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Insights into Fusarium Wilt of Peas (*Pisum sativum*) and its Management Strategies

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Abstract

Fusarium wilt of peas, caused by *Fusarium oxysporum* f. sp. *pisi*, is a destructive disease affecting pea crops globally. This paper examines the pathogen's biology, epidemiology, and transmission mechanisms, focusing on how soil-dwelling insects, human activities, machinery, water, wind, and animals contribute to disease spread. It also explores recent disease management strategies, such as developing resistant pea varieties, crop rotation, and soil health practices. The importance of integrated disease management, combining cultural, biological, and chemical approaches, is emphasized as a means to reduce Fusarium wilt's impact. This review aims to synthesize current research and provide practical insights for researchers, agronomists, and farmers working to control the disease and ensure sustainable pea production.

Keywords: Epidemiology, Characterization, Distribution, Disease management, Transmission

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Introduction

The rising frequency and severity of plant disease outbreaks increasingly threaten primary productivity, global food security, and biodiversity, especially in vulnerable regions (Nauman et al., 2023; Naqvi et al., 2024). These outbreaks cause significant losses in crop yields and ecosystems, costing around US$220 billion annually due to pathogens and pests. This impacts food security, local economies, and various interconnected social and economic factors (Azeem et al., 2020; Ali et al., 2020; Anwaar et al., 2022; Rehman et al., 2023; Iftikhar et al., 2024). Pea (*Pisum sativum*), also called garden pea, is an herbaceous plant belonging to the family Fabaceae and is cultivated primarily for its edible seeds. It is a rabi-season crop grown throughout the world, with planting occurring from winter to early summer, depending on the region's climate. Peas are relatively easy to grow and offer a good source of protein and nutritional fiber. The weight of a pea ranges from 0.1 to 0.36 grams. The native regions of the pea are Western Asia and North Africa, with wild varieties still found in Afghanistan, Iran, and Ethiopia (Jadon et al., 2020). Pea farming spread to India and Eastern Europe about 4,000 years ago and was introduced to China in the first century, soon reaching the New World (Pratap & Kumar, 2011).

The pea seed is a small spherical pod that contains numerous green or yellow peas. Botanically, pea pods are classified as fruits since they develop from the ovaries of pea flowers and contain seeds. The term "pea" is also used to describe other edible seeds from the Fabaceae family, such as pigeon peas (*Cajanus cajan*), cowpeas (*Vigna unguiculata*), and other species of *Lathyrus*. Field peas, typically grown for dry peas, resemble split peas removed from ripe pods. Seeds can be sown once the soil reaches 10°C, but peas grow best between 13 and 18°C. They thrive in cooler, higher-altitude tropical locations but cannot withstand the summer heat of hot temperate or lowland tropical climates. Many cultivars reach maturity approximately 60 days after planting. The pea karyotype consists of seven chromosomes, five of which are acrocentric and two sub-metacentric. Its relatively large genome (4.45 GB) is often studied in genetic research.

Peas are a significant annual pulse crop, first cultivated in the Mediterranean region (Khulbe & Sharma, 2020). The plant has hollow stems that trail or climb, reaching lengths up to 1.8 meters (6 feet). Climbing tendrils and compound leaves with three leaflets are seen on the stems. Each stalk bears two to three clusters of butterfly-shaped flowers in shades of red, purple, pink, or white. The fruit is a pod that splits in two and can grow up to 10 cm (4 inches) in length, containing five to ten seeds connected by thin stalks. The seeds may be green, yellow, white, or variegated. Peas are widely produced in countries such as China, India, France, the United States, Kenya, Egypt, Algeria, the United Kingdom, and Morocco. In Pakistan, pea production in 2015-16 totaled 144,422 tons from an area of 22,436 hectares, with an average yield of 6.44 tons per hectare. The highest output in Punjab during the same period was 112,267 metric tons, covering 17,644 hectares. Gujranwala, Nankana Sahib, Multan, Sahiwal, Toba Tek Singh, Sialkot, Jhang, and Sheikhupura are primary pea-producing areas in Punjab. Pea cultivation is widespread across Pakistan, with production shares of 71.2%, 4.7%, 12.8%, and 11.3% in Punjab, Sindh, KPK, and Baluchistan, respectively (Ullah et al., 2020). Pea plants prefer cool weather and suffer when the temperature rises above 27°C (Marsh, 2014). Additional shoots emerge from nodes beneath the soil surface if the main shoot is killed by frost. (Davies & Muehlbauer, 2020).

