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RESEARCH ARTICLE

BIOLOGICAL CONTROL OF FUSARIUM WILT OF CHICKPEA: A REVIEW

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ABSTRACT

Chicpeas (*Cicer arietinum* L.) are a nutrient-rich legume valued for their higher content of protein, fiber, folate, and other essential minerals and vitamins, offering benefits such as improved digestion and heart health, enhanced blood sugar regulation, and support for brain function. They are a global food source, appearing in various dishes like hummus, soups, and flour. Multiple pathogen such as fungi, bacteria, nematode, and viruses have been reported in association with chickpeas, causing damage at different stages of crop cycle. Certain diseases may limit the cultivation area, resulting in losses of up to 100% depending on pathogen timing of infection, cultivated variety, and climatic conditions. Major diseases affecting chickpeas globally include Fusarium wilt, black rot, dry root rot, and seed decay, with Fusarium wilt being the most common. These diseases can be controlled by use of medicinal plants. The present paper is a review of biological control of Fusarium wilt of chickpea.

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INTRODUCTION

Chickpea is the third most important pulse crop, after dry bean and peas, produced in the world. It is an annual legume crop belonging to the family Fabaceae. Its morphology is characterized by a deep tap root system that enables the plant to thrive in arid and semi-arid regions. The plant grows to a height of 30 to 60 cm and features compound leaves with pinnate leaflets. The flowers, self-pollinated by nature, range from white to pink or purple and eventually give way to pods containing one or two seeds. It accounts for 20% of the world pulses production. Major producers of chickpea include India, Pakistan and Mexico. Six countries including India, Australia, Turkey, Myanmar, Pakistan and Ethiopia account for about 90% of world chickpea production. India is also the largest consumer of chickpea in the world. As a result, the country occupied second place in world despite contributing for about 70% of world's total production. According to the latest available estimates by the FAO, Pakistan is the largest importer of chickpea while Australia is the largest exporter in the world in 2011. In India, chickpea accounts for about 45% of total pulses produced in the country. Its high nutritional content, long shelf life and culinary diversity make it the most popular ingredient in a variety of traditional and modern dishes, further consolidating its role in the global diet. In addition to its importance in human nutrition, chickpea cultivation also brings significant benefits to the agricultural system. It helps to break the cycle of pests and diseases, improve soil fertility, promote crop rotation, and reduce dependence on monoculture practices. By promoting a more flexible and productive agricultural system, chickpeas play a vital role in sustainable agriculture, supporting environmental health and economic prosperity. It plays an important role in human nutrition as well as in restoring the fertility of soil. There are mainly two distinct market types i.e., desi and kabuli (Pundir *et al.,* 1985). The desi types (microsperma) are grown in semi-arid tropics. They produce pink flowers, have anthocyanin pigment in stem with seeds having coloured, rough and thick seed coat. The kabuli (macrosperma) types are mainly grown in temperate areas. They produce white flowers, stem lack anthocyanin pigment and seeds have white coloured seed coat with smooth surface (Jukanti *et al*., 2012 and Maheri *et al*., 2008). The desi types account for about 85% of total chickpea growing area while kabuli types cover 15% (Babanrao, 2009). The major chickpea growing states in India are Madhya Pradesh, Maharashtra, UP, Rajasthan, Haryana and Karnataka. Gram (Chickpea) recorded a highest production of 11.91 MT with a record productivity level of 1192 kg/ha in an area of 9.99 Mha in India. Chickpea is one of the major crops in Rajasthan, grown in 2.11 Mha area with total production of 2.26 MT and productivity of 1072 kg/ha (Anonymous, 2021). In Rajasthan, it is grown in almost all districts but grown extensively in Jaipur, Dausa, Sikar, Sri Ganganagar, Hanumangarh, Baran and Kota. Chickpea is a cheap source of protein compared to animal protein. Its proteins are of higher nutritive value than those of other grain legumes (Gupta and Kapoor, 1980). Chickpea proteins also have higher digestibility, due to the particular amino acid composition. The grains have high contents of essential amino acids like cysteine, methionine and tryptophan in addition to being rich in minerals, vitamins and carbohydrates (Williams and Singh, 1987). Bengal gram husk is used as cattle feed and being a legume crop fixes a significant amount of nitrogen and improves the fertility status of the soil. It is a hardy and deep-rooted legume crop grown mostly on marginal land, which is unsuitable for growth and production of other crops. In addition, being a legume, it can enrich the soil with at least 50 kg of nitrogen/ ha every season. The Chickpea (*Cicer arietinum*) is caused by soil-borne fungal pathogen, *Fusarium oxysporum* f.sp. *ciceri.* This pathogen enters in the vascular system and the plant where it may cause symptoms such as yellowing of leaves, wilting and plant death. Chickpea production is severely affected by *Fusarium* wilt, which causes large decreases in crop yield and quality. Typically the disease is difficult to manage, because it can live long in the soil, thus limiting the effectiveness of traditional control measures like crop rotation or fungicide applications. As such, there has been an increasing concern over over use of chemical fungicides that enhance development of resistance, pose environmental toxicity and health risk to humans thus motivating researchers to find alternative sustainable means to combat the disease.

