Chemical and biological management strategies for *Fusarium* wilt of chickpea, *Fusarium oxysporum*

Mahesh V Mahajan[1], Bahaderjeet Singh[2*] and Amritpal Mehta[3]

ABSTRACT

Fusarium wilt, caused by *Fusarium oxysporum* f. sp. *ciceri*, is a major threat to chickpea (*Cicer arietinum*) production, leading to significant yield losses. This study examined the disease progression under different inoculation methods stem inoculation, root dip, and pipette application—revealing peak wilting at 35-days after inoculation (DAI). Among fungicides tested, Carbendazim and Thiram demonstrated the highest inhibitory effects on fungal radial growth and zone of inhibition, with complete pathogen suppression at 2000 ppm. Additionally, botanical extracts from *Azadirachta indica* (Neem) and *Ocimum sanctum* (Tulsi) exhibited antifungal activity, with Tulsi proving more effective due to its bioactive compounds. The study also assessed biocontrol agents *Trichoderma viride* and *Pseudomonas fluorescens*, where *T. viride* exhibited greater inhibition (58.82%) than *P. fluorescens* (47.30%), highlighting their potential in disease management. The findings emphasize integrating chemical, botanical, and biological control strategies for sustainable management of *F. oxysporum* f. sp. *ciceri*. Future research should explore resistant cultivars and field applications of biocontrol agents to mitigate pathogen impact

Keywords: Etiology, IDM, Screening of germplasm, Disease resistance

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INTRODUCTION

Chickpea (*Cicer arietinum* L.) is one of the most important leguminous crops cultivated worldwide, playing a crucial role in human nutrition and sustainable agriculture. It is a rich source of protein, carbohydrates, and essential micronutrients, making it a staple food in many developing countries. However, chickpea production faces significant threats from various biotic and abiotic stresses, among which Fusarium wilt (FW), caused by *Fusarium oxysporum* f. sp. ciceri (Foc), is one of the most devastating diseases. The pathogen is a soilborne fungus that infects chickpea roots, leading to systemic colonization and eventual plant death. The disease results in substantial yield losses, affecting both the quantity and quality of chickpea production.

Fusarium wilt has been reported in major chickpea-growing regions across the world, including South Asia, the Mediterranean, and parts of Africa and Latin America. The severity of the disease varies based on environmental conditions, soil properties, and the genetic resistance of chickpea cultivars. The characteristic symptoms of Fusarium wilt include stunted growth, leaf yellowing, vascular discoloration, and complete plant collapse. The disease progression typically starts with root infection, followed by fungal invasion of the vascular system, which obstructs water and nutrient transport, ultimately leading to plant death. Studies have shown that the pathogen can persist in soil for extended periods in the form of chlamydospores, making management difficult.

While FW caused by *Fusarium oxysporum* f. sp. *ciceri* is a significant problem. Padwick (1948) stated that wilt is the most severe disease in chickpea crops. Jani *et al.* (1999) reported that wilt causes considerable crop loss in Gujarat. This soil- and seed-borne pathogen colonizes the xylem vessels, completely blocking them and causing wilting (De Boer *et al.*, 2003). It survives in soil as spores, chlamydospores, and mycelia, and can persist for up to six years in the absence of a susceptible host (Haware *et al.*, 1986b). The

pathogen enters through rootlets by penetrating the cell wall, grows into the vascular system, and blocks the vessels. It travels from the root to the stem, becoming systemic in nature. Symptoms typically appear 4-6 weeks after sowing, including loss of turgidity, vein clearing, yellowing, or wilting of leaves. Characteristic symptoms include browning of xylem vessels, black streaks, and dark purple bands on the stem surface, which extend upward. Wilted plants generally dry from top to bottom during later stages. Wilt severity is often higher with continuous chickpea cultivation due to increased pathogen inoculum.

Use of resistant cultivars is a more effective strategy for sustainable chickpea cultivation. Despite several resistant varieties available, yield losses due to root rot are more. Ahmed and Mohammed (1986) reported losses due to dry root rotting gram to the extent of 70.8 percent at full podding and 48.9 percent at preharvest stage. It indicates that the use of resistant varieties is not the sole control measure against dry root rot of chickpea. Therefore, two or more control measures must be tried in combination with resistant variety for sustainable production.