The review aims to explore the biology, transmission and plant pathogen interaction. Helping to improving pea production sustainability through integrated pest management and climate-resilient practices.

Fusarium Wilt

Among the common diseases affecting peas are root rot, powdery mildew, and viral infections (Kharte, 2022). Several diseases, including those caused by Fusarium species, such as Rhizoctonia seedling blight, bacterial blight, Ascochyta foot rot, downy mildew, powdery mildew, Pythium blight, Aphanomyces root rot, and wilt, impact pea crops (Soylu & Dervis, 2011). Fusarium wilt, caused by *Fusarium oxysporum* f.sp. pisi, is prevalent wherever peas (Pisum sativum L.) are commercially produced (Merzoug, 2014). The pathogen resides in the soil as hard, resting chlamydospores, which can survive for more than ten years (Gupta & Gupta, 2019). *F. oxysporum* invades roots and damages the vascular system at any stage of pea plant growth (Bani et al., 2018). Infected plants typically exhibit orange or dark red discoloration in the lowest stem and root portions. Above-ground symptoms during flowering to pod-fill stages include yellowing, wilting, and downward curling of leaves. Early infection often results in seedling death, although the development of neighboring plants can conceal it (Sampaio et al., 2020). *FOP* isolates are categorized based on host-pathogen interactions using the genetic makeup of both the host and the pathogen (Kraft, 1994). The availability of complete genomic sequences of plants and pathogens has provided profound insights into the host-pathogen relationship through comparative genomics (Jadon, 2020). Maximum yield losses in most varieties can reach up to 100% (Persson et al., 2007). Four *FOP* races have been discovered based on differential pathogenicity in pea varieties (Jenkins et al., 2021). The majority of *Fusarium oxysporum* f. sp. species produce chlamydospores, which remain dormant until triggered to germinate in decomposing host tissue and soil (Sidharthan et al., 2019). The most frequent entry sites for the *Fusarium wilt* pathogen in pea plants are the cotyledonary node, the undifferentiated zone of the root tips, and damaged roots (Sharma, 2011). Before the xylem elements are invaded, a susceptible pea plant may become infected inter- or intracellularly (Beckman & Talboys, 1981). *Fusarium oxysporum* is identified as one of the most harmful plant pathogens, with numerous toxigenic forms (formae speciales), and is the most common resident in cultivated fields (Savary et al., 2019). Fusarium wilt is an important disease in peas and often results in near-total crop loss (Sharma, 2011).

Distribution

Pea wilt disease, caused by *Fusarium oxysporum* f.sp. pisi, has been documented in all countries where peas are commercially cultivated (Snyd & Hans, cited in Haglund, 1984). Fusarium wilt is one of the most destructive diseases in Minnesota (Starr, 1933). In Holland, the intensity of the disease increased in 1951, with a further expansion of pea-growing areas contaminated by *Fusarium oxysporum* f.sp. pisi race I (Kerling, 1952). In Britain, pea wilt has also been reported, with infected plants yielding *Fusarium* species. In India, *Fusarium* wilt is common in Maharashtra, where it caused significant damage to pea crops (Sukapure et al., 1957). During 1981-82 and 1982-83, pea wilt in northern Madhya Pradesh ranged from 12.5% to 30.25% and from 19.57% to 37.39%, respectively (Sharma et al., 1989). Root rot in peas was reported in the United States by Vaughan in 1924, causing significant crop losses in New Jersey (Stevens & Stevens, 1941). Fusarium rot of the pea stem was reported by Reiling et al. (1960), and Basu et al. (1978) estimated a yield loss of 22.7% due to severe root rot. Infested pea fields in the U.S. have resulted in up to 50% yield reduction (Oyarzun, 1993). In Ningxia, the disease caused significant yield losses (KuanCang et al., 1995). In India, Fusarium wilt is a serious threat, causing up to 60% losses in affected regions. Pathogenicity tests using pathogen metabolites and spores confirmed the prevalence of Fusarium wilt in India, with severe pathogenicity exhibited by isolates from Ghana village (Sharma, 2011). In the study by Luhová et al. (2006), two genotypes of *Pisum sativum* (cv. Smaragd and line DP1059) with varying susceptibilities to *Fusarium oxysporum* and *Fusarium solani,* and their impact on enzyme activity, were evaluated.