METABOLITES IN MEDICINAL AND AROMATIC PLANTS

Few recent studies on the antifungal action of plants, especially medicinal and aromatic plants, have been carried out as a natural remedy in *Fusarium* wilt management. Secondary metabolites such as alkaloids, flavonoids, terpenoids and phenolic compounds produced by many plants have been shown to possess strong antifungal activity against diverse plant pathogens. These bioactive compounds can break fungal cell structure, stop growth and promote plant resistance, providing a non chemical, environmentally friendly, cost effective alternative fungicide. Our studies indicate that the antifungal properties of extracts of neem (*Azadirachta indica*), garlic (*Allium sativum*), and tulsi (*Ocimum sanctum*) can be used in controlling the *Fusarium oxysporum* f. sp. *ciceri* in chickpea. There is growing interest for organic farming and sustainable agriculture, which makes this work of identifying plants with potent antifungal activity against *Fusarium* wilt quite exciting to apply natural bio-control against the fungus. In this review, we review the possibility of higher plant metabolites for the control of *Fusarium* wilt in chickpea in terms of their mechanism of action, antifungal efficacy, and adaptability for on farm use.

DISEASES IN CHICKPEA AND THEIR BIOLOGICAL CONTROL

Khan *et al*. (2005) reported Chickpea (*Cicer arietinum*) is an important leguminous crop susceptible to various diseases, including wilt disease caused by the fungal pathogen *Fusarium oxysporum* f. sp. *ciceri* (FOC). Resistance mechanisms in chickpea against this devastating disease involve intricate biochemical processes. One key component of chickpea's resistance is the activation of the plant's innate immune system. When FOC enters the plant through the roots, it triggers a series of biochemical responses. Recognition receptors on the plant's cell surface detect pathogen-associated molecular patterns (PAMPs) from FOC, initiating a defense response. This recognition leads to the production of reactive oxygen spp. (ROS) and activation of various defense-related enzymes, such as peroxidases and polyphenol oxidases. These enzymes play a crucial role in strengthening the cell wall, preventing pathogen penetration.chickpea produces antimicrobial peptides and secondary metabolites like phytoalexins as part of its defense arsenal. These compounds inhibit the growth and spread of FOC within the plant tissues. Additionally, the activation of resistance (R) genes in chickpea results in the synthesis of proteins that recognize specific effectors produced by the pathogen, leading to a hypersensitive response that restricts the pathogen's growth. Chickpea's resistance against Fusarium wilt disease involves a complex interplay of biochemical processes, including ROS production, enzymatic activities, antimicrobial peptides, and the activation of R genes. Understanding these mechanisms can aid in the development of more resistant chickpea varieties through breeding or biotechnology, helping to protect this essential crop from FOC and ensuring food security. The evaluation of *Trichoderma* spp. *against Fusarium oxysporum* f. sp. *ciceri* (FOC) for integrated management of chickpea wilt represents a vital and sustainable approach to combat this destructive disease. *Trichoderma* is a group of beneficial fungi well-known for their bio-control capabilities against various plant pathogens, including FOC. *Trichoderma* spp. exhibit several mechanisms by which they suppress FOC and enhance the overall health of chickpea plants. They compete with the pathogen for resources and space, thereby inhibiting its growth and colonization of chickpea roots. *Trichoderma* can also produce a wide array of antifungal metabolites and enzymes, such as chitinases and β-1,3-glucanases, which directly target and degrade the FOC cell wall components increased crop productivity and food security (Dubey *et al*.,2007)**.**

