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Outlook of Verticillium Wilt Diseases of Apricot: Biology, Epidemiology, and Management

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Abstract

Verticillium Wilt Is one of the most important vascular diseases of apricot. The primary cause of the disease is a soil-borne fungus, Verticillium dahliae, which can persist in soil for many years as resistant structures called microsclerotia. The pathogen enters plant roots, infects the vascular tissues, and impairs water movement, leading to wilt, chlorosis, defoliation, branch dieback, and tree decline. Highly susceptible hosts include apricot, almond, peach, and cherry, which can lead to significant economic losses in orchards. Disease development and severity are greatly affected by environmental conditions, soil type, intercultural practices, root damage, and the presence of susceptible plants. Management is challenging, as the fungus can spread through infected planting material, irrigation water, soil movement, and contaminated tools. Chemical control is ineffective because of the pathogen's persistence in xylem tissue and soil; integrated disease management strategies are needed. Management practices are important, including disease-free nursery stock, resistant/tolerant rootstocks, soil solarization, sanitation, crop rotation, irrigation management, and avoiding susceptible intercrops. Inoculum level and disease incidence are also lowered through pre-plant soil disinfection and cultural practices. Biological control agents and improved soil health management methods are becoming viable options for long-term control of the pathogen. This review focuses on apricot Verticillium wilt

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disease and integrated management strategies, including resistant cultivars, for effective control, and summarizes the biology, epidemiology, symptomatology, and disease cycle.

Keywords: Apricot, Verticillium wilt, Rootstocks, Integrated Disease Management (IDM)

1 Introduction

Prunus armeniaca, commonly known as Apricot (Latin meaning precocious or early ripening) or khubbani. In Mediterranean countries, Central Asia, Russia, the USA, Iran, Iraq, Afghanistan, Pakistan, Syria, and Turkey, apricots are mostly grown. The 90% of the world's apricot crop is produced in the United States (Uzundumlu et al., 2021). The individuals of the Prunus cultivated community, generally known as stone fruits, all experience to differing extents from verticillium wilt. The susceptible plants are Apricots, Almonds, Pleasant cherry, Sour cherry, European plum, and Japanese plum. *V. dahliae* is predominantly liable, but there are a few confirmed reports of *V. alboatrum* infection: apricot Wilt caused by Verticillium is also vulnerable to Prunus plants and variants, which can be used as rootstocks for stone fruits. Many other reports of verticillium wilt in stone fruits have already been documented. At present, stone fruits affected by verticillium wilt seem to be far more relevant in North America, Eastern Europe, the Mediterranean region, and Australasia. In particular, in north-western Europe, verticillium wilting of stone fruits would not be a critical topic. Generally speaking, although cherry and plum would be less sensitive, apricot, almond, and peach seemed to be more seriously affected (Parker, 1959).

1.1 Causal organism

In several areas of the world, it affects a large number of plants and is thus widely recognized. They are mostly affected by the genera Verticillium, *V. dahliae* Kleb., and *V. albo-atrum* Reinke & Berth. Two interrelated fungi, Verticillium, belong to the order Hypomycetes and are also a genus of microfungi; conidia are formed in moist droplets by these fungi on the tips of phialides, which develop in groups on the conidiophores in the upright position. Conidiophores of *V. dahliae* are hyaline; conidia are subspherical and extended; and microsclerotia are melanized. These characters differentiate this species from other species (Barbara & Clewes, 2003). No sexual state is known for any of these fungi. *V. dahliae* is widely distributed between latitudes 60 °N and 50^{0}S, but in the lowlands of the tropical areas, this fungus is absent. More than 50 crops are infected by this fungus, including pome and stone fruits, vegetables, and legumes, across over 60 genera of woody and herbaceous ornamental plants. 25 genera of the weeds belonging to the dicotyledonous group are also infected by this fungus, with or without producing symptoms. In the soil, *V. dahliae* persists as microsclerotia formed in the declining tissues of the plant host. Across a range of soil water and temperature levels, these forms can persist, but in rainy, hot soil, they become less feasible more quickly. When infested with *V. dahliae*, the soil remains infected for 10 or more years (Wilhelm, 1955), and a significant factor in this durability is the longevity of microsclerotia. In response to root exudates, microsclerotia germinate, hyphae enter the cortical cells of developing roots, and the stele develops into the fungus. The pathogen propagates through the growth of mycelium in xylem vessels and the development of conidia, which are transferred throughout the transpiration system. In that way, in vulnerable crops, the fungus easily becomes endogenous. It is suspected that the severe disease symptoms are due to vessel blockage. In addition to the intrinsic resistance of the infected crop, a variety of factors are expected to affect the incidence and severity of verticillium wilt epidemics. Wilt occurs across a wide range of soil types and is likely to worsen in soils that are monitored for disease-conductive soil temperatures in a particular region: light soils in cool places and heavy soils in hotter areas (Schnathorst, 1981).

