International Journal of Research in Agricultural Sciences
Volume 12, Issue 1, ISSN (Online): 2348 – 3997

Fusarium Wilt Disease of Vegetable Crops and its Management through Biocontrol Agent: A Review

Nikhat Begum[1], Merajul Islam Robab[2], Waseem Uddin Md[3*], S. Maqbool Ahmed[4] and Mohammad Danish[5]

[1,2,4,5]Department of Botany, School of Sciences, Maulana Azad National Urdu University, Hyderabad-500032, India.

[3]Department of Genetics & Biotechnology, Osmania University, Hyderabad-500007, India.

[*]Corresponding author email id: waseem.genetics@gmail.com

Date of publication (dd/mm/yyyy): 07/02/2025

***Abstract* – *Fusarium* wilt disease is a destructive plant disease and it affects a wide range of vegetable crops. It impacts many important crops, including field crops, ornamental plants, fruits, and vegetables. The disease is caused by vascular wilt pathogens in the soil called Fusarium species. *Fusarium* spp. in particular are among the most significant and toxic organisms that cause plant diseases, impacting almost all commercially important plant species. *Fusarium* spp. produce macro conidia, microconidia, and chlamydospores, and it act as propagules infect host plant. *Fusarium* spp. identified. saprophytic, parasitic and dormant three stages in the life cycle. The presence of reddish-brown discoloration in the xylem vessels, yellowing and wilting of the leaves, reduced growth rate, and decay of the roots or stems are indicative of fusarium wilt. The development of fungal growth on the outer surface of damaged stems. Plants become challenging to manage *Fusarium* spp. invade the roots and proliferate in the vascular tissues, disrupting the water-conducting capillaries of the plant. Due to the soil-borne nature of this plant pathogen, chemical fungicides are rendered useless because the spores can live in the soil for many years. The physical, chemical, and cultural techniques used to manage *Fusarium* wilt disease are not only expensive but also ineffective. This makes the disease hard to manage. The most effective method to manage *Fusarium* wilt disease is through biocontrol. Both pathogenic and non-pathogenic isolates are found in the same environment and they both infiltrate plant roots. Many attempts have been made to employ non-pathogenic isolates as biocontrol agents to treat Fusarium wilt infestations, as they have comparable nutritional and environmental needs. This review focuses on biocontrol techniques such as bacterial biocontrol, that are used to manage *Fusarium* wilt disease. (*Pseudomonas* species, *Bacillus* species, *Rhizobiu-m* species), fungal bio-control (*Trichoderma* species), AMF fungus.**

***Keywords* – *Fusarium*, Wilt Disease, Biological Control, Vegetable Crops.**

I. Introduction

A vast range of vegetables are produced in large quantities in India. It makes a substantial contribution to the domestic and international vegetable markets. India ranks the second-largest producer with 16% of global vegetable production in the world. Plant diseases are a global concern to agricultural productivity and cause significant losses in vegetable output. Diseases cause losses in vegetable harvests of up to 40-60% annually. Vegetable crops are more susceptible to a wide range of diseases caused by bacteria, viruses, nematodes, phytoplasma, fungus, and viroid. (Tripathi et al.., 2024). The main things restricting agricultural output are these diseases. Plant diseases cause around 10% of the losses in plant productivity worldwide. Farm productivity and quality can be severely hampered by fungus-related plant diseases. The global economy, food security, and the prevalence of diseases transmitted by soil could all be negatively impacted by climate change. As part of its worldwide nutrition and health initiatives. The World Health Organization (WHO) and the Food and Agriculture Organization (FAO) recommend eating more vegetables. Vegetable crops have been severely harmed by fungi like *Alternaria, Aschochyta, Colletotrichum, Didymella, Phoma, Phytophthosra, Pythium, Rhizoctonia, Sclerotinia, and Sclerotium*. [2].

Fusarium spp.

Fusarium fungus belong to the Class Ascomycetes and family Hypocreaceae [3]. Fusarium species can be found in a wide range of environments, including the tropics, temperate zones, deserts, alpine regions, and polar regions with harsh climates. Certain species of this fungus produce mycotoxins such as fumonisins, zearalenones, and trichothecenes, and it infect seeds. Their effective spore distribution techniques and ability to adapt a broad spectrum of substrates help to explain. Fusarium species are found around the world [4]. There are presently more than 20 species in the genus Fusarium [5]. Fusarium solani, Fusarium oxysporum, Fusarium equisetti, and Fusarium chlamydosporum are the most common species [6]. The primary cause of fusarium wilts is F. oxysporum. [7]. Numerous pathogenic species of this fungus can infect plants and produce wilts in crops that are important to the economy. Soil-borne pathogen Fusarium oxysporum, a facultative fungus, produces significant economic losses across several crops [8]. There are three stages in the life cycle of Fusarium species: dormant, parasitic, and saprophytic [9]. The dormant period is characterized by the repression and germination of latent soil forms. The phases of the parasitic stage are entering root, colonizing root cortex and endodermis, migrating to the xylem, colonizing the stems and leaves in the xylem, symptoms developing, and finally host death. They grow into new hyphae and puncture surrounding vascular components to continue colonization and transmit infection. Fusarium hyphae multiplied within the cell apoplast, causing major cytological changes that eventually led to the emergence of symptoms [10]. There are many things that can cause an infected plant's water economy to break down, such as mycelia, spores, gels, gums, tyloses, and neighboring parenchyma cells from the host plant multiplying in an effort to defend itself crushing the vessels [11]. As a result, the plant initially wilts its lowest branches before dying as a whole.

Table 1. Diseases caused by *Fusarium* spp. in different vegetable crop.

S. No	Vegetable	Disease	Causal Organism	References
1	Tomato (*solanum lycopersicum*)	*Fusarim* wilt of Tomato	*Fusarium oxysporum*	[12]
2	Brinjal (*solanum melongena L.)*	*Fusarim* Wilt of Brinjal	*Fusarium oxysporum*	[13]
3	Lettuce *(Lactuca sativa)*	*Fusarium* wilt of lettuce	*Fusarium oxysporum f. sp lactucae*	[14]
4	Onion (*Allium cepa)*	*Fusarium* wilt of onion	*Fusarium oxysporum f. sp cepae*	[15]
5	Potato (*solanum tuberosum*)	Fusarium wilt of potato	*Fusarium oxysporum f.sp tuberosi*	[16]
6	Pepper (*Capsicum annum*)	*Fusarium* wilt of capsicm	*Fusarium spp.*	[17]
7	Watermelon (*Citrullus lanatus*)	*Fusarium* Wilt on Cucurbits	*Fusarium Oxysporum f.sp. niveum*	[18]
8	Cabbage *(Brassica oleracea*)	*Fusarium* wilt of crucifers	*Fusarium. Conglutinans*	[19]
9	Bean (*phaseolus vulgaris*)	*Fusarium* wilt of bean	*F.oxysporumf. sp phaseoli*	[20]
10	Cauliflower (*Brassica oleraceae*)	*Fusarium wilt of cauliflower*	*Fusarium oxysporum f. sp. conglutinans*	[21]

II. Bio-Control Agent

Non-pathogenic Fusarium spp. a Biological Control

Plant disease is not induced by non-pathogenic *Fusarium* strains. These strains may be naturally occurring or introduced into the soil as biocontrol agents. Non-pathogenic infections invade epidermis, and veins [22]. The non-pathogenic isolates *Fusarium* in the treatment of *Fusarium* wilts has been extensively investigated [23]. Pathogenic and nonpathogenic isolates live together in the same environment when they invade plant root systems. Non-pathogenic isolates have been investigated in a variety of ways as potential biocontrol agents for infestations of *Fusarium* wilt because they share similar nutritional and abiotic requirements with pathogenic isolates [23]. Plant disease is not induced by non-pathogenic *Fusarium* strains. These strains may be naturally occurring or introduced into the soil as biocontrol agents. Non-pathogenic infections invade the brain, the epidermis, and veins [22]. The non-pathogenic F. *oxysporum* strains to prevent *Fusarium* illnesses stems from research on soils that naturally inhibit *Fusarium* wilts [24]. The non-pathogenic strain demonstrates defensive responses comparable to pathogenic infections. Sensitization stimulates immunological responses, allowing plants to better battle pathogenic strains. Plants rely on their cell walls to defend themselves against diseases. The main barrier prevents pathogens from entering plant scells [25] revealed that avirulent *Fusarium* achieve success through a variety of methods, including resource and space competition, as well as systemic resistance.Extra compounds that are toxic to fungi and bacteria are present in culture filtrates, which are produced by non-infective isolates.Among the constituents are anthroquinones, alkaloids, flavonoids, tannins, saponins, and phenols [26]. Root-colonizing *Fusarium* strains can have a major impact on soil ecology and plant health.

Table 2. Non-pathogenic *Fusarium f.sp uses* as a biological control.

S. No	***Fusarium spp.***	Vegetable	Disease	References
1	*F. oxysporum*	Eggplant	Verticillium wilt	[27]
2	*F. oxysporum*	Banana	*Fusarium wilt of banana*	[28]
3	*Fusarium oxysporum f. sp. niveum* (FON)	Water melon	*Fusarium* wilt of water melon	[29]
4	*F. oxysporum*	Tomato	*Sclerotium, sclerotiorum, Phytophthora erythroseptica*, Pythium ultimum	[26]
5	*Fusarium oxysporum* FO12	Olive	*Verticillium dahliae*	[30]
6	F. oxysporum	Tomato	root-knot nematode	[26]
7	*F. oxysporum*	Eggplant	*Verticillium dahliae*	[31]
8	*F. solani f. sp. Cucurbitae*	Pumpkin	*Fusarium* foot and fruit	[32]
9	*F. oxysporum*	Banana	*F. oxysporum f. sp. cubense*	[33]
10	*F. oxysporum* Strain Fo47	Sugar Beets	*Rhizoctonia* disease	[34]
11	Fusarium *oxysporum* f. sp. *niveum* race 2 (FON2)	Water melon	*Fusarium* wilt	[35]
12	*Fusarium clavum (F. incarnatum-equiseti* species complex 5	sugar beet	Seedling rot	[36]

S. No	*Fusarium spp.*	Vegetable	Disease	References
13	F. oxysporum isolate (F.o-T5)	Tomato	*Fusarium* rot	[26]
14	*Fusarium oxysporum*	Flax	*Fusarium* wilt of flax	[25]
15	*F. oxysporum* Fo47	Pepper	Verticillium wilt	[37]
16	*F.oxysporum f. sp. radicis-cucumerinum* strain	Cucumber	Cucumber root-rot	[38]
17	F. *oxysporum*	Pisum sativum	*Fusarium wilt of pea*	[39]
18	*F. oxysporum* F221-B	Lettuce	*Fusarium* root rot	[40]
19	Fusarium sp.	Watermelon	*Fusarium* wilt	[35]
20	*F. solani f. sp cucurbitaceae* race 1 and race 2	Pumpkins	*Fusarium* fruit rot (FFR)	[41]

III. Bacterial Bio-Control

Bacillus spp.

The bacterial genus Bacillus spp. is one of the most commonly utilized endophytes as a biocontrol agent among the numerous endophytes linked to plants that do not harm the host. Bacillus species are a suitable choice for bio-control agents because they can form endospores, which shields them from harsh environmental conditions. The creation of siderophores and extracellular metabolites may be the source of Bacilli's antagonistic impact [42]. According to [42], *Bacillus* may encourage plants to develop induced systemic resistance (ISR), strengthening their resistance against bacterial, fungal, and viral illnesses. Pathogenic fungi and bacteria can be inhibited in their growth by bacterial species such *as B. amyloliquefaciens, B. cereus, B. pumilius, B. licheniformis, and B. subtilis* [43]. Bacillus species use a variety of strategies to inhibit pathogenic fungi growth, including antibiosis (antibiotics), enzyme synthesis, competition (space and nutrition), parasitism (bacteria attach to germinated surfaces and release catalytic enzymes), systemic resistance in plants (via the jasmonic acid pathway) and siderophore synthesis [43], [44]. While certain populations may directly increase plant nutrition intake through rhizobial and mycorrhizal symbiosis or direct atmospheric nitrogen fixation, others may create antimicrobial chemicals that suppress pests and plant diseases.

Table 3. Bacillus spp to control Fusarium spp. in crop plants.

S. No	Bacillus spp	Disease in Plant	Plant Pathogen	References
1	*B. subtilis*	Fusarium wilt of chickpea	*Fusarium oxysporum f. sp ciceris*	[45]
2	*B. amyloliquefaciens* FZB42	Wilt	*F. oxysporum*	[46]
3	*Bacillus subtilis* CAS15	*Fusarium wilt pepper*	*Fusarium oxysporum* Schl. f.sp. *capsica*	[47]
4	Bacillus veiezensis WB	*Fusarium* wilt of water melon	*Fusarium oxysporum f. sp. niveum*	[48]
5	*B. subtilis B579*	Fusarium wilt of cucumber	*Fusarium oxysporum*	[49]
6	*Bacillus amyloliquefaciens* DHA55	Fusarium wilt of watermelon	*Fusarium oxysporum* f. sp. *niveum*	[29]

S. No	Bacillus spp	Disease in Plant	Plant Pathogen	References
7	*Bacillus thuringiensis*	Fusarium Wilt of Tomato	*Fusarium spp.*	[50]
8	Bacillus strain PE1,	Fusarium Wilt of potato	*Fusarium languescens*	[51]
9	*B. subtilis* Qst713	Fusarium wiltof lettuce	*Fusarium oxysporum f. sp. lactucae,*	[52]
10	*Bacillus subtilis* strain 1JN2	Fusarium Wilt of cucumber	*Fusarium oxysporum f. sp. cucumerinum*	[53]
11	*Bacillus siamensis YC-9*	Fusarium wilt in cucumber	*Fusarium oxysporum f.sp cucumericum*	[53]
12	*Bacillus sp.* B67	Fusarium Wilt of Watermelon	*F. oxysporum f. sp. Niveum*	[54]
13	*Bacillus amyloliquefaciens* Strain W19	Fusarium Wilt of Banana	*Fusarium oxysporum f. sp. cubense (FOC)*	[55]
14	*Bacillus subtilis*	Fusarium wilt of lettuce	*Fusarium oxysporum f. sp. lactucae*	[49]
15	*B. subtilis* SQR 9	Fusarium wilt of cucumber	*Fusarium spp.*	[56]

Psuedomonas spp.

The Pseudomonas species generate a variety of antibiotics that directly inhibit the development of the Fusarium fungus. Substances such as phenazines, pyoluteorin, and pyrrolnitrin efficiently reduce Fusarium oxysporum. Which are among these antibiotics. Siderophores are substances made by these bacteria that chelate iron from the surrounding environment. Siderophores effectively starve the pathogen by sequestering the iron, which prevents the fungi from growing because iron is necessary for fungal growth. Pseudomonas species compete with pathogenic fungi for nutrients and accessible space, preventing their development and spread. Enzymatic Compound Production: Some strains of Pseudomonas produce chitinases and proteases, which degrade the cell walls of fungal pathogens and prevent them from growing any further. Pseudomonas species that have been isolated from the tomato rhizosphere generate HCN, which has the ability to suppress Fusarium wilt. P. fluorescens is the most commonly used bacterium to treat plant problems in soil. Many P. fluorescens strains have been identified from plant roots and rhizosphere soil during the past 30 years, and these strains have demonstrated potential as bio-control agents against soil-borne and foliar diseases [57].

Table 4. Psuedomonas sp. uses as bio control agent.

S. No	Pseudomonas sp.	Disease in Plant	Plant Pathogen	References
1	*Pseudomonas aeruginosa strain91*	Fusarium wilt of Banana	*Fusarium oxysporum f. sp.cubensei*	[58]
2	*Pseudomonas fluorescens*	Fusarium wilt of cucumber	*Fusarium oxysporum*	[27]
3	*P. fluorescens*	Fusarium wilt of tomato	*Fusarium oxysporum f.sp oxysporum*	[59]
4	*Pseudomonas fluorescens*, six isolates (Pf4, Pf13, Pf14, Pf18, Pf19, and Pf20)	Fusarium wilt of chick pea	*Fusarium oxysporum*	[60]
5	*Pseudomonas spp.*	Fusarium wilt of lettuce	*Fusarium oxysporum f. sp lactucae*	(Lopez-Reyes, G

S. No	Pseudomonas sp.	Disease in Plant	Plant Pathogen	References
				Gilardi (et al., 2014))
6	*Pseudomonas spp.Pf12*	Onion Basal Rot	*Fusarium oxysporum. f. sp.cepae*	[63]
7	*Pseudomonas fluorescens* strain Pf1	Fusarium wilt of bean	*Fusarium oxysporum f. sp phaseoli*	[64]
8	*Pseudomonas aeroginosa strains91*	Fusarium wilt of banana	*Fusarium oxysporum f. sp cubense*	(Xie et al., 2023)
9	*Psuedomonas aeroginosa PM12*	Fusarium wilt of tomato	*Fusarium oxysporum f. sp lycopersici*	[65]
10	*Pseudomonas strains*	Fusarium wilt watermelon	*Fusarium oxysporum f. sp. niveum*	[49]

Rhizobium spp.

Rhizobium species are being used against *Fusarium* wilt and other plant diseases. *Rhizobium spp.* are well-known for their symbiotic connection with leguminous plants and their function in nitrogen fixation. It is commonly recognized that rhizobia are a great biological control agent against soilborne diseases and a source of nitrogen for plants [66]. Through N2 fixation and increased nutrient and mineral availability, rhizobia can enhance plant development. Comparably, it has been demonstrated that Rhizobia promote plant growth by secreting alkaloids, flavonoid and secondary metabolites. Which strengthen the plant's defenses against infections [67]. *Fusarium* wilt decreased tomato plants and co-inoculated with *Rhizobium* and plant growth-promoting rhizobacteria [27]. Rhizobium spp. improved tomato providing the benefits of higher production and resistance to disease. *Rhizobium leguminosarum* helped chickpea plants against *Fusarium* wilt. The generation of siderophores and competition for root colonization sites were credited with the biocontrol's effectiveness. *Rhizobium phaseoli* was found to lessen the severity of *Fusarium* wilt in common bean plants. *Rhizobium* species have a lot of potential for use as biocontrol agents against *Fusarium* wilt because they produce antimicrobials, induce systemic resistance, and compete with other plants for nutrients.

Table 5. List of rhizobium spp. and host uses as bio control agent.

S. No	Genus	Species/Strain	Host Plant	Reference
1	*Bradyrhizobium spp.*	SEMIA 5080, SEMIA 5079, SEMIA 5019 and SEMIA 587,	Soyabean	[68]
2	*Rhizobacteria*	B1: Rhizobium pusense and B2: Burkholderia *contaminans*	Lentil	[69]
3	*Rhizobium*	*Rhizobium* sp. L5	Tomato	[70]
4	*Rhizobium*	*Rhizobium* sp. (isolate b1)strain	Tomato	[71]
5	*Bradyrhizobium*	*Bradyrhizobium sp.* IC-4059	Pigeon pea	[72]
6	*Mesorhizobium sp*	*Mesorhizobium sp*	Pigeon pea	[73]
7	*Bradyrhizobium*	*Bradyrhizobium diazoefficiens*	Soybean	[74]
8	*Rhizobium*	*Rhizobium bangladeshense*	Lentil	[74]
9	*Sinorhizobium/Ensifer*	Ensifer meliloti comb. Medicago sativa	Aifaaifa	[74]

S. No	Genus	Species/Strain	Host Plant	Reference
10	*Mesorhizobium*	*Mesorhizobium mediterraneum*	Chickpea	[74]
11	*Rhizobium*	Rhizobium spp TZSR12C Rhizobium sp. TZSR25B	Soyabean	[75]
12	*Bradyrhizobium sp. ,*	*Bradyrhizobium* sp. TZSR41A,	Soyabean	[75]
13	*Rhizobium leguminosorum*	*Rhizobium leguminosorum*	Chickpea	[76]
14	*Rhizobium*	*Rhizobium* strain, RH 2	Pigeon pea	[77]
15	*Bradyrhizobium spp.*	*Macrophomina phaseolina, Rhizoctonia solani, Fusarium solani and F. oxysporum*	Soyabean	[78]

IV. Fungal Bio-Control

Trichoderma spp.

Fungi are found in agricultural soils and decaying wood. Fungi not only function as biocontrol agents but also promote plant growth, development, and resistance. *Trichoderma spp*. are facultative, anaerobic, cosmopolitant agricultural output, according to recent studies. Tricoderma spp. has the potential to serve as an alternative to chemical control of tomato wilt disease. Mycoparasitism, antibiotics and nutrient competition are the biocontrol agents that also cause plants to develop defense or systemic resistance responses. *Trichoderma spp.* is one of the best biocontrol agents for controlling plant pathogenic fungi. It has been used for a long time. It is normal practice to employ *Trichoderma spp*. to prevent and stimulate crop development. Roughly 90% of researched fungal biological control agents (BCAs) and over 60% of registered biofungicides globally are attributed to *Trichoderma* [79]. Only a small number of the approximately 200 *Trichoderma* species have been commerciali--zed as BCAs [80]. Through mycoparasitism, competition, and antibiosis, trichoderma suppresses pathogens and induces defensive reactions in plants ([81]; [82]. Another possible strategy is to employ *trichoderma* as a seed treatment. This is especially useful for crops that are drilled straight into the soil, such field/row crops and some horticultural crops, as the soils are likely to contain phytopathogeni fungi. and [28]observed an increase in defense enzymes such as Peroxidase and Phenylalanine Ammonia Lyase (PAL) and a higher total phenolic content in comparison to the control T. viride NRCB1 was used as the rice chaffy grain formulation and Foc was used for the challenge inoculation in cv. Rasthali.

Table 6. List of Tricoderma spp. for the management of Fusarium spp. in vegetable crops.