Vector and Transmission

Fusarium wilt of peas, caused by *Fusarium oxysporum* f.sp. pisi, primarily spreads through soil and plant debris (Sampaio et al., 2020). However, various vectors facilitate its transmission indirectly. Soil-dwelling insects, such as nematodes, contribute by carrying fungal spores on their bodies as they move through the soil. These insects do not directly infect plants but create wounds that allow the fungus to enter or transport spores to new locations, enhancing the pathogen's spread. Human activities also play a significant role in vector transmission (de Souza & Weaver, 2024). Workers moving between infected and healthy fields can inadvertently carry infested soil or plant debris on their clothing, footwear, and tools. These particles harbor Fusarium spores, which are then deposited in previously uninfected areas, initiating new infection sites (Smith, 2007). Agricultural machinery, including tractors, plows, and harvesters, can be vectors of Fusarium transmission (Reddy, 2007). Soil and plant debris lodged in the machinery can be transported to healthy fields, accelerating disease spread (Hazell et al., 2010). Improper disposal of plant debris and soil during field operations further exacerbates the problem, as decomposing infected plant material releases spores into the soil. Even routine activities such as planting, weeding, and harvesting contribute to disease spread if proper sanitation practices are not followed (Katan, 2000). Water, particularly in surface irrigation systems, can also transport Fusarium spores from infected areas to healthy plants (Lima et al., 2019). Although wind is not a primary vector, it can lift and carry contaminated soil particles containing Fusarium spores, thereby spreading the infection over considerable distances (Hoffmann et al., 2021). Animals, including rodents, birds, and livestock, can transmit Fusarium wilt by picking up fungal spores on their bodies and depositing them in new areas.

Molecular Characterization

Pea plants infected with *Fusarium oxysporum* exhibit symptoms of chlorotic leaflets that curl downward and become flaccid (Azeem et al., 2022). The plants ultimately wither, developing a yellowish-brown hue. The vascular system above and below ground often shows a range of colors from light yellow to brick-red. The underground stem becomes enlarged, particularly at the lower portion (Kraft, 1994). Symptoms of wilt include premature drooping of leaves, which may or may not be accompanied by discoloration. The tap root and lower internodes often show vascular redness and vein infections. The disease typically develops in circular patterns, causing the most damage in fields where peas have been cultivated consecutively for several years (Haglund & Pepin, 1987). Fusarium species cause rapid and noticeable discoloration in the vascular system, particularly *Fusarium solani,* although *Fusarium oxysporum* does not significantly affect the root system’s color. The fungi infiltrate the root hairs and epidermal cells without causing visible damage. Multiple protrusions are generated on the inner cell wall as the hyphae penetrate the two cortical cell layers. In severe cases, the mycelium extends from the outer layer of cells into the vessels, primarily through the bordered pits (Went, 1934). Young seedlings are most commonly infected at the root tip or cotyledonary node but can also be infected at almost any point along the root and epicotyl region. Once inside the plant, the fungus is confined to the xylem vessels. In susceptible varieties, the fungus can extend along the entire stem, while in resistant varieties, it may be restricted to a localized area. Sometimes, the fungus reaches the seed through the vascular system and can be located in the seed coat and cotyledons. Seedlings infected with Fusarium often develop diseased plants (Virgin, 1940).

Figure 1. Symptoms of *Fusarium Wilt* of Peas

Mechanism of Transmission of Seed in Fusarium Wilt Pathogen

Snyder (1933) reported that *Fusarium oxysporum* f. sp. *pisi* race one can be intermittently transmitted by seeds gathered from wilt-affected fields. Only four out of 8,000 seeds examined were identified as carriers of the wilt pathogen, as determined by conducting a field grow-out test. Snyder clarified that in exceptional circumstances, small soil particles can become trapped in a concavity on the exterior of a seed, potentially serving as a habitat for the fungus. Snyder claimed that the race 1 pathogen can be obtained from the stem node on a withered plant, particularly the spot where the initial pod emerges. Although there is no evidence, the infection could penetrate the pedicel, impacting the pod and seed. In their study, Maheshwari et al. (1982) successfully recovered *Fusarium oxysporum* f. sp. *pisi* from the surface-disinfested seed of six varieties cultivated in the Hoshiarpur district of Punjab, India, a region known for pea root rot and wilt. The discovered isolates of *Fusarium oxysporum* exhibited pathogenicity. However, the researchers refrained from classifying these isolates into any specific race based on differential variations.