1.2 Host Range

Plants belonging to the dicotyledonous group are susceptible to Verticillium wilt, but no infection was found on monocotyledonous woody trees, and gymnosperms were not affected by this fungus. From many reports, it was confirmed that the wilt was mostly caused by the fungus *V. dahliae.*

From 22 samples collected from different sources, 51 Verticillium species were isolated, all of which were *V. dahliae*. In Europe and North America, plants attacked by Verticillium wilt include shade trees, fruit-bearing trees, and ornamental or nursery trees. The trees of the trees are scarcely affected by the wilt caused by *Verticillium*: in the Netherlands, no wilt was found on the young trees of ash in the forest, and two species of *Verticillium,* i.e., *V. dahliae* and *V. albo-atrum* were observed to be associated with them. Parker (1959), reviewed wilt caused by *Verticillium* on fruits. Maples, fruits, almonds, cacao, olives, apricots, etc., are mostly infected with *Verticillium* wilt. Alnus, Fagus, Platanus, Quercus, Betula, Populus, and Salix were observed to be not affected by the *Verticillium* wilt, but *V. dahliae* was isolated from a species, *F. sylvatica*.

1.3 Symptom development

Due to infections caused by *V. dahliae* and other wilt pathogens, the vessels that transport water to other parts of the plant are blocked. Local infections may also occur due to toxicosis (Figure 1). Very complex branches and a network of vessels are formed in the stem of the trees belonging to the dicotyledonous group (Puhalla & Hummel, 1983). Symptoms of wilt sometimes don't develop because of vessel blockages, which affect water transport, as in resistant plants. Nevertheless, in susceptible hosts, the several typical local occlusions inevitably block the vascular system, resulting in water stress. The impact is even greater if the microorganism enters the petioles, because, as vessels, they are much smaller and easier to block, and alternative pathways for fluid transport are quite limited. The induced water deficit contributes to wilting, desiccation, and leaf drop. If blocked vessels are also not replaced by the new, safe xylene vessels, the consequence can be a dieback. Metabolites produced by the fungus can induce host defensive responses, but they may also be counteracted by preventing gel plug formation in affected vessels. By trying to plug the holes throughout the pit membranes, rather than being harmful, high-molecular-weight compounds, especially polysaccharides and glycopeptides, can be beneficial. A significant feature of the host-pathogen relationship is perhaps the accumulation of callose and other substances on cell walls. By closing the vessel walls, such particles tend to localize the microorganism and, in turn, lead to water stress within the plant (Bishop & Cooper, 1983).