S. No	Vegetables	Disease	Pathogen	Bioagents	References
1	Cucumber	Fusarium wilt of Cucumber	*Fusarium oxysporumn f. sp. cucumerinum*	*T. harzianum* T. atroviride, T. virens	[83]
2	Brinjal	Fusarium wilt of Brinjal	*F. solani*	*T. viride, T. virens*	[84]
3	Tomato	Fusarium wilt of Tomato	*F.oxysporum f. sp lycopersici*	*Trichoderma harzianum (ANR-1)*	[85]
4	Bottle gourd	Fusarium wilt of bottlegourd	*F. oxysporum*	*T. viride, T. virens, B. subtilis*	[86]
5	Cow pea	Fusarium wilt of cow pea	*F. oxysporum*	*T.harzianum, T. viride*	[87]

S. No	Vegetables	Disease	Pathogen	Bioagents	References
6	Cucumber	Fusarium wilt of Cucumber	*Fusarium oxysporum*	*T. longibrachiatum NGJ167 (Rifai)*	[88]
7	*Chilli*	Fusarium wilt of Chilli	*Fusarium solani*	*T. harzianum T. viride,*	[88]
8	*Onion*	Fusarium wilt of *onion*	*Fusarium oxysporum*	*Tricoderma spp.*	[89]
9	Tomato	Fusarium wilt of Tomato	*Fusarium solani*	*T. viride, T. harzianum*	[90]
10	*Watermelon*	Fusarium wilt of *watermelon*	*Fusarium oxysporum f. sp. niveum*	*Trichoderma harzianum* SQR-T037s	[91]

Arbuscular Mycorrhizal Fungi:

Alternative biological control strategies, such as the use of symbiotic endophytic fungi like *arbuscular mycorrhizal fungi* (AMF), have evolved to solve these issues. Classified as members of the phylum Glomeromycota, AMF are essential to plant development because they boost growth and increase the plant's resilience to a variety of pests. AMF are helpful biocontrol agents that improve plant disease resistance, provide plant nourishment, and regulate microbial balance of the mycorrhizosphere [92]. Numerous investigations have revealed a correlation between enhanced disease resistance and higher mineral uptake in AMF-colonized plants. The potential for using AM fungi's preventive qualities in concert with other rhizospheric microorganisms that have antagonistic against root diseases utilized in biological control approaches.

Table 7. List of soil borne disease of vegetables managed by AMF.

S. No	Name of Arbuscular mycorhizal fungi	Plant	Pathogen	References
1	*Funneliformis mosseae*	*Onion*	*F. oxysporum* f. sp. *cepae* (FOC)	[93]
2	Glomus etunicatum, G. leptotichum and Rhizophagus intraradices	Tomato	Fusarium oxysporum f. sp. lycopersici	[94]
3	Rhizophagus irregularis	Banana	Fusarium oxysporum f. sp. cubense	[95]
4	*Funneliformis mosseae*	Pepper	*Verticillium dahliae* (Vd)	[96]
5	*Glomus intradices*	*Pepper*	*Fusarium solani (48-and 18 Fusarium and F-147)*	[97]
6	*Rhizophagus irregularis*	Olive	*V. dahliae*	[96]
7	*Funneliformis mosseae* and *Glomus fasciculatum*	Tomato	Fusarium	[98]
ss8	*Glomus* spp.	Banana	*Fusarium oxysporum* f. sp. *cubense*	[99]
9	*Glomus mosseae, Glomus hoi,*	Chickpea	*Fusarium oxysporum f. sp. ciceris*	[62]
10	*Glomus and Acaulospora, Entrophospora*	Chickpea	*F. solani*	[100]

V. CONCLUSION

The soil-borne fungus *Fusarium oxysporum* is the source of the devastating plant disease fusarium wilt. Numerous vegetable crops are impacted, such as lettuce, tomatoes, cucumbers, and peppers. The pathogen enters the plant by its roots and settles in the vascular system, causing wilting, leaf yellowing, and, in many cases, plant death. Because *Fusarium* wilt hosts is persistent in the soil, managing the disease can be difficult. Because of its capacity to contaminate plant products and ruin agricultural yields, *Fusarium* species play a major role in international trade and socioeconomic processes related to food security. Micro-evolution and the development of novel infections will continue to lead to the formation of new Fusarium pathogen populations. In order to ascertain the function of non-host crops and the duration of chlamydospore survival in soil, study on the biology of the fungus is required. On the other hand, biocontrol drugs provide a long-term and efficient way to control this illness. A viable, long-term solution for controlling *Fusarium* wilt disease in vegetable crops is provided by biocontrol agents. Utilizing naturally occurring organisms like *Trichoderma*, *Bacillus*, *Pseudomon--as* and AMF, it is possible to efficiently control populations and improve the health of plants. These biocontrol techniques support environmental sustainability, lessen the need for chemical pesticides, and safer food production. By these measures, biocontrol can contribute significantly to sustainable agriculture, protecting crop.

REFERENCES

[1] A.N. Tripathi, S. Maurya, K.K. Pandey, and T.K. Behera, “Global Scenario of Vegetable Fungal Diseases,” Vegetable Science, vol. 51, no. Special Is, pp. 54-65, Feb. 2024, doi: 10.61180/vegsci.2024.v51.spl.06.
[2] G. Gilardi, M. Pugliese, A. Garibaldi, and M.L. Gullino, “Emerging vegetable crop diseases and their management options,” CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, vol. 19, no. 1, Jan. 2024, doi: 10.1079/CABIREVIEWS.2024.0007.
[3] J.I. Pitt, A.D. Hocking, K. Bhudhasamai, B.F. Miscamble, K.A. Wheeler, and P. Tanboon-Ek, “The normal mycoflora of commodities from Thailand. 2. Beans, rice, small grains and other commodities,” Int J Food Microbiol, vol. 23, no. 1, pp. 35–53, 1994, doi: 10.1016/0168-1605(94)90220-8.
[4] P.E. Nelson, M.C. Dignani, and E.J. Anaissie, “Taxonomy, biology, and clinical aspects of Fusarium species,” Clin Microbiol Rev, vol. 7, no. 4, pp. 479–504, 1994, doi: 10.1128/CMR.7.4.479.
[5] H. Wang et al., “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,” J Clin Microbiol, vol. 49, no. 5, pp. 1890–1898, 2011, doi: 10.1128/JCM.02415-10.
[6] “Burgess, L.W., Summerell, B.A., Bullock, S., Gott, K.P. and Backhouse, D. (1994) Laboratory anual for Fusarium Research. Third edition, Sydney, Australia. References-Scientific Research Publishing.” Accessed: Dec. 30, 2024. [Online]. Available: https://www.scirp.org/reference/referencespapers?referenceid=582728
[7] B. Lievens, M. Rep, and B.P.H.J. Thomma, “Recent developments in the molecular discrimination of formae speciales of Fusarium oxysporum,” Pest Manag Sci, vol. 64, no. 8, pp. 781-788, 2008, doi: 10.1002/ps.1564.
[8] V. Edel-Hermann and C. Lecomte, “Current status of fusarium oxysporum formae speciales and races,” Phytopathology, vol. 109, no. 4, pp. 512-530, Apr. 2019, doi: 10.1094/PHYTO-08-18-0320-RVW.
[9] “Okungbowa, F.I., & Shittu, H.O. (2012). Fusarium wilts: An overview. Environ. Res. J, 6(2), 83-102”.
[10] [10] S. Walter, P. Nicholson, and F.M. Doohan, “Action and reaction of host and pathogen during Fusarium head blight disease,” New Phytol, vol. 185, no. 1, pp. 54–66, 2010, doi: 10.1111/j.1469-8137.2009.03041.x.
[11] G.N. Agrios, “Plant Pathology,” in Plant Pathology, United States: Elsevier Science & Technology, 2005.
[12] T.R. Aalders et al., “Specific members of the TOPLESS family are susceptibility genes for Fusarium wilt in tomato and Arabidopsis,” Plant Biotechnol J, vol. 22, no. 1, pp. 248–261, 2024, doi: 10.1111/pbi.14183.
[13] R. Kumar et al., “Fusarium Infection of Eggplant: Disease Cycle and Management Strategies,” in Molecular Dynamics of Plant Stress and its Management, Singapore: Springer Nature Singapore, 2024, pp. 281-306. doi: 10.1007/978-981-97-1699-9_12.
[14] G. Gilardi, C. Pons, B. Gard, S. Franco-Ortega, and M.L. Gullino, “Presence of Fusarium Wilt, Incited by Fusarium oxysporum f.sp. lactucae, on Lettuce in France,” Plant Dis, vol. 101, no. 6, p. 1053, 2017, doi: 10.1094/PDIS-12-16-1815-PDN.
[15] K. Sakane, T. Ueno, M. Shigyo, K. Sasaki, and S.-I. Ito, “Pathogenicity Differentiation of Fusarium spp. Causing Fusarium Basal Rot and Wilt Disease in Allium spp,” Pathogens (Basel), vol. 13, no. 7, p. 591, 2024, doi: 10.3390/pathogens13070591.
[16] A. Kerkeni, M. Daami-Remadi, N. Tarchoun, and M. B. Khedher, “In vitro and in vivo Suppression of Pythium ultimum the Causal Agent of the Cucumber Damping-Off by Some Compost Fungi,” Asian Journal of Agricultural Research, vol. 1, no. 3, pp. 50–58, 2007.
[17] I. Engalycheva et al., “Fusarium Species Causing Pepper Wilt in Russia: Molecular Identification and Pathogenicity,” Microorganisms (Basel), vol. 12, no. 2, p. 343, 2024, doi: 10.3390/microorganisms12020343.
[18] M.Z. Rahman et al., “Biology, Diversity, Detection and Management of Fusarium oxysporum f. sp. niveum Causing Vascular Wilt Disease of Watermelon (Citrullus lanatus): A Review,” Agronomy, vol. 11, no. 7, p. 1310, 2021, doi: 10.3390/agronomy11071310.
[19] T. Jelinek, M. Koudela, V. Kofranková, and J. Salava, “Effect of temperature on severity of Fusarium wilt of cabbage caused by Fusarium oxysporum f. sp. conglutinans,” Eur J Plant Pathol, vol. 155, no. 4, pp. 1277-1286, 2019, doi: 10.1007/s10658-019-01855-3.
[20] E.D. de Toledo Souza, P.M. da Silveira, A.C. Cafe Filho, and M. Lobo Junior, “Fusarium wilt incidence and common bean yield according to the preceding crop and the soil tillage system,” Pesqui Agropecu Bras, vol. 47, no. 8, pp. 1031-1037, 2012, doi: 10.1590/S0100-204X2012000800002.
[21] J. Ling et al., “Genetic Diversity and Population Structure of Fusarium oxysporum f. sp. conglutinans Race 1 in Northern China Samples,” Journal of Fungi, vol. 8, no. 10, p. 1089, Oct. 2022, doi: 10.3390/JOF8101089/S1.
[22] A. Sajeena, D. S. Nair, and K. Sreepavan, “Non-pathogenic Fusarium oxysporum as a biocontrol agent,” Indian Phytopathol, vol. 73, no. 2, pp. 177–183, 2020, doi: 10.1007/s42360-020-00226-x.
[23] S. Patil and S. Sriram, “Biological control of Fusarium wilt in crop plants using non-pathogenic isolates of Fusarium species,” Mar. 01, 2020, Springer. doi: 10.1007/s42360-020-00202-5.

[24] C. Alabouvette and C. Olivain, "Modes of action of non-pathogenic strains of Fusarium oxysporum in controlling Fusarium wilts," Plant protection science, vol. 38, no. SI 1-6th Conf EFPP, pp. 195–199, 2002, doi: 10.17221/10354-PPS.
[25] W. Wojtasik et al., "Endophytic non-pathogenic Fusarium oxysporum reorganizes the cell wall in flax seedlings," Front Plant Sci, vol. 15, pp. 1352105–1352105, 2024, doi: 10.3389/fpls.2024.1352105.
[26] L.S. Nawar, "Phytochemical and SDS-dissociated proteins of pathogenic and nonpathogenic Fusarium oxysporum isolates".
[27] J.A. Patil, S. Yadav, and A. Kumar, "Management of root-knot nematode, Meloidogyne incognita and soil borne fungus, Fusarium ox--ysporum in cucumber using three bioagents under polyhouse conditions," Saudi J Biol Sci, vol. 28, no. 12, pp. 7006–7011, 2021, doi: 10.1016/j.sjbs.2021.07.081.
[28] R. Thangavelu and M.M. Mustaffa, "First Report on the Occurrence of a Virulent Strain of Fusarium Wilt Pathogen (Race-1) Infecting Cavendish (AAA) Group of Bananas in India," Plant Dis, vol. 94, no. 11, pp. 1379-1379, Nov. 2010, doi: 10.1094/PDIS-05-10-0330.
[29] D.M.K. Al-Mutar, N.S.A. Alzawar, M. Noman, Azizullah, D. Li, and F. Song, "Suppression of Fusarium Wilt in Watermelon by Bacillus amyloliquefaciens DHA55 through Extracellular Production of Antifungal Lipopeptides," Journal of fungi (Basel), vol. 9, no. 3, p. 336, 2023, doi: 10.3390/jof9030336.
[30] J. Sevillano-Caño, J. Nunez-Cano, P. Prieto, A. Trapero, A. R. Sánchez-Rodríguez, and C. Agustí-Brisach, "The endophytic role and growth-promoting ability of the nonpathogenic strain Fusarium oxysporum FO12 in herbaceous hosts," Sci Hortic, vol. 332, p. 113220, 2024, doi: 10.1016/j.scienta.2024.113220.
[31] I.S. Pantelides, S.E. Tjamos, I.A. Striglis, I. Chatzipavlidis, and E.J. Paplomatas, "Mode of action of a non-pathogenic Fusarium oxysporum strain against Verticillium dahliae using Real Time QPCR analysis and biomarker transformation," Biological control, vol. 50, no. 1, pp. 30–36, 2009, doi: 10.1016/j.biocontrol.2009.01.010.
[32] Y. Yang, Z. Li, H. Sun, C. Jian, Q. Zhang, and Z. Li, "Identification of Fusarium solani f. sp. cucurbitae Causing Zucchini Fruit Rot in Inner Mongolia, China," Horticulturae, vol. 9, no. 9, p. 1020, 2023, doi: 10.3390/horticulturae9091020.
[33] A. Kumari and H. Kumar, "Association of nonpathogenic fusarium oxysporum species with cultured shoot apices of banana (musa acuminata) cultivars," The Bioscan, vol. 10, no. 2, pp. 629–634, May 2015, Accessed: Dec. 29, 2024. [Online]. Available: https://the bioscan.com/index.php/pub/article/view/1263
[34] F. Nouayti, I. Madani, A. Tahiri, A. Blenzar, and R. Lahlali, "Ability of Non-Pathogenic Fusarium oxysporum Strain Fo47 to Suppress Rhizomania Disease of Sugar Beets in Morocco," Not Sci Biol, vol. 10, no. 1, pp. 137–142, 2018, doi: 10.15835/nsb10110231.
[35] V.E. Thomas and S. Antony-Babu, "Core hyphosphere microbiota of Fusarium oxysporum f. sp. niveum," Environ Microbiome, vol. 19, no. 1, pp. 14–14, 2024, doi: 10.1186/s40793-024-00558-5.
[36] M.F.R. Khan et al., "Fusarium clavum causes sugar beet seedling root rot in Wyoming, USA," Canadian journal of plant pathology, vol. 46, no. 3, pp. 257–264, 2024, doi: 10.1080/07060661.2024.2303650.
[37] J. Veloso, M. Lois, J. Díaz, J.-M. Mérillon, and K. G. Ramawat, "Fusaria Strains as Biocontrol Agents: The Case of Strain Fo47 and Verticillium dahliae," in Plant Defence: Biological Control, in Progress in Biological Control., Cham: Springer International Publish--ing, 2020, pp. 309–331. doi: 10.1007/978-3-030-51034-3_13.
[38] D.M. Afordoanyi, R.G.C. Diabankana, Y.A. Akosah, and S.Z. Validov, "Are formae speciales pathogens really host specific? A broadened host specificity in Fusarium oxysporum f.sp. radicis-cucumerinum," Brazilian journal of microbiology, vol. 53, no. 4, pp. 1745–1759, 2022, doi: 10.1007/s42770-022-00793-3.
[39] A.M. Sampaio et al., "A diversity of resistance sources to Fusarium oxysporum f. sp. pisi found within grass pea germplasm," Plant Soil, vol. 463, no. 1–2, pp. 19–38, 2021, doi: 10.1007/s11104-021-04895-z.
[40] T. Thongkamngam and T. Jaenaksorn, "Efficacy of Culture Filtrate from Fusarium oxysporum F221-B against Plant Pathogenic Fungi In Vitro and Fusarium Root Rot and Wilt Disease in Hydroponics," International Journal of Agricultural Technology, vol. 12, no. 3, pp. 513–526, 2016.
[41] Y. Yang, Z. Li, H. Sun, C. Jian, Q. Zhang, and Z. Li, "Identification of Fusarium solani f. sp. cucurbitae Causing Zucchini Fruit Rot in Inner Mongolia, China," Horticulturae, vol. 9, no. 9, p. 1020, 2023, doi: 10.3390/horticulturae9091020.
[42] D. Miljakovic, J. Marinkovic, and S. Balesevic-Tubic, "The Significance of Bacillus spp. in Disease suppression and growth Promo--tion of Field and Vegetable Crops," Microorganisms (Basel), vol. 8, no. 7, p. 1037, 2020, doi: 10.3390/microorganisms80710 37.
[43] C.F. Ajilogba, O.O. Babalola, and F. Ahmad, "Antagonistic Effects of Bacillus Species in Biocontrol of Tomato Fusarium Wilt," Studies on ethno-medicine, vol. 7, no. 3, pp. 205–216, 2013, doi: 10.1080/09735070.2013.11886462.
[44] S. Ali, S. Hameed, A. Imran, M. Iqbal, and G. Lazarovits, "Genetic, physiological and biochemical characterization of Bacillus sp. strain RMB7 exhibiting plant growth promoting and broad spectrum antifungal activities," Microb Cell Fact, vol. 13, no. 1, pp. 144–144, 2014, doi: 10.1186/s12934-014-0144-x.
[45] K. Karimi, J. Amini, B. Harighi, and B. Bahramnejad, "Evaluation of biocontrol potential of 'pseudomonas' and 'bacillus' spp. against fusarium wilt of chickpea," Aust J Crop Sci, vol. 6, no. 4, pp. 695–703, 2012.
[46] S.P. Chowdhury, A. Hartmann, X. Gao, and R. Borriss, "Biocontrol mechanism by root-associated Bacillus amyloliquefaciens FZB42 - a review," Front Microbiol, vol. 6, pp. 780–780, 2015, doi: 10.3389/fmicb.2015.00780.
[47] X. Yu, C. Ai, L. Xin, and G. Zhou, "The siderophore-producing bacterium, Bacillus subtilis CAS15, has a biocontrol effect on Fusarium wilt and promotes the growth of pepper," Eur J Soil Biol, vol. 47, no. 2, pp. 138–145, 2011, doi: 10.1016/j.ejsobi.2010. 11.001.
[48] Z. Chen, Z. Wang, and W. Xu, "Bacillus velezensis WB induces systemic resistance in watermelon against Fusarium wilt," Pest Manag Sci, vol. 80, no. 3, pp. 1423–1434, 2024, doi: 10.1002/ps.7873.
[49] F. Yang et al., "Mechanism of a novel Bacillus subtilis JNF2 in suppressing Fusarium oxysporum f. sp. cucumerium and enhancing cucumber growth," Front Microbiol, vol. 15, 2024, doi: 10.3389/FMICB.2024.1459906.
[50] Z. Kiani Dehkian, H. Taheri, B. Pakdaman Sardrood, and M. Farkhari, "Controlling Tomato Fusarium Wilt Disease through Bacillus thuringiensis-Mediated Defense Primining," Iran J Biotechnol, vol. 22, no. 1, pp. e3690–e3690, 2024, doi: 10.30498/ijb.2024.3942 91.3690.
[51] B. Valenzuela-Aragon, A. C. Montoya-Martínez, F. I. Parra-Cota, and S. de los Santos-Villalobos, "Genomic Insight into a Potential Biological Control Agent for Fusarium-Related Diseases in Potatoes: Bacillus cabrialesii Subsp. cabrialesii Strain PE1," Horticulturae, vol. 10, no. 4, p. 357, 2024, doi: 10.3390/horticulturae10040357.
[52] G. Gilardi, M. Pugliese, M. L. Gullino, and A. Garibaldi, "Nursery treatments with resistant inducers, soil amendments and biocontrol agents for the management of the Fusarium wilt of lettuce under glasshouse and field conditions," Journal of phytopathology, vol. 167, no. 2, pp. 98–110, 2019, doi: 10.1111/jph.12778.
[53] K. Yang et al., "Joint metabolomic and transcriptomic analysis identify unique phenolic acid and flavonoid compounds associated with resistance to fusarium wilt in cucumber (Cucumis sativus L.)," Front Plant Sci, vol. 15, p. 1447860, 2024, doi: 10.3389/fpls.2024.144 7860.
[54] J. Shafi, Z. Sun, M. Ji, Z. Gu, and W. Ahmad, "ANN and RSM based modelling for optimization of cell dry mass of Bacillus sp. Strain B67 and its antifungal activity against Botrytis cinerea," Biotechnol Biotechnol Equip, vol. 32, no. 1, pp. 58–68, 2018, doi: 10.1080/13

102818.2017.1379359.

[55] B. Wang et al., "Effects of novel bioorganic fertilizer produced by Bacillus amyloliquefaciens W19 on antagonism of Fusarium wilt of banana," Biol Fertil Soils, vol. 49, no. 4, pp. 435–446, 2013, doi: 10.1007/s00374-012-0739-5.

[56] H.-W. Wang, M. Xu, X.-Y. Cai, T. Feng, and W.-L. Xu, "Application of spent mushroom substrate suppresses Fusarium wilt in cucu--mber and alters the composition of the microbial community of the cucumber rhizosphere," Eur J Soil Biol, vol. 101, p. 103245, 2020, doi: 10.1016/j.ejsobi.2020.103245.

[57] R. Vivekananthan, M. Ravi, A. Ramanathan, and R. Samiyappan, "Lytic enzymes induced by Pseudomonas fluorescens and other biocontrol organisms mediate defence against the anthracnose pathogen in mango," World J Microbiol Biotechnol, vol. 20, no. 3, pp. 235–244, 2004, doi: 10.1023/B:WIBI.0000023826.30426.f5.

[58] J. Xie et al., "Pseudomonas aeruginosa Strain 91: A Multifaceted Biocontrol Agent against Banana Fusarium Wilt," Journal of fungi (Basel), vol. 9, no. 11, p. 1047, 2023, doi: 10.3390/jof9111047.

[59] L. Paranthaman et al., "Levering proteomic analysis of Pseudomonas fluorescens mediated resistance responses in tomato during pathogenicity of Fusarium oxysporum f. sp. oxysporum," Front Sustain Food Syst, vol. 7, 2023, doi: 10.3389/fsufs.2023.1157575.