The author believes that the ability of the pea wilt pathogen to be transmitted internally within seeds depends on the age of the plant when signs of wilt are observed. The likelihood of seed transmission of the race 2 pathogen, which targets a pea plant during the flowering to pod development stage, is significantly higher compared to race 1, 5, or 6, which typically result in the death of a vulnerable plant before it blooms.

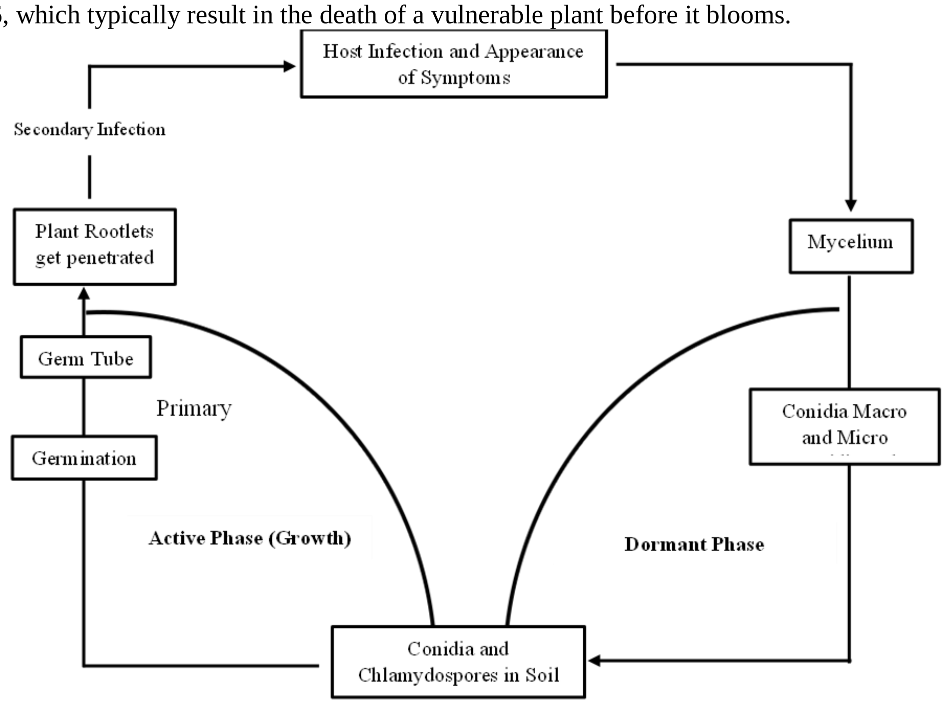

Figure 2. Disease cycle of *Fusarium Wilt* of Peas

Management

Extended crop rotations and early planting can limit the occurrence of disease, but the most useful and economical management technique is the use of biocontrol agents and resistant cultivars (Hashem et al., 2020; Ali et al., 2024a; Ali et al., 2024b; Ayub et al., 2024). Due to the soil-borne pathogen's ability to persist as hard resting chlamydospores in soil for ten years or more, the incidence of wilt disease frequently increases when pea crop rotations are employed with different crops (Kraft, 1994). This enables the disease to infect the soil sufficiently, leading to catastrophic crop losses when a susceptible cultivar is planted later. Fungicides cannot effectively manage the soil-borne Fusarium wilt (Sharma, 2011). As a result, most of the controls for *Fusarium oxysporum* f. sp. *pisi* depend on using resistant pea varieties, which is why most researchers have focused on developing and identifying resistant varieties (Bani et al., 2012; Sharma, 2011). Although using disease-free pea cultivars is a successful strategy, there remains a persistent danger of reduced resistance due to the emergence of new pathogenic strains (Bani et al., 2012). Shubha et al. (2016) proposed that being a soil-borne fungus, *Fusarium* is extremely difficult to treat chemically, leaving the breeding of resistant cultivars as the only viable option.

To uncover sources of resistance against Fusarium wilt, 34 genotypes of garden peas gathered from various sources were assessed during the winter seasons under sick plots and in an artificially controlled environment. The ratios of Mendelian segregation resistance and susceptibility among the infected progeny were calculated using chi-square analysis. The outcomes showed that a monogenic dominant gene controls the resistance to Fusarium wilt in garden peas. Varieties or lines in sick plots and their resistance to Fusarium wilt produced by *Fusarium oxysporum* f. sp. *pisi* were assessed by Akash et al. (2022), and only one of the 20 kinds or lines, Garrow, was moderately resistant. The efficacy of five fungicides antagonistic to *Fusarium oxysporum* f. sp. *pisi* was assessed in vitro, with substantial differences between treatments. The three most successful fungicides in preventing fungal growth were Tilt (propiconazole), Daconil (chlorothalonil), and Crest (carbendazim). The given fungicide list highlights their importance and mode of action (Table 1).