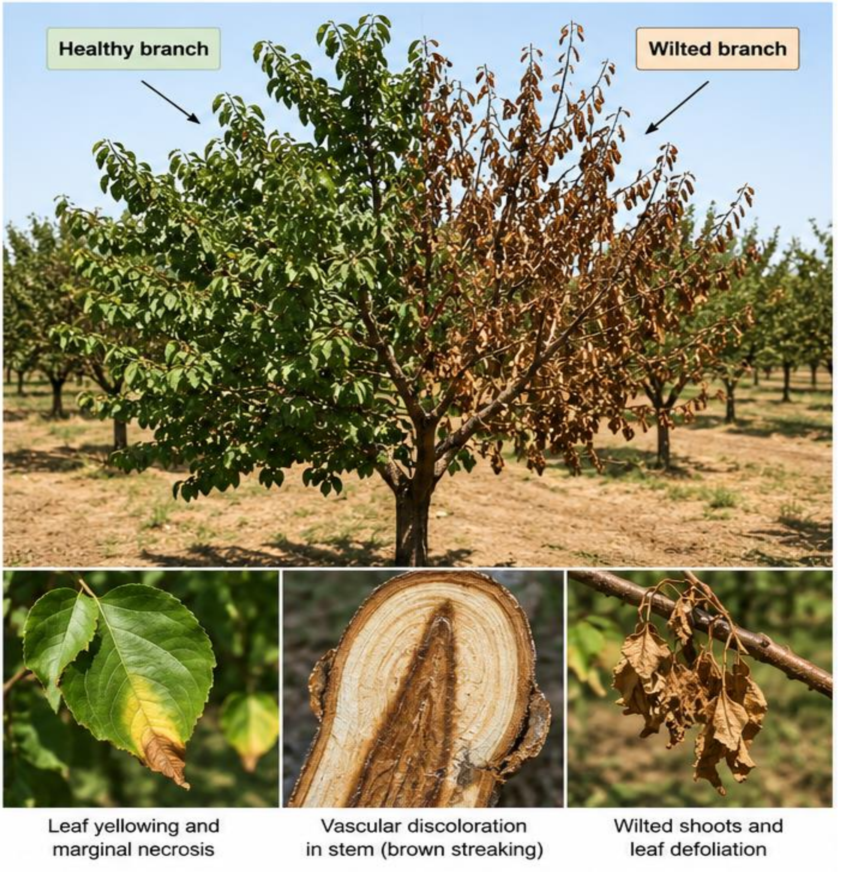

Figure 1. Typical field Symptom of Verticillium Wilt on apricot tree

2 Disease cycle

2.1 Survival and Spread of Fungus

Through microsclerotia, the wilt fungus survives in the soil and forms colonies in the dying and dead tissues of plants, i.e., leaves and stems. The microsclerotia are incorporated into the soil, which first localizes on host debris, but at later stages, due to microbial activity, decomposition, and cultural practices, the fungus is distributed widely. In this way, the fungus's propagules increase in the soil. The upper layers of the soil are where microsclerotia are mostly found, and from there the fungus spreads to other sites through dust, rain, or irrigation water (Seethapathy *et al.,* 2022). The spread of the fungus may also occur through the wind, from which the diseased leaves spread from one field to another, as in cotton. The infected planting stock is also a source of fungal distribution from one area to another. The scions, buds, and rootstocks are the main sources of infection spread in nursery plants (Ligoxigakis *et al.,* 2002).

2.2 Infection of the Root

Exudates from the roots stimulate microsclerotia to germinate or alter soil nutrient availability. The plants that are immune to Verticillium infection can also germinate through their roots. The *V. dahliae* colonizes the uninfected young root of the cotton. The cap of the root and cells of the epidermis become penetrated by the hyphae, crossed by the intra- and intercellular growth. After penetrating the endodermis, some hyphae, after 3 days, may also enter xylem vessels. The internal, pertinent layer of epidermal cells, the gum-like residues within the cell walls of cortical cells, and the endodermis can hinder hyphal invasion (Talboys, 1960). Therefore, only a tiny fraction of cortex invasions ends in systemic contamination. These mechanisms are evidently highly successful in wild-immune plants (plants resistant to vascular disease). Vascular invasion, however, occurs in many other plants, and the overall colonization response (susceptible or resistant) depends to a large extent on subsequent host plant tissue behavior (Esmailzade *et al.,* 2023).

2.3 Colonization of the Vascular System

Conidia move through transpiration in the vascular bundles, and thus the pathogen moves upward rapidly in other parts of the plant. Using this method to establish the colonies, the pathogen spread to the leaves and stems of the plants during a single growth season, and the same is true for large trees. Conidia are produced within the vessels by budding or through simple conidiophores. Lower oxygen levels and a negative pressure potential are indeed considered to induce conidial development in *V. dahliae*: the development of conidia rather than hