the chemicals has several disadvantages, such as the inability to perform under various environmental and biotic conditions. Commonly used fungicides are usually inexpensive, but their efficacy is disputed due to the complications associated with diverse pest management strategies.

Nitrate nitrogen added to the soil at a higher pH has been used to control Fusarium wilt effectively [25]. A similar study has also reported that the use of nitrate-nitrogen significantly reduced the occurrence of Fusarium wilt on chrysanthemums, King asters, and carnations [26, 27]. Potassium quantity in soil has also been related to the occurrence of soilborne diseases and crop production. However, research has demonstrated that Fusarium soilborne pathogens incidence in tomatoes can be minimized by increasing potassium quantity in soil [28]. Similar studies have confirmed that high potassium levels can reduce the severity of Fusarium wilt in cotton [29]. The quantity of phosphate in soil has been investigating for its association with Fusarium diseases in crops. The findings revealed that higher phosphate quantity was associated with the occurrence of Fusarium wilt in muskmelon and cotton [30].

Numerous studies have established that the use of chemical disinfection to restore and prevent the occurrence of Fusarium wilt is not sustainable due to the environmental concerns because of the high toxicity and deteriorating effects of these chemical fungicides as well as the development of fungicides resistance; therefore, alternative control methods are recommended. Among the highly preferred methods include deep plowing, rotation, heating, grafting techniques, flooding, solarization, and various pesticides. Biofumigants and crop rotations are also among the environmental friendly methods that can be used to control soilborne pathogens especially Fusarium wilt. The methods to apply should be selected depending on the location and climate. Some methods such as soil solarization are ineffective where solar radiation is inefficient, while soil flooding requires a more extended period, approximately between 3 and 4 months, and is not preferred when the quantity of soil pathogens is high [6, 31–33].

5. Future directions

Plant-microbial interactions, ecological soil conditions, and the use of chemical and biological control agents to suppress soilborne pathogens play a significant role in the successful growth of plants. There is limited research investigating the importance of root exudates, intraspecific variation due to Fusarium infection. There is also a significant research gap in understanding the genetic control of Fusarium spore germination, its pathogenicity, and vascular occlusion that results in plant diseases. Therefore, these key research areas should be investigated further to ameliorate our understanding of the Fusarium organisms to improve the control of soilborne pathogens.

6. Conclusion

In our opinion, the combination of chemical fungicides and biological control agents can successfully inhibit soilborne pathogens, but more research is required to determine the effect of these methods on the soil microorganism's populations. The future success and effectiveness of these methods require rigorous testing of their protective ability and risk assessment. In addition, the influencing ecological characteristics of the soil should be determined accurately to enhance the effectiveness of these control methods. Moreover, more research is required to understand in detail the mechanisms involved in enhancing the protective ability of Fusarium strain to enhance the industrial production of bio fungicides, safe formulation of chemical methods, and safe application procedures.

Acknowledgements

This review article writing was supported by the Copperbelt University, Africa Centre of Excellence for Sustainable Mining (CBU ACESM).

Conflict of interest

The authors declare no conflict of interest.

Author details

Leonce Dusengemungu
School of Mathematics and Natural Sciences, The Copperbelt University, Kitwe, Zambia

*Address all correspondence to: dusengeleonce@yahoo.fr

References

[1] Roncero MIG et al. Fusarium as a model for studying virulence in soilborne plant pathogens. Physiological and Molecular Plant Pathology. 2003;**62**(2):87-98. DOI: 10.1016/S0885-5765(03)00043-2

[2] Alabouvette C, Olivain C, Migheli Q, Steinberg C. Microbiological control of soilborne phytopathogenic fungi with special emphasis on wilt-inducing Fusarium oxysporum. The New Phytologist. 2009;**184**(3):529-544. DOI: 10.1111/j.1469-8137.2009.03014.x

[3] Smith SN. An overview of ecological and habitat aspects in the genus Fusarium with special emphasis on the soilborne pathogenic forms. Plant Pathology Bulletin. 2007;**16**:97-120 Available: http://140.112.183.1/cpps/pdf/16-3/p097-120.pdf