Table 1. List of Fungicides with Their Mode of Action

Fungicide	Chemical Group	IRAC Classification	Mode of Action
Thiophanate-methyl	Benzimidazole	1	Inhibits mitosis and cell division
Fludioxonil	Phenylpyrrole	12	Interferes with signal transduction
Metalaxyl-M	Phenylamide	4	Inhibits RNA synthesis
Azoxystrobin	Qol (Strobilurin)	11	Inhibits mitochondrial respiration
Propiconazole	Triazole	3	Inhibits ergosterol biosynthesis
Boscalid	Succinate dehydrogenase inhibitor (SDHI)	7	Inhibits mitochondrial respiration
Cyprodinil	Anilinopyrimidine	9	Interferes with methionine biosynthesis
Pyrimethanil	Anilinopyrimidine	9	Interferes with methionine biosynthesis
Tebuconazole	Triazole	3	Inhibits ergosterol biosynthesis
Myclobutanil	Triazole	3	Inhibits ergosterol biosynthesis

Conclusion

Fusarium wilt, caused by *Fusarium oxysporum* pv. *pisi*, poses a significant threat to pea cultivation worldwide, leading to substantial yield losses and economic impact. This review has highlighted the complex nature of the disease, encompassing its pathogen biology, epidemiology, and the environmental conditions that favor its proliferation. Effective management of Fusarium wilt necessitates an integrated approach combining cultural practices, resistant cultivars, biological controls, and chemical treatments. Using resistant pea varieties remains the most sustainable and effective long-term strategy.

However, developing such varieties is challenging due to the genetic variability and adaptability of *Fusarium oxysporum*. Cultural practices like crop rotation, soil health management, and sanitation are crucial in reducing disease incidence. Chemical fungicides, although effective, must be used judiciously to prevent resistance buildup and environmental harm. Recent advancements in molecular techniques have provided more profound insights into pathogen-host interactions, aiding in identifying resistance genes and developing molecular markers for breeding programs. Additionally, exploring biological control agents offers promising alternatives to chemical treatments, contributing to sustainable disease management practices.

Future Recommendations

Future research and management strategies for Fusarium wilt in peas should focus on several key areas to enhance the effectiveness and sustainability of control measures. Breeding programs must intensify efforts to develop resistant pea varieties using advanced genomic tools and molecular markers. These tools can help identify and incorporate resistance genes from diverse germplasm. Additionally, the potential of gene-editing technologies, such as CRISPR/Cas9, should be explored to develop Fusarium wilt-resistant pea varieties with precision. Biological control strategies offer promising alternatives to chemical treatments. Investigating the efficacy of beneficial microbes, such as *Trichoderma* spp., *Bacillus* spp., and mycorrhizal fungi, in suppressing Fusarium wilt through biocontrol mechanisms is crucial. Moreover, manipulating soil and plant microbiomes to enhance natural disease resistance and suppress pathogenic Fusarium populations presents an innovative approach worth pursuing. Developing and testing novel fungicides with unique modes of action are essential to combat Fusarium wilt effectively while minimizing the risk of resistance development. Implementing integrated fungicide management strategies that combine chemical treatments with cultural and biological controls can achieve more sustainable disease management. Comprehensive studies on the genetic diversity and pathogenicity of *Fusarium oxysporum* pv. *pisi* populations are necessary to understand their evolution and adaptation mechanisms. It will be increasingly important to assess the impact of climate change on the epidemiology of Fusarium wilt and develop adaptive management strategies to mitigate its effects. Precision agriculture technologies, such as remote sensing and advanced monitoring systems, should be utilized to detect early disease outbreaks and implement timely management interventions. Developing decision support systems that integrate epidemiological data, weather forecasts, and soil health parameters can guide farmers in making informed management decisions. By addressing these future recommendations, researchers and practitioners can significantly improve the understanding and management of Fusarium wilt in peas, contributing to sustainable agricultural practices and food security.

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Competing Of Interest

The authors declare that the research was carried without any commercial or financial relationships that could be construed as a potential conflict of interest.

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