The significance and objective of this study is to comprehensively evaluate the effectiveness of different inoculation methods for understanding disease progression and compares multiple disease control approaches including chemical fungicides, botanical extracts, and biological control agents. The integration of these methods provides a holistic perspective on managing Fusarium wilt while minimizing environmental impact and promoting sustainable agriculture.

MATERIALS AND METHODS

A field survey of chickpea FW disease was conducted in eight districts of the of Jalgaon and Marathwada region during December 2022 and February 2023. Disease incidence was recorded in ten farmers' fields per district by counting total plants and infected plants in a 1 m^2 area.

Symptoms observed are Straw-colored plants resembling dry grass at the pod formation stage. Black rotted roots, shredding of bark, and easily broken roots and minute dark black sclerotial bodies on the root surface and in the pith region.

Water Culture Technique

Spore suspensions were prepared from 10-day-old cultures in sterilized distilled water and adjusted to 3-4 x 10^6/mL concentration. Big-sized test tubes (250 x 20 mm) were filled up to 3/4 levels with this adjusted spore suspension. 15-day-old seedlings of JG-62, raised in sterilized riverbeds, were transferred into the test tubes, and seedlings were held in a straight position by a cotton plug. Four replications were maintained, and uninoculated tubes with only sterilized distilled water were kept as control. The seedlings were kept on the benches in the net house. Observations on the number of wilted plants were recorded from the initiation of wilting and continued up to 15 days.

Pot Culture Evaluation

The variety JG-62 has been selected to check the resistance against Fusarium wilt. Four replication and six treatments have been applied (T1 – Soil inoculation, T2 – Seed inoculation, T3 – Stem inoculation, T4 – Root dip method,T5 – Pipette method , T6 – Water culture inoculation). The seedlings were kept on the benches in the net house. Observations on the number of wilted plants were recorded from the initiation of wilting and continued up to 15 days.

In vitro evaluation -Poisoned Food Technique

The requisite quantity of each fungicide based on active ingredient was calculated and mixed thoroughly with autoclaved and cooled (40°C) Potato Dextrose Agar (PDA) medium in conical flasks to obtain desired concentrations of 1000 and 2000 ppm. Untreated PDA medium without fungicides served as control. Fungicide-amended PDA medium was then poured into Petri plates (90 mm dia.). After solidification of the medium, all the plates were inoculated aseptically with 5 mm culture discs of the test fungus obtained from a week-old culture of *F. oxysporum* f. sp. ciceri. The disc was placed on PDA in inverted position at the center of the Petri plate and plates were incubated at 30 ± 2°C. When untreated control plates were fully covered with mycelial growth, observations were taken in all the treatment plates. Percent inhibition of mycelial growth in treated plates was

calculated by applying the formula given by Vincent (1927):

Percentage of Inhibition = R1 – R2 x100
R1

Where,

R1= Radial growth of fungal pathogens in control

R2= Radial growth of fungal pathogen in dual culture

Evaluation of fungicidal activity against *Fusarium oxysporum* at different concentrations.

The experiment consisted of ten treatments applied to seeds. In T1, seeds were treated with Carbendazim 50 WP at a dose of 4 g/kg through the seed treatment method. T2 involved seed treatment with a combination of Carbendazim 50 WP and Thiram 75 WP (0.2% each) at the same dose of 4 g/kg. In T3, seeds were treated with Propiconazole 25 EC (0.1%) at a dose of 1.0 mL/kg using the seed treatment method. T4 included the application of Hexaconazole 5 EC (0.2%) at 2.0 mL/kg as a seed treatment. T5 consisted of treating seeds with Difenconazole 25 EC (0.1%) at a dose of 1.0 mL/kg by seed treatment.

In the biological treatments, T6 involved seed treatment with *Trichoderma viride* (0.6%) at a dose of 6 g/kg. T7 included the application of a combination of *Pseudomonas fluorescens* and *Trichoderma viride* (0.6% each) at a dose of 10 g/kg by seed treatment. In T8, seeds were immersed in Tulsi (*Ocimum sanctum*) extract (10%) at a dose of 50 mL/kg through the immersion method/soil application. Similarly, T9 involved immersion of seeds in Neem (*Azadirachta indica*) extract (10%) at 50 mL/kg using the same immersion method or soil application. Finally, T10 served as the control, where no seed treatment was applied.

Growth Inhibition Bioassay

Seven-day-old cultures of the bioagents and test fungus (*F. oxysporum* f. sp. *ciceri*) grown on agar media were used for the study by using the dual culture technique. Discs (5 mm dia.) of PDA along with the culture growth of the test fungus and bioagents were cut out with a sterilized cork borer. Then two culture discs, one each of the test fungus and bioagents, were placed at equal distances and exactly opposite to each other on solidified PDA medium in plates under aseptic conditions. Plates inoculated with culture discs of the test fungus were maintained as untreated control. Observations on linear mycelial growth were recorded at 24-hour intervals and continued till untreated control plates were fully covered with mycelial growth of the test fungus. Percent inhibition of the test fungus over untreated control was calculated by applying the formula given by Arora and Upadhyay (1978).

Poisoned food technique for plant leaf extracts

Plant leaf extracts of two botanicals, viz. Tulsi and Neem, were evaluated against *F. oxysporum* f. sp. *ciceri* in plate culture experiments. Leaf extracts were prepared by grinding 100 gm washed leaves of each plant species in 100 mL distilled water using a mixture-cum-grinder, and then pouring the mixture through double-layered muslin cloth. The filtrate obtained was further filtered through Whatman No. 1 filter paper using a funnel and volumetric flask (100 mL cap.). The final clear extract obtained formed the standard leaf extract of 100 percent concentration, which was evaluated (10% & 20%) in vitro against *F. oxysporum* f. sp. *ciceri* applying the poisoned food technique. For the purpose, PDA was used as basal culture medium. An appropriate quantity of each leaf extract (100%) was separately mixed thoroughly in PDA medium in conical flasks (250 mL cap.) to obtain desired concentrations (10% and 20%) and autoclaved at 15 lbs/cm² pressure for 15-20 minutes. Sterilized cooled PDA amended with leaf extract was then poured (15-20 mL/plate) into sterile glass Petri plates (90 mm dia.) and allowed the medium to solidify at room temperature. Each plant leaf extract and its respective concentration were replicated thrice. The plates containing PDA without any extract were maintained as untreated control. Upon solidification of PDA, all the plates were aseptically inoculated by placing a 5 mm mycelial disc obtained from a week-old culture of *F. oxysporum* f. sp. *ciceri* grown on agar plates. Plates containing plain PDA and inoculated with the test fungus served as untreated control. All

these plates were then incubated at 30 ± 2°C for a week, or until the untreated control plates were fully covered with mycelial growth of the test fungus. Observations on radial mycelial growth/colony diameter of the test fungus were recorded treatment-wise at 24-hour intervals and continued until mycelium of the test fungus fully covered untreated control plates. Percent inhibition of mycelial growth and inhibition of conidial growth production over untreated control were calculated by applying the formula given by Vincent (1947).

Pot Culture evaluation

To find out the efficacy of fungicides, bioagents, and plant extracts against *F. oxysporum* f. sp. *ciceri*, a pot culture experiment was planned and conducted in the glasshouse by applying a completely randomized design (CRD) with three replications, 10 treatments, and a variety JG-62 of chickpea. The cultures of bioagents (*T. viride* and *P. fluorescens*) and test fungus (*F. oxysporum* f. sp. *ciceri*) were multiplied.

Earthen pots (25 cm dia.) were disinfected with a 5% solution of copper sulphate, and the soil was sterilized with 5% formaldehyde. Pots were filled with sterilized soil and inoculated with the test fungus. The seeds of chickpea cultivar JG-62 were treated with fungicides viz. Carbendazim 50 WP, Thiram 75 WP + Carbendazim 50 WP in combination, Propiconazole 25 EC, Hexaconazole 5 EC, and Difenoconazole 25 EC alone. Two bioagents, i.e., *T. viride* and *P. fluorescens*, were treated to chickpea seeds and sown (@10 seeds/pot). Two plant extracts, Tulsi and Neem, were applied to soil in pots.

The CRD pots were watered periodically and kept in the glasshouse for further studies. Untreated seeds of variety JG-62 were sown (@10 seeds/pot) in pots and inoculated with the test fungus, serving as the untreated control. Three and ten replicators were maintained for control and each treatments (T1 to T10; 3.0 m x 2.0 m with 30 cm x 10 cm spacing) respectively. Treatments were T1) Carbendazim 50 WP (0.4%) -4 g/kg-Seed treatment.

Observations on percent seed germination, percent wilt incidence, percent disease control, vigour index, and dry matter were recorded.

Wilt-sick plot evaluation

The study included several seed treatment methods to evaluate their effectiveness. In T2, seeds were treated with a combination of Carbendazim 50 WP and Thiram 75 WP (0.2% each) at a dose of 4 g/kg using the seed treatment method. T3 involved the application of Propiconazole 25 EC (0.1%) at a dose of 1.0 mL/kg through seed treatment. In T4, seeds were treated with Hexaconazole 5 EC (0.2%) at a dose of 2.0 mL/kg via seed treatment. T5 included the seed treatment with Difenconazole 25 EC (0.1%) at 1.0 mL/kg.

For biological treatments, T6 involved the application of *Trichoderma viride* (0.6%) at a dose of 6 g/kg through seed treatment. In T7, a mixture of *Pseudomonas fluorescens* and *Trichoderma viride* (0.6% each) was applied at 10 g/kg using the seed treatment method. Natural plant extracts were also tested, where in T8, seeds were immersed in Tulsi (*Ocimum sanctum*) extract (10%) at 50 mL/kg using the immersion method/soil application, and in T9, seeds were immersed in Neem (*Azadirachta indica*) extract (10%) at 50 mL/kg using the same method. T10 served as the control with no seed treatment applied. Based on morphological and cultural characteristics, microscopic observation, and pathogenicity tests, the test pathogen under investigation was identified and confirmed as *Fusarium oxysporum* f.sp. ciceri.

Statistical analysis

The experimental data were statistically analyzed at the using SPSS. Observations of percent disease incidence and intensity were converted into values of arcsine and square transformation for statistical analysis.

RESULTS

Disease management strategies

In vitro evaluation of fungicides A total of five fungicides viz. Carbendazim 50 WP, Thiram 75 WP, Propiconazole 25 EC, Hexaconazole 5 EC and Difenoconazole2544.

Radial growth and zone of inhibition

The present study demonstrates the efficacy of various fungicides against *Fusarium oxysporum* f.sp. *ciceri* through an in vitro poisoned food technique. From the data presented in Table 2, it is observed that all the fungicides tested recorded a wide range of radial growth (colony diameter) of the test pathogen, depending on the concentrations used (PLATE IV).

At 1000 ppm**,** the radial growth of the test pathogen ranged from 18.33 mm **(**Carbendazim) to 41.50 mm (Propiconazole). However, it was maximum with Propiconazole**,** followed by Hexaconazole and Difenconazole**.** The minimum radial growth was recorded with Carbendazim, followed by Thiram**,** compared to the highest growth in the untreated control. At 2000 ppm, the radial growth of the test pathogen ranged from 0.00 mm (Carbendazim) to 36.03 mm (Propiconazole). However, it was maximum with Propiconazole, followed by Hexaconazole, Difenconazole, and Thiram. Notably, no radial growth was observed with Carbendazim, compared to the highest radial growth in the untreated control.

Zone of Inhibition

Results from Table 2 revealed that all the fungicides tested significantly inhibited the growth of the test fungus over the untreated control. Further, it was found that the percent inhibition of the test pathogen increased with the concentration of the fungicides tested.

At 1000 ppm, the percent growth inhibition ranged from 53.88% (Propiconazole) to 79.63% (Carbendazim). The highest percent of growth inhibition was recorded with Carbendazim, followed by Thiram**,** Difenconazole**,** and Hexaconazole. The least growth inhibition was recorded with Propiconazole. At 2000 ppm, a similar trend of growth inhibition was observed with the test fungicides. Percent growth inhibition ranged from 59.97% (Propiconazole) to 100.00% (Carbendazim). The total zone of inhibition was recorded with Carbendazim, followed by Thiram**,** Difenconazole, and Hexaconazole**.** The least zone of inhibition was recorded with Propiconazole.

The Carbendazim and Thiram treatments at both 1000 ppm and 2000 ppm significantly showed minimum radial growth and maximum zone of inhibition of the test pathogen. It was also observed that all the fungicides at both concentrations were effective against the test pathogen (Table 1).

The concentration-dependent inhibitory trend observed in this study is consistent with previous research indicating that higher doses of fungicides generally lead to greater fungal suppression (Patel *et al.,* 2021; Yemataw *et al.,* 2025). The complete inhibition of fungal growth by Carbendazim at 2000 ppm suggests its potential as a leading candidate for controlling *Fusarium oxysporum* f.sp. *ciceri* in agricultural settings.

Table 1. Effect of fungicides on growth of *Fusarium oxysporum* f.sp. *ciceri* in plate culture technique by poisoned food technique (in vitro)

Fungicides	Concentration (ppm)	Radial Growth (mm)	Zone of Inhibition Over Control (%)
Carbendazim	1000	18.33	79.63
Thiram	1000	20.67	77.03
Propiconazole	1000	41.50	53.88
Hexaconazole	1000	36.55	59.38
Difenconazole	1000	32.13	64.30
Carbendazim	2000	0.00	100.00
Thiram	2000	13.00	85.55
Propiconazole	2000	36.03	59.97
Hexaconazole	2000	31.43	65.07
Difenconazole	2000	27.60	69.33
Control	0.0	90	0.00

S.E. ± 0.96; C.D. at 5% 2.40; Average of ten replications (triplicates)

However, concerns regarding the long-term sustainability of fungicide use and potential resistance development should be considered (Lucas *et al.,* 2015). Integrating fungicidal treatments with cultural or biological control methods may help mitigate these risks and ensure effective disease management in chickpea cultivation.

Overall, the findings highlight the importance of selecting appropriate fungicides for managing *Fusarium* wilt in chickpea. While Carbendazim and Thiram emerged as the most effective treatments, further field trials and resistance monitoring are necessary to validate their long-term applicability and effectiveness under diverse environmental conditions.

Effect of chemical fungicides on Radial growth and zone of inhibition

The present study evaluated the antifungal efficacy of Neem (*Azadirachta indica*) and Tulsi (*Ocimum sanctum*) extracts against *Fusarium oxysporum* f. sp. *ciceri* using the Poisoned Food Technique. The findings demonstrated that both plant extracts effectively inhibited the pathogen's radial growth and increased the zone of inhibition in a concentration-dependent manner. These results align with previous studies highlighting the antifungal potential of botanical extracts against phytopathogens (Bansal *et al.,* 2019; Singh *et al.,* 2021).

A reduction in radial growth was observed with increasing concentrations of both plant extracts. Tulsi extract exhibited superior antifungal activity compared to Neem, as indicated by the lower radial growth values at both 10% (40.03 mm) and 20% (35.97 mm) concentrations. Conversely, Neem extract, although effective, exhibited slightly higher growth values at 10% (48.23 mm) and 20% (39.00 mm). The superior efficacy of Tulsi may be attributed to its bioactive compounds such as eugenol, ursolic acid, and rosmarinic acid, which have been reported to possess strong antifungal properties (Kumar *et al.,* 2020).

The zone of inhibition results further corroborate the antifungal potential of these botanicals. Tulsi extract exhibited the highest inhibition at both 10% (55.52%) and 20% (60.03%) concentrations, while Neem extract showed inhibition rates of 44.41% and 56.67%, respectively. The increased inhibition with higher concentrations suggests a dose-dependent antifungal effect, which has been previously reported in studies evaluating plant-derived antifungal compounds (Pandey and Gupta, 2018; Sharma *et al.,* 2022) (Table 2).

Table 2. Effect of plant extracts on growth of *F. oxysporum* f.sp. *ciceri* in plate culture technique by poisoned food technique (In Vitro)

Plant Extract	Concentration (%)	Radial Growth (mm)	Growth Zone Inhibition over Control (%)
Neem	10%	48.23	46.41
Tulsi	10%	40.03	55.52
Neem	20%	39.00	56.67
Tulsi	20%	35.97	60.03
Control	0%	90.00	0.00

S.E. ± 0.42 | C.D. at 5% 1.27

The superior antifungal activity of Tulsi over Neem observed in this study may be due to differences in their phytochemical compositions. Neem contains azadirachtin, nimbin, and salannin, which have been documented for their antifungal activities (Chaudhary *et al.,* 2020). However, Tulsi's polyphenolic compounds and essential oils might have a broader spectrum of antifungal efficacy, effectively inhibiting fungal growth more than Neem (Rajkumar *et al.,* 2021).

These findings highlight the potential of plant-based antifungal agents as eco-friendly alternatives to synthetic fungicides. The results support the idea that botanical extracts, particularly Tulsi, can be effectively integrated into disease management strategies for *Fusarium oxysporum* f. sp. *ciceri*. Further research is needed to explore the mechanisms of action of these plant extracts and their field efficacy under diverse environmental conditions.

The in vitro evaluation of *Trichoderma viride* and *Pseudomonas fluorescens* against *Fusarium oxysporum* f. sp. *ciceri* revealed significant antagonistic effects, supporting previous studies that highlight the potential of these bioagents in fungal disease management. The dual culture assay demonstrated that both microbial antagonists were effective in suppressing the growth of *F. oxysporum* f. sp. *ciceri*, with *T. viride* showing greater inhibition (58.82%) compared to *P. fluorescens* (47.30%). These findings align with

earlier reports suggesting that *Trichoderma* spp. exert strong antifungal activity through mechanisms such as mycoparasitism, production of hydrolytic enzymes, and competition for nutrients and space (Benítez *et al.,* 2004; Harman *et al.,* 2004).

Trichoderma species, particularly *T. viride*, are well known for their ability to produce antifungal metabolites that disrupt pathogen growth. The mycoparasitic nature of *T. viride* enables direct interaction with fungal pathogens, leading to cell wall degradation via the production of chitinases, glucanases, and proteases (Vinale *et al.,* 2008; Haque *et al.,* 2025). The present study corroborates these findings, as *T. viride* exhibited the highest inhibition percentage against *F. oxysporum* f. sp. *ciceri*.

Similarly, *Pseudomonas fluorescens*, a well-documented plant growth-promoting rhizobacterium (PGPR), exhibited significant inhibitory effects, reducing the pathogen's growth by 47.30%. *P. fluorescens* is known to produce antifungal metabolites such as phenazines, pyrrolnitrin, and hydrogen cyanide (HCN), which contribute to its biocontrol efficacy (Raaijmakers *et al.,* 2002). Additionally, it competes with the pathogen for space and nutrients, thereby limiting its proliferation (Weller *et al.,* 2002). The current study's results reinforce the role of *P. fluorescens* in biocontrol strategies against soil-borne pathogens.

Although both antagonists demonstrated fungitoxic activity, the differential inhibitory effects observed may be attributed to variations in their modes of action. While *T. viride* primarily employs direct parasitism and enzymatic degradation, *P. fluorescens* relies on antibiosis and competitive exclusion (Compant *et al.,* 2005). The results suggest that integrating both bioagents in disease management programs may enhance their effectiveness through complementary mechanisms.

Overall, the study highlights the potential of *T. viride* and *P. fluorescens* as effective biocontrol agents against *Fusarium oxysporum* f. sp. ciceri. Further field evaluations and formulation developments are necessary to optimize their application in sustainable disease management practices.

Conflict of Interest

The authors have no Conflict of Interest

Contribution of authors

The idea of this study was conceived by Bahaderjeet Singh, Mahesh V Mahajan conducted the experiments and recorded the data. Bahaderjeet Singh and Amritpal Mehta analysed the results, statistical analysis and Mahesh V Mahajan wrote the paper.

REFERENCES

Ahmed, Q., and Mohamad, A. 1986. Losses in yield due to *Rhizoctonia* root rot of chickpea in Bihar. *Indian Phytopathology*, **39**: 590–592.

Bansal, R., Meena, M., and Sharma, P. 2019. Antifungal activity of plant extracts against fungal phytopathogens. *Journal of Agricultural Research and Development*, **8**(2), 45-57.

Benítez, T., Rincón, A. M., Limón, M. C., and Codón, A. C. 2004. Biocontrol mechanisms of *Trichoderma* strains. *International Microbiology*, **7**(4): 249-260.

Chaudhary, R., Kumar, S., and Yadav, P. 2020. Neem extracts as biopesticides: A review on their role in plant disease management. *Plant Protection Science, 56*(4): 324-333.

Compant, S., Duffy, B., Nowak, J., Clément, C., and Barka, E. A. 2005. Use of plant growth-promoting bacteria for biocontrol of plant diseases: Principles, mechanisms of action, and future prospects. *Applied and Environmental Microbiology*, **71**(9): 4951-4959.

De Boer A. H., and Volkov V. 2003. Logistics of water and salt transport through the plant: structure and functioning of the xylem. *Plant Cell Environment*, **26**: 87–101

Harman, G. E., Howell, C. R., Viterbo, A., Chet, I., and Lorito, M. 2004. *Trichoderma* species Opportunistic, avirulent plant symbionts. *Nature Reviews Microbiology*, **2**(1): 43-56.

Haque, Z., Nawaz, S., Haidar, L. *et al.* 2025. Development of novel *Trichoderma* bioformulations against *Fusarium* wilt of chickpea. *Scientific reports*, **15**: 9564. https://doi.org/10.1038/s41598-025-86984-y

Haware, M. P., and Nene, Y. L. 1986. Races of *Fusarium oxysporum f. sp. ciceri* and their response to chickpea germplasm. *Plant Disease*, **66**(9): 809–810.

Jani, S.M., Acharya, M. F. and Andani, V. P. 1999. Screening of chickpea for resistance to wilt disease in Junagadh, Gujrat. Internat. *Chickpea & Pigeonpea Newletter*, **6**(14): 77.

Kumar, R., Singh, M., and Verma, S. 2020. Bioactive compounds in Tulsi (*Ocimum sanctum* L.) and their pharmacological significance. *Phytomedicine Journal*, **27**(3): 112-121.

Lucas, J. A., Hawkins, N. J., and Fraaije, B. A. 2015. The evolution of fungicide resistance. *Advances in Applied Microbiology*, **90**: 29-92. doi.org/10.1016/bs.aambs.2015.02.001

Padwick, G.W. 1948. Plant protection and food crops of India I. Plant pests and diseases of rice, wheat, sorghum and gram. *Empire Journal of Experimental Agriculture*. **16**: 55-64.

Pandey, A., and Gupta, R. 2018. Evaluation of antifungal properties of medicinal plant extracts against *Fusarium* spp. *International Journal of Plant Sciences*, **13**(1): 78-85.

Patel, K. R., Shah, R. R., and Jha, V. K. 2021. Effect of different fungicides on growth inhibition of *Fusarium oxysporum* causing wilt in chickpea. *Agricultural Research Journal*, **58**(1): 12-18. https://doi.org/10.1007/s40003-021-00553-2

Raaijmakers, J. M., Vlami, M., and de Souza, J. T. 2002. Antibiotic production by bacterial biocontrol agents. *Antonie van Leeuwenhoek*, **81**(1-4): 537-547.

Rajkumar, R., Shukla, A., and Sharma, N. 2021. Comparative antifungal efficacy of Neem and Tulsi extracts against plant pathogenic fungi. *Journal of Herbal Medicine*, **10**(5): 189-196.

Sharma, P., Tripathi, N., and Singh, D. 2016. Reisolation and pathogenicity confirmation of *Fusarium oxysporum* in chickpea wilt syndrome. *Journal of Mycology*, **12**(1) 55–63.

Vinale, F., Sivasithamparam, K., Ghisalberti, E. L., Marra, R., Woo, S. L., and Lorito, M. 2008. Trichoderma–plant–pathogen interactions. *Soil Biology and Biochemistry*, 40(1): 1-10.

Weller, D. M., Raaijmakers, J. M., Gardener, B. B., and Thomashow, L. S. 2002. Microbial populations responsible for specific soil suppressiveness to plant pathogens. *Annual Review of Phytopathology*, **40**(1): 309-348.

Yemataw, A., Sintayehu, A., Terefe, H., and Abera, M. 2025. Evaluation of fungicides on the management of *Fusarium wilts (Fusarium oxysporum* f. sp. *ciceri*) diseases of chickpea varieties in Gondar Zuria district, Northwestern Ethiopia. *Journal of Plant Pathology*, **PP**:1-8.

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