[4] Al-Hatmi AMS, Meis JF, de Hoog GS. Fusarium: Molecular Diversity and Intrinsic Drug Resistance. PLoS Pathogens. 2016;**12**(4):1-8. DOI: 10.1371/journal.ppat.1005464

[5] Nucci M, Anaissie E. Fusarium infections in immunocompromised patients. Clinical Microbiology Reviews. 2007;**20**(4):695-704. DOI: 10.1128/CMR.00014-07

[6] Huang XQ et al. Control of soilborne pathogen Fusarium oxysporum by biological soil disinfestation with incorporation of various organic matters. European Journal of Plant Pathology. 2015;**143**(2):223-235. DOI: 10.1007/s10658-015-0676-x

[7] Dita MA, Waalwijk C, Buddenhagen IW, Souza JT, Kema GHJ. A molecular diagnostic for tropical race 4 of the banana fusarium wilt pathogen. Plant Pathology. 2010;**59**(2):348-357. DOI: 10.1111/j.1365-3059.2009.02221.x

[8] Momma N, Kobara Y, Uematsu S, Kita N, Shinmura A. Development of biological soil disinfestations in Japan. Applied Microbiology and Biotechnology. 2013;**97**(9):3801-3809. DOI: 10.1007/s00253-013-4826-9

[9] M. Q, Baker R. Mechanisms involved in biological control of Fusarium Wilt of Cucumber with strains of Nonpathogenic Fusarium Oxysporum. Disease Control Pest Management. 2007;**81**(4):1-8. Available: papers3://publication/uuid/E21EE9B8-A028-447C-B8CB-E27A75E30C62

[10] Alabouvette C, Olivain C. Modes of action of nonpathogenic strains of Fusarium oxysporum in controlling Fusarium wilts. Plant Protection Science. 2018;**38**(SI) 1-6th Conf EFPP 2002:195-199. DOI: 10.17221/10354-pps

[11] Sajeena A, Nair DS, Sreepavan K. Nonpathogenic Fusarium oxysporum as a biocontrol agent. Indian Phytopathology. 2020;**73**(2):177-183. DOI: 10.1007/s42360-020-00226-x

[12] Larkin RP, Fravel DR. Mechanisms of action and dose-response relationships governing biological control of Fusarium wilt of tomato by nonpathogenic Fusarium spp. Phytopathology. 1999;**89**(12):1152-1161. DOI: 10.1094/PHYTO.1999.89.12.1152

[13] Schardl CL, Leuchtmann A, Spiering MJ. Symbioses of grasses with seedborne fungal endophytes. Annual Review of Plant Biology. 2004; **55**(November 2014):315-340. DOI: 10.1146/annurev.arplant.55.031903.141735

[14] Zuo Y, Li X, Yang J, Liu J, Zhao L, He X. Fungal endophytic community and diversity associated with desert shrubs driven by plant identity and organ differentiation in extremely arid desert ecosystem. Journal of Fungi. 2021;**7**(7):578. https://doi.org/10.3390/jof7070578

[15] Abbasi S, Safaie N, Sadeghi A, Shamsbakhsh M. Streptomyces Strains Induce Resistance to Fusarium oxysporum f. Sp. Lycopersici Race 3 in Tomato through Different Molecular Mechanisms. Frontiers in Microbiology. 2019;**10**(JUL):1-16. DOI: 10.3389/fmicb.2019.01505

[16] Ye X et al. A predatory myxobacterium controls cucumber Fusarium wilt by regulating the soil microbial community. Microbiome. 2020;**8**(1):1-17

[17] López-Berges MS et al. HapX-mediated iron homeostasis is essential for rhizosphere competence and virulence of the soilborne pathogen Fusarium oxysporum. Plant Cell. 2012;**24**(9):3805-3822. DOI: 10.1105/tpc.112.098624