Mukhtar (2007) find during experiment *Azadirachta indica* and *Datura metel* plant extract exhibit fungicidal activity against *Fusarium oxysporum* f.sp.*ciceri.* Chickpea wilt caused by *Fusarium oxysporum* f. sp. *ciceri* (FOC) is a critical challenge in chickpea cultivation. Integrated disease management strategies are essential for reducing the impact of this pathogen on crop yield and quality. Crop rotation is a fundamental practice to manage chickpea wilt. Rotating chickpea with non-host crops can help break the disease cycle by depriving FOC of its primary host. The selection of disease-resistant chickpea cultivars through breeding programs can significantly reduce disease incidence. Soil health and sanitation play a crucial role in disease management. Proper irrigation practices that avoid water logging and soil drainage improvement can help create unfavorable conditions for FOC survival. Fungicide application may be necessary in severe cases, but it should be used judiciously to prevent the development of fungicide-resistant strains. The incorporation of organic matter into the soil can enhance microbial diversity, including beneficial antagonistic micro-organisms that can suppress FOC. Biological control agents, such as *Trichoderma* spp., have shown promise in reducing FOC populations when applied as biofungicides (Nikam, *et al*. 2007). Uzma *et. al*. (2008) tested antifungal properties of Asafetida (*Ferula asafoetida*), black cumin seed (*Nigella sativa*), Neem (*Azadirachta indica*) and mustard (*Brassica campestris*) oil against wilt pathogen. The neem extract was also effective as an interrupient of pathogen cellular processes due to active compounds (azadirachtin and nimbin). Tulsi and ginger extracts show moderate antifungal activity because they contain phenolic and flavonoid content that facilitate defense natural compounds observed by Babanrao (2009). Ramanjeet Kaur *et al.* (2009) reviewed antifungal activity of ayurvedic medicinal plants, such as *Allium sativum, Zingiber officinale, Glychyrrhiza glabra, Curcuma longa, Mentha piperita, Azadirachta indica, Withania somnifera, Acrous calamus, Piper betel, Adhatoda vasica* and *Ocimum sanctum*. The antifungal activity of ginger and tulsi extracts was moderate, with the inhibition 40–50%. Such effects can be attributed to their phenolic and flavonoid content, with natural fungitoxic effects. In addition, antifungal activity was higher in alcoholic than in water extracts. The alcohol is a much better solvent, extracting a wider range of bioactive compounds which concentrate the potency of the plant extracts (Shrivastava and Agrawal, 2010). Gayatri *et al*. (2012) worked on botanical extracts to the management of *Fusarium* wilt. By combining use of these natural antifungal agents with other approaches, such as using resistant varieties, crop rotation and soil amendments, their use could be further enhanced. These extracts can also be used as seed dressers or as soil drenches for preemptive protection against FOC infection. From some of the higher plant antifungal, a promising environment friendly alternatives for the synthetic fungicides can be found and can provide a sustainable chickpea production without the environmental risks. The mycelial growth inhibitory efficacy of *Azadirachta indica* (neem), *Allium sativum* (garlic), *Ocimum sanctum* (tulsi) and *Zingiber officinale* (ginger) extracts were evaluated by Jukanti (2012) against FOC mycelial growth. These plant extracts contain bioactive compounds disrupt the fungal growth and reproduction, by example, alkaloids, flavonoids, phenolics, sulphur containing compounds but the antifungal efficacy of the examined extracts was shown to be highly variable. Garlic extract, which contains allicin, powerful antifungal materials limiting in garlic such as sulfur compounds, showed the most mycelial growth inhibition.