[60] M. Pandey, A.K. Maurya, V. John, and M. Kumar, "Evaluation of different isolates of Pseudomonas fluorescens against Fusarium oxysporum f. sp. ciceri, causing wilt of chickpea (Cicer arietinum L.)," Ann Phytomed, vol. 11, no. 2, 2022, doi: 10.54085/ap.2022.11. 2.99.

[61] J.G. Lopez-Reyes, G. Gilardi, A. Garibaldi, and M.L. Gullino, "Efficacy of bacterial and fungal biocontrol agents as seed treatments against Fusarium Oxysporum F. sp. Lactucae on lettuce," Journal of plant pathology, vol. 96, no. 3, pp. 535-539, 2014.

[62] A. Khanna, K. RAJ, and P. Kumar, "Effect of mycorrhizal fungi in combination with botanicals, fungicides and bio-agents in ameliorating Fusarium wilt management in chickpea (Cicer arietinum)," The Indian journal of agricultural sciences, vol. 92, no. 6, pp. 757–762, 2022, doi: 10.56093/ijas.v92i6.118681.

[63] S. Malathi, "Biological control of onion basal rot caused byFusarium oxysporum f. sp. cepae," Asian Journal of Bio Science, vol. 10, no. 1, pp. 21–26, 2015, doi: 10.15740/HAS/AJBS/10.1/21-26.

[64] "Mechanisms of Action of Pseudomonas Fluorescens Against Fusarium Oxysporum F. Sp Phaseoli." Accessed: Jan. 04, 2025. [Onli--ne]. Available: https://researchjournali.com/view.php?id=5701

[65] S. Fatima and T. Anjum, "Identification of a Potential ISR Determinant from Pseudomonas aeruginosa PM12 against Fusarium Wilt in Tomato," Front Plant Sci, vol. 8, pp. 848-848, 2017, doi: 10.3389/fpls.2017.00848.

[66] V.K. Deshwal, P. Pandey, S.C. Kang, and D.K. Maheshwari, "Rhizobia as a biological control agent against soil borne plant pathogenic fungi," Indian J Exp Biol, vol. 41, no. 10, pp. 1160–1164, 2003.

[67] A. Basu et al., "Plant Growth Promoting Rhizobacteria (PGPR) as Green Bioinoculants: Recent Developments, Constraints, and Prospects," Sustainability, vol. 13, no. 3, p. 1140, 2021, doi: 10.3390/su13031140.

[68] M.C.S. Russiano, S.M. Mazaro, C.G. dos S. Russiano, M.A. Nogueira, and M. da Silva, "Strains of Bradyrhizobium spp. in the biological control of phytopathogens in the soybean," Cienc Agron, vol. 55, 2024, doi: 10.5935/1806-6690.20240046.

[69] J. Ayub et al., "Effective biological control of Lentil (Lens culinaris) Fusarium wilt and plant growth promotion through native Rhizobacteria," Physiol Mol Plant Pathol, vol. 129, p. 102203, 2024, doi: 10.1016/j.pmpp.2023.102203.

[70] F. Konig, M.R. Sandri, A. Russi, C.E. Granada, and J. Schwambach, "Biocontrol of tomato pathogens by Bacillus subtilis F62 and its synergistic action in plant growth promotion with Rhizobium sp. L5," Biocontrol Sci Technol, vol. 34, no. 6, pp. 551–565, 2024, doi: 10.1080/09583157.2024.2354387.

[71] Z. Shao, P.M. Schenk, and P. Dart, "Phyllosphere bacterial strains Rhizobium b1 and Bacillus subtilis b2 control tomato leaf diseases caused by Pseudomonas syringae pv. tomato and Alternaria solani," J Appl Microbiol, vol. 134, no. 7, 2023, doi: 10.1093/jambio/lxad139.

[72] S. Tewari and S. Sharma, "Rhizobial-metabolite based biocontrol of fusarium wilt in pigeon pea," Microb Pathog, vol. 147, pp. 104278–104278, 2020, doi: 10.1016/j.micpath.2020.104278.

[73] S. Nagpal, P. Sharma, A. Sirari, and R. K. Gupta, "Coordination of Mesorhizobium sp. and endophytic bacteria as elicitor of bio control against Fusarium wilt in chickpea," Eur J Plant Pathol, vol. 158, no. 1, pp. 143–161, 2020, doi: 10.1007/s10658-020-02062-1.

[74] E. Kebede, "Competency of Rhizobial Inoculation in Sustainable Agricultural Production and Biocontrol of Plant Diseases," Front Sustain Food Syst, vol. 5, 2021, doi: 10.3389/fsufs.2021.728014.

[75] M.D. Nakei, P.B. Venkataramana, and P. A. Ndakidemi, "Evaluating Rhizobium and Bradyrhizobium species as potential biocontrol agents for root rot fungi in soybean seedlings," Technology in agronomy, vol. 4, no. 1, pp. 1–11, 2024, doi: 10.48130/tia-0024-0007.

[76] P.K. Singh, M. Singh, and D. Vyas, "Biocontrol of Fusarium Wilt of Chickpea using Arbuscular Mycorrhizal Fungi and Rhizobium leguminosorum Biovar," Caryologia, vol. 63, no. 4, pp. 349–353, 2010, doi: 10.1080/00087114.2010.10589745.

[77] S. Dutta, P. Morang, N. Kumar S, and B.S. Dileep Kumar, "Two rhizobacterial strains, individually and in interactions with Rhizobiu--m sp., enhance fusarial wilt control, growth, and yield in pigeon pea," The journal of microbiology, vol. 52, no. 9, pp. 778–784, 2014, doi: 10.1007/s12275-014-3496-3.

[78] G. Parveen, R. Noreen, H.A. Shafique, V. Sultana, S. Ehteshamul-Haque, and M. Athar, "Role of Rhizobia in Suppressing the Root Diseases of Soybean Under Soil Amendment," Planta daninha, vol. 37, 2019, doi: 10.1590/s0100-83582019370100038.

[79] M. Verma, S.K. Brar, R.D. Tyagi, R.Y. Surampalli, and J.R. Valéro, "Antagonistic fungi, Trichoderma spp.: Panoply of biological control," Biochem Eng J, vol. 37, no. 1, pp. 1–20, 2007, doi: 10.1016/j.bej.2007.05.012.

[80] N. Elhazzat et al., "Comparative pathogenesis of Fusarium spp. obtained from diseased chickpea plants in Morocco," Not Sci Biol, vol. 15, no. 3, p. 11361, 2023, doi: 10.55779/nsb15311361.

[81] J. Poveda, "Trichoderma as biocontrol agent against pests: New uses for a mycoparasite," Biological Control, vol. 159, Aug. 2021, doi: 10.1016/J.BIOCONTROL.2021.104634.

[82] P. Guzmán-Guzmán et al., "Trichoderma Species: Our Best Fungal Allies in the Biocontrol of Plant Diseases-A Review," Plants 2023, Vol. 12, Page 432, vol. 12, no. 3, p. 432, Jan. 2023, doi: 10.3390/PLANTS12030432.

[83] N. Akbari Oghaz, K. Rahnama, R. Habibi, S. Hatamzadeh, S.I. Razavi, and A.R.G. de Farias, "Endophytic and rhizospheric Trichoder--ma spp. associated with cucumber plants as potential biocontrol agents of Fusarium oxysporum f. sp. cucumerinum," Asian J Mycol, vol. 7, no. 1, pp. 31–46, May 2024, doi: 10.5943/ajom/7/1/3.