[18] Ortoneda M et al. Fusarium oxysporum As A Multihost Model for the Genetic Dissection of Fungal Virulence in Plants and Mammals. Infection and Immunity. 2004;**72**(3):1760-1766. DOI: 10.1128/IAI.72.3.1760-1766.2004

[19] Alabouvette C, Olivain C, L'Haridon F, Aimé S, Steinberg C. Using strains of Fusarium oxysporum to control Fusarium wilts: Dream or reality? NATO Security through Science Series A: Chemistry and Biology. 2007:157-177. DOI: 10.1007/978-1-4020-5799-1_8

[20] Abiala MA, Oleru K, Balogun T, Saharia M, Opere B, Sahoo L. Soil borne Fusarium solani exhibited pathogenic effect on tomato cultivars in Nigeria. Archives of Phytopathology and Plant Protection. 2021;**54**(3-4):137-151

[21] Yadeta KA, Thomma BPHJ. The xylem as battleground for plant hosts and vascular wilt pathogens. Frontiers in Plant Science. 2013;**4**(APR):1-12. DOI: 10.3389/fpls.2013.00097

[22] Siegel-Hertz K, Edel-Hermann V, Chapelle E, Terrat S, Raaijmakers JM, Steinberg C. Comparative microbiome analysis of a Fusarium wilt suppressive soil and a Fusarium wilt conducive soil from the Châteaurenard region. Frontiers in Microbiology. 2018;**9**(APR):1-16. DOI: 10.3389/fmicb.2018.00568

[23] Soltanzadeh M, Soltani Nejad M, Shahidi Bonjar GH. Application of Soilborne Actinomycetes for Biological Control against Fusarium Wilt of Chickpea (Cicer arietinum) caused by Fusarium solani fsp pisi. Journal of Phytopathology. 2016;**164**(11-12):967-978. DOI: 10.1111/jph.12517

[24] Song W, Zhou L, Yang C, Cao X, Zhang L, Liu X. Tomato Fusarium wilt and its chemical control strategies in a hydroponic system. Crop Protection. 2004;**23**(3):243-247. DOI: 10.1016/j.cropro.2003.08.007

[25] Chauhan MS, Yadav JPS, Gangopadhyay S. Chemical control of soilborne fungal pathogen complex of seedling cotton. Tropical Pest Management. 2008;**34**(2):159-161. DOI: 10.1080/09670878809371233

[26] Woltz SS, Engelhard AW. Fusarium wilt of chrysanthemum: Effect of Nitrogen Source and Lime on Disease Development. Phytopathology. 1972;**63**:155-157

[27] Chai X, Zhou T, Liu Y. Effects of nitrogen deficiency induced by straw decomposition after incorporation into soil on the autophagy and pathogenicity of Fusarium graminearum based on an off-line simulation. Journal of Phytopathology. 2021;**169**(4):239-246

[28] Foster RE, Walker JC. Predisposition of tomato Fusarium wilt. Journal of Agricultural Research. 1947;**74**(165):165-185

[29] Sullivan P. Sustainable Management of Soilborne Plant Diseases. Washington, DC, USA: ATTRA, USDA's Rural Business Cooperative Service; 2001 https://attra.ncat.org/

[30] Duffy BK, Défago G. Macro- and microelement fertilizers influence the severity of fusarium crown and root rot of tomato in a soilless production system. HortScience. 1999;**34**(2): 287-291. DOI: 10.21273/hortsci.34.2.287

[31] Fan P et al. Crop rotation suppresses soilborne Fusarium wilt of banana and alters microbial communities. Archives of Agronomy and Soil Science. 2020:1-13

[32] Panth M, Hassler SC, Baysal-Gurel F. Methods for management of soilborne diseases in crop production. Agric. 2020;**10**(1):16. https://doi.org/10.3390/agriculture10010016

[33] Sun K et al. Peanut preinoculation with a root endophyte induces plant resistance to soilborne pathogen Fusarium oxysporum via activation of salicylic acid-dependent signaling. Plant and Soil. 2021;**460**(1):297-312