Minz *et al.* (2012) studied on the effect of plant extracts on the growth of wilt-causing fungi *Fusarium oxysporum* has been a subject of significant research interest due to its potential application in the management of devastating plant diseases. Plant extracts, derived from various botanical sources, contain a wide array of secondary metabolites with antimicrobial properties, and these compounds have shown promise in inhibiting the growth and development of *Fusarium oxysporum*. Many plant extracts contain phytochemicals such as alkaloids, flavonoids, phenolics, and terpenoids, which possess fungicidal properties. These compounds can disrupt critical fungal processes, including spore germination, mycelial growth, and the formation of infection structures. As a result, *Fusarium oxysporum*'s ability to colonize and infect plant roots is compromised, leading to reduced disease severity. The suppression of chickpea (*Cicer arietinum* L.) *Fusarium* wilt by *Bacillus subtilis* and *Trichoderma harzianum* represents a promising and eco-friendly approach to managing this destructive disease. *Fusarium* wilt, caused by *Fusarium oxysporum* f. sp. *ciceri* (FOC), is a major threat to chickpea crops worldwide, making effective disease management crucial. *Bacillus subtilis* is a well-known beneficial bacterium with antagonistic properties against various plant pathogens, including FOC. It can produce antimicrobial metabolites and enzymes that inhibit FOC growth and colonization reported by Moradi *et al.* (2012). According to Shukla & Dwivedi (2012) plant extracts of turmeric, garlic and black pepper can effectively reduce the growth of *Fusarium oxysporum* and such plant extracts can be used in control of wilt in chickpeas and pigeonpea. The integrated management of *Fusarium* wilt of chickpea (*Cicer arietinum* L.) caused by *Fusarium oxysporum* f. sp. *ciceri* (FOC) is a holistic approach that combines microbial antagonists and botanical extracts to effectively control this devastating disease (Hossain *et al*.,2013). However, it is essential to optimize the selection of microbial antagonists and botanical extracts, their application timing, and concentrations to achieve the best results and minimize potential risks associated with disease management.

Nair and Sandhu (2013) reported a Kunitz trypsin inhibitor found in chickpea (*Cicer arietinum* L.) has been discovered to possess antimicrobial properties against *Fusarium oxysporum* f. sp. *ciceri* (FOC), the pathogen responsible for causing *Fusarium* wilt in chickpea plants. Kunitz trypsin inhibitors are a class of proteins commonly found in various leguminous plants, where they primarily serve as defense mechanisms against herbivores by inhibiting proteases in their digestive systems. The field performance of *Trichoderma* spp. against the wilt disease complex of chickpea, caused *by Fusarium oxysporum* f. sp. *ciceri* (FOC) and *Rhizoctonia solani* represents a valuable and integrated approach to managing these devastating pathogens in chickpea cultivation observed by Khan *et al.* (2014) during experiment. *Trichoderma* spp. are well-known bio-control agents with the ability to antagonize a wide range of plant pathogens, including FOC and *Rhizoctonia solani*.

Mintz and Levy (2014) tested twenty five plants against *Fusarium* which are as follows *Adhatoda vasica, Aerva javanica, Aloe barbadensis, Alpinia carinata, Anagalis arvensis, Bixa Orellana, Chenopodium ambrosioides, Cinnamomum zeylanicum , Curcuma amada, Cyperus rotundus, Euphorbia hirta, Ferula foetida, Gompherina globosa, Lawsonia inermis, Memosa pudica, Momordica charantia, Ocimum gratissimum, Parthenium hysterophorus , Putranjiva roxburghii, Rauvolfia serpentine, Solanum nigrum, Thevetia peruviana, Tridax procumbans, Vitex negundo and Xanthium strumarium. Out of which extract of Chenopodium ambrosioides* was the most effective of all the botanicals and showed 100% inhibition of mycelial growth. Five medicinal plant extracts were tested in 2015 by Dwivedi and Sangeeta against *Fusarium oxysporum* f.sp.*ciceri* .Selected plants and their parts used viz. *Trachyspermum ammi* –Seeds, *Zingiber officinale*-Rhizome, *Tinospora cordifolia*-Leaves, Cymbopogon citrates-Leaves and *Moringa oleifera*-Bark, From the results it was concluded that all five aqueous plant extracts possess strong antifungal property. But these three medicinal plant extracts-*Tinospora cordifolia*- Leaves, *Cymbopogon citrates*- Leaves and *Moringa oleifera*- Bark They showed greater antifungal properties and can be used as natural biocontrol agent.

The plant extracts of neem (*Azadirachta indica*), garlic (*Allium sativum*), ginger *(Zingiber officinale*), and tulsi (*Ocimum sanctum*) were tested using the poisoned food technique for their antifungal activity (Mahmood, 2015). Results showed that the inhibitory potential of these extracts was varied and significant. The most effective was found in garlic extract, which caused over 70% inhibition of fungal growth. The plant extracts inhibiting the mycelial growth of *Fusarium oxysporum* f. sp. *ciceri* (FOC), the causing agent for *Fusarium* wilt in chickpeas, to use in sustainable disease management. Mahmood *et al*. (2015) studied on the comparative efficacy of fungicides and biological control

Table-1 Toxicity of plants against pathogen *Fusarium oxysporum* f.sp. *ciceri* (Navneet and Rao 2024)

S.No	Botanical Name	Common/Local Name	Family	Pathogen
1	*Azadirachta indica*	Neem	Meliaceae	*Fuarium oxysporum* f.sp. *ciceri*
2	*Curcuma longa*	Turmeric	Zingiberaceae	*Fuarium oxysporum* f.sp. *ciceri*
3	*Allium sativum*	Garlic	Amaryllidaceae	*Fuarium oxysporum* f.sp. *ciceri*
4	*Zingiber officinale*	Ginger	Zingiberaceae	*Fuarium oxysporum* f.sp. *ciceri*
5	*Ocimum sanctum*	Tulsi	Lamiaceae	*Fuarium oxysporum* f.sp. *ciceri*
6	*Eucalyptus globulus*	Eucalyptus	Myrtaceae	*Fuarium oxysporum* f.sp. *ciceri*
7	*Aloe barbadensis*	Aloe Vera	Liliaceae	*Fuarium oxysporum* f.sp. *ciceri*
8	*Mentha piperita*	Mint	Lamiaceae	*Fuarium oxysporum* f.sp. *ciceri*
9	*Allium cepa*	Onion	Amaryllidaceae	*Fuarium oxysporum* f.sp. *ciceri*
10	*Cymbopogon citratus*	Lemongrass	Poaceae	*Fuarium oxysporum* f.sp. *ciceri*
11	*Murraya koenigii*	Curry Leaf	Rutaceae	*Fuarium oxysporum* f.sp. *ciceri*
12	*Ocimum basilicum*	Basil	Lamiaceae	*Fuarium oxysporum* f.sp. *ciceri*
13	*Piper nigrum*	Pepper	Piperaceae	*Fuarium oxysporum* f.sp. *ciceri*
14	*Syzygium aromaticum*	Clove	Myrtaceae	*Fuarium oxysporum* f.sp. *ciceri*
15	*Trigonella foenum-graecum*	Fenugreek	Fabaceae	*Fuarium oxysporum* f.sp. *ciceri*
16	*Coriandrum sativum*	Coriander	Apiaceae	*Fuarium oxysporum* f.sp. *ciceri*
17	*Petroselinum crispum*	Parsley	Apiaceae	*Fuarium oxysporum* f.sp. *ciceri*
18	*Thymus vulgaris*	Thyme	Lamiaceae	*Fuarium oxysporum* f.sp. *ciceri*
19	*Tagetes erecta*	Marigold	Asteraceae	*Fuarium oxysporum* f.sp. *ciceri*
20	*Salvia rosmarinus*	Rosemary	Lamiaceae	*Fuarium oxysporum* f.sp. *ciceri*
21	*Withania somnifera*	Ashwagandha	Solanaceae	*Fuarium oxysporum* f.sp. *ciceri*
22	*Hibiscus rosa-sinensis*	Hibiscus	Malvaceae	*Fuarium oxysporum* f.sp. *ciceri*
23	*Matricaria chamomilla*	Chamomile	Asteraceae	*Fuarium oxysporum* f.sp. *ciceri*
24	*Moringa oleifera*	Moringa	Moringaceae	*Fuarium oxysporum* f.sp. *ciceri*
25	*Laurus nobilis*	Bay Leaf	Lauraceae	*Fuarium oxysporum* f.sp. *ciceri*

agents for managing chickpea wilt caused by *Fusarium oxysporum* f. sp. *ciceri* (FOC) is a critical consideration in disease management strategies. Both approaches have their advantages and limitations, and their effectiveness can vary depending on various factors. Fungicides are chemical compounds specifically formulated to combat fungal pathogens like FOC. They offer rapid and often reliable control of the disease when applied correctly. Triazole-based fungicides, such as tebuconazole and propiconazole, have demonstrated efficacy in inhibiting FOC growth and reducing disease severity. However, their long-term sustainability is a concern, as repeated use may lead to the development of fungicide-resistant strains of FOC. Biological control agents, such as *Trichoderma* spp. and *Bacillus* spp., harness naturally occurring micro-organisms to suppress FOC. The choice between fungicides and biological control agents should be based on a careful assessment of local conditions, disease pressure, and the goal of achieving effective, eco-friendly chickpea wilt management. Patra and Biswas (2017) had done their experiment on eco-friendly management of *Fusarium oxysporum* f. sp. *ciceri* (FOC), the causal agent of chickpea wilt disease, is a crucial endeavor even under in-vitro conditions. This approach seeks to control the pathogen while minimizing environmental harm and promoting sustainable agriculture. One eco-friendly method involves the use of biological control agents, such as *Trichoderma* spp. and *Pseudomonas fluorescens* in in-vitro studies. Plant extracts from various botanical sources have also demonstrated eco-friendly antifungal properties under in-vitro conditions. These extracts contain secondary metabolites like alkaloids, flavonoids, and terpenoids, which exhibit fungicidal activity against FOC. The antifungal activity of metabolites from medicinal plants tested against wilt of chickpea caused by *Fusarium oxysporum* f. sp. *ciceri* (FOC) presents a promising avenue for the sustainable management of this devastating disease. Medicinal plants are renowned for their diverse secondary metabolites, many of which exhibit potent antimicrobial properties. Various studies have investigated the efficacy of plant metabolites in combating FOC. Compounds such as alkaloids, flavonoids, polyphenols, and terpenoids found in medicinal plants have demonstrated antifungal activity. These metabolites can disrupt key fungal processes, including spore germination, mycelial growth, and pathogenicity, thereby reducing the severity of *Fusarium* wilts in chickpea crops. Kumari and Khanna (2020) reported that the beneficial soil micro-organisms such as *Bacillus* and *Pseudomonas* have the ability to produce antimicrobial metabolites and lytic enzymes that can inhibit the growth and pathogenicity of FOC. By colonizing the chickpea rhizosphere, they create an environment that is hostile to the pathogen, reducing its ability to infect plant roots. Jamil and Ashraf (2021**)** studied on the sustainable management of chickpea wilt caused by *Fusarium oxysporum* f. sp. *ciceri* (FOC) using plant extracts has emerged as a promising eco-friendly approach in agriculture. Plant extracts, derived from various botanical sources, contain bioactive compounds with antimicrobial and antifungal properties that can help mitigate the devastating impact of FOC on chickpea crops. One effective strategy involves using plant extracts as natural fungicides. These extracts often contain secondary metabolites such as alkaloids, flavonoids, and terpenoids, which possess fungicidal properties. When applied to chickpea plants, these extracts can inhibit the growth and development of FOC, reducing disease severity. Overall, utilizing plant extracts as a sustainable management strategy holds great promise in combating *Fusarium* wilt in chickpea cultivation while minimizing environmental impacts. Poveda (2021) performed their work on the biological control of *Fusarium oxysporum* f. sp. *ciceri* (FOC) and *Ascochyta rabiei* pathogens. *Trichoderma* spp. Employ various mechanisms to combat FOC and *Ascochyta rabiei*. They compete with the pathogens for resources and space in the rhizosphere, inhibiting their growth and colonization of chickpea roots. *Trichoderma* also produces antimicrobial metabolites and lytic enzymes, such as chitinases and glucanases, which directly target and degrade the fungal cell walls of these pathogens. *Trichoderma* spp. can induce systemic resistance in chickpea plants against both FOC and *Ascochyta rabiei*. Epidemiology and pathogenicity of vascular wilt of chickpea (*Cicer arietinum* L.) caused by *Fusarium oxysporum* f. sp. *ciceri* (FOC) is a complex and significant issue in chickpea agriculture. FOC is a soil-borne fungal pathogen that poses a severe threat to chickpea crops worldwide. The disease epidemiology involves various factors, including the survival of FOC in soil, its transmission through infected plant debris, and its spread via contaminated seeds and irrigation water. The fungus enters the plant through the root system, colonizing the vascular tissues and causing wilting symptoms. Understanding the epidemiology, pathogenicity, and host defense responses of chickpea vascular wilt is essential for developing effective disease management strategies. These may include breeding for resistant cultivars, implementing cultural practices, and exploring bio-control agents to mitigate the impact of FOC and ensure the sustainability of chickpea production observed in during experimentation by Muche and Yemata (2022). Faima (2023) reported the *Bacillus thuringiensis* strain CHGP12 demonstrates a multifaceted approach to effectively suppress *Fusarium oxysporum* f. sp. *ciceri* (FOC), the causal agent of chickpea wilt. The *Bacillus thuringiensis* CHGP12 produces antimicrobial compounds, including antibiotics and lipopeptides, which exhibit strong antagonistic activity against FOC. These antimicrobial metabolites inhibit the growth and development of the pathogen, reducing its pathogenicity and virulence. *Bacillus thuringiensis* CHGP12 can induce systemic resistance in chickpea plants. The multifaceted approach of *Bacillus thuringiensis* CHGP12, combining direct antagonism against FOC, enzymatic degradation, and the induction of systemic resistance, makes it a promising bio-control agent for sustainable chickpea cultivation. Its ability to enhance plant growth further underscores its potential as a valuable tool for integrated disease management and improved crop productivity.