[84] P. Chakraborty, P. Deb, S. Chakraborty, B. Chatterjee, and J. Abraham, "Cytotoxicity and antimicrobial activity of Colocasia esculenta," J Chem Pharm Res, vol. 7, no. 12, pp. 627–635, Dec. 2015, Accessed: Mar. 17, 2024. [Online]. Available: https://www.jocpr.com/abstract/cytotoxicity-and-antimicrobial-activity-of-colocasia-esculenta-7351.html

[85] S. Sundaramoorthy and P. Balabaskar, "Biocontrol efficacy of Trichoderma spp. against wilt of tomato caused by Fusarium oxysporum f. sp. lycopersici Article info Abstract," J Appl Biol Biotechnol, vol. 1, no. 03, pp. 36–040, 2013, doi: 10.7324/JABB.2013. 1306.

[86] Ruchika, N. Singh, D.S. Buttar, A.K. Choudhary, and T. Pawar, "Evaluation of the bioformulation of potent strains of Trichoderma spp. and Pseudomonas spp. against Fusarial wilt of bottle gourd (Lagenaria siceraria)," Plant Disease Research, vol. 37, no. 2, pp. 99-1

09, 2022, doi: 10.5958/2249-8788.2022.00018.X.
[87] H. Ramezani and G. B. Khaniki, “Evaluation Effect of Bioagents on Fusarium Wilt of Cowpea”, Accessed: Jan. 04, 2025. [Online]. Available: http://www.journalijdr.com
[88] M. N. Bhat et al., “Biological control of Fusarium wilt of chillies using Trichoderma spp,” Indian Journal of Horticulture, vol. 73, no. 1, p. 74, 2016, doi: 10.5958/0974-0112.2016.00021.9.
[89] I.M. Sudantha, S. Suwardji, I.G.P.M. Aryana, I.M.A. Pramadya, and I. Jayadi, “The Effect of Liquid Bio Fungicides Dosage Trichoderma spp. against Fusarium Wilt Diseases, Growth and Yield of Onion,” J Phys Conf Ser, vol. 1594, no. 1, p. 12013, 2020, doi: 10.1088/1742-6596/1594/1/012013.
[90] E.F.A. Awad-Allah, A.H.M. Shams, A.A. Helaly, and E.I.M. Ragheb, “Effective Applications of Trichoderma spp. as Biofertilizers and Biocontrol Agents Mitigate Tomato Fusarium Wilt Disease,” Agriculture (Basel), vol. 12, no. 11, p. 1950, 2022, doi: 10.3390/agriculture12111950.
[91] W. Raza, M. Faheem CFRN Rimouski, F. Uddin Rajer, M. Faheem, S. Yousaf, and M. Yameen, “Volatile and non-volatile antifungal compounds produced by Trichoderma harzianum SQR-T037 suppressed the growth of Fusarium oxysporum f. sp. niveum,” 2014. [Online]. Available: https://www.researchgate.net/publication/262844237
[92] S. K. Vishwakarma et al., “Arbuscular Mycorrhizal Fungi (AMF) as Potential Biocontrol Agents,” in Rhizosphere Microbes, vol. 40, in Microorganisms for Sustainability, vol. 40. , Singapore: Springer, 2022, pp. 197–222. doi: 10.1007/978-981-19-5872-4_10.
[93] A. Yagmur et al., “Onion Fusarium Basal Rot Disease Control by Arbuscular Mycorrhizal Fungi and Trichoderma harzianum,” Plants (Basel), vol. 13, no. 3, p. 386, 2024, doi: 10.3390/plants13030386.
[94] M.S. Yasir, Z.K. Taha, F.F. Hassan, and T.A.A. Muhsen, “Role of Arbuscular Mycorrhiza (AM) Fungi and Lignin in Biological Control against Vascular Fusarium Wilt Disease,” International Journal of Phytopathology, vol. 13, no. 1, pp. 75–84, Apr. 2024, doi: 10.33687/phytopath.013.01.5037.
[95] H.K. Kamore, E.M. Njeru, S.B. Nchore, R.O. Ombori, J.M. Muthini, and J. Kimiti, “Prevalence of banana diseases and post-harvest losses in Kenya, and biocontrol potential of arbuscular mycorrhizal fungi against Fusarium wilt,” Int J Hortic Sci, 2024, doi: 10.31421/ijhs/30/2024/13781.
[96] H. Guneş, S. Demir, E.D. Durak, and G. Boyno, “The effect of Arbuscular Mycorrhizal fungal species Funneliformis mosseae and biochar against Verticillium dahliae in pepper plants under salt stress,” Eur J Plant Pathol, vol. 170, no. 3, pp. 669–686, 2024, doi: 10.1007/s10658-024-02926-w.
[97] A. Bilgili and A. V. Bilgili, “Comparison of compost, PGPR, and AMF in the biological control of tomato Fusarium wilt disease,” Eur J Plant Pathol, vol. 167, no. 4, pp. 771–786, Dec. 2023, doi: 10.1007/S10658-023-02710-2.
[98] N.O. Devi, R.K. Tombisana Devi, M. Debbarma, M. Hajong, and S. Thokchom, “Effect of endophytic Bacillus and arbuscular mycorrhiza fungi (AMF) against Fusarium wilt of tomato caused by Fusarium oxysporum f. sp. lycopersici,” Egypt J Biol Pest Control, vol. 32, no. 1, pp. 1–14, 2022, doi: 10.1186/s41938-021-00499-y.
[99] A.G. Castillo, C.G. Puig, and C.J.R. Cumagun, “Non-Synergistic Effect of Trichoderma harzianum and Glomus spp. in Reducing Infection of Fusarium Wilt in Banana,” Pathogens (Basel), vol. 8, no. 2, p. 43, 2019, doi: 10.3390/pathogens8020043.
[100] N. EL Hazzat et al., “Effect of a Composite Endomycorrhizal Inoculum on the Manifestation of Chickpea Wilt, Caused by Fusarium solani,” Plant Cell Biotechnol Mol Biol, vol. 20, no. 12, pp. 486–500, Aug. 2019, Accessed: Dec. 31, 2024. [Online]. Available: https://ikprress.org/index.php/PCBMB/article/view/4655

AUTHOR’S PROFILE

First Author
Nikhat Begum, Completed B.sc in Botany (First Division) from sunderwati mahila college under Tilka Manjhi Bhagalpur University, Bihar in the year 2007, M.sc in Botany, P.G. Department of Botany, (First Division) under Tilka Manjhi Bhagalpur University, Bihar in the year 2010, pursuing P.hd. from the Botany section, School of sciences, Maulana Azad National urdu University, Hyderabad, Attended National level seminars and workshops. email id: nikhatbgp01@gmail.com

Second Author
Dr. Merajul Islam Robab, Assistant Professor, Botany section, School of Sciences, Maulana Azad National Urdu University, Hyderabad, India. email id: meraj.botanica@gmail.com

Third Author
Waseem Uddin Md, Corresponding author, completed B.Sc.-Biotechnology from Vasu Degree College, Osmania University with First Division in the year-2009, Pursued M.Sc.-Genetics in first division with distinction from University College of Science-Osmania University in the year-2011. Cleared APSLET in the year 2012, Qualified GATE (Life Sciences) 4 times, Cleared CSIR-Net Rank-43rd in the year 2014. Presented research papers in National & International Seminars, Attended national level conferences and workshops. Received best research paper award in the year 2024. Member of Indian Science Congress Association (ISCA).

Fourth Author
Dr. S. Maqbool Ahmed, Professor of Botany, Botany section, School of sciences, Maulana Azad National Urdu University, Hyderabad, India. email id: maqboolbotany@gmail.com.co.in

Fifth Author
Dr. Mohammad Danish, Assistant Professor, Botany section, School of sciences, Maulana Azad National Urdu University, Hyderabad, India. email id: danish.botanica@gmail.com