Navneet and Rao (2024) tested against 25 plant species *Fusarium oxysporum* f.sp. *ciceri*.' medicinal, aromatic and culinary species, which demonstrate bioactive compounds, were selected for antifungal study. For example, various compounds like azadirachtin (Neem, *Azadirachta indica*), allicin (Garlic, *Allium sativum*), curcumin (Turmeric, *Curcuma longa*), etc. have antimicrobial properties that make Neem, Garlic, and Turmeric well known. Flavonoids and essential oils from Eucalyptus (*Eucalyptus globulus*), Tulsi (*Ocimum sanctum*) and Mint (*Mentha piperita*) also have antifungal activity. However, lesser known species such as Marigold (*Tagetes erecta*), Ashwagandha (*Withania somnifera*), and Moringa (*Moringa oleifera*) broaden the horizon of bio-control strategies that are plant based. Their potential in the sustainable agriculture as eco-friendly substitutes for the management of chickpea wilt by way of reducing the dependency on the synthetic fungicides were tested by determining these plants' ability to inhibit the growth of chickpea wilt pathogen, *Fusarium oxysporum* f.sp. *ciceri* (Table-1).

CONCLUSION

The conventional use of synthetic fungicides has led to the emergence of numerous challenges, including environmental pollution, residue accumulation in grains, and harm to non-target organisms. As a result, there is an urgent need for cost-effective and environmentally sustainable management practices to mitigate the losses incurred by *Fusarium* wilt. This necessitates a comprehensive understanding of the disease's various aspects, including symptomatology, and the pathogen's behavior. To address these challenges, this study delves into exploring alternative management strategies for Fusarium wilt. By investigating the efficacy of bioagents and plant extracts against *Fusarium oxysporum* f.sp.*ciceri*, the research aims to provide insights into sustainable approaches for disease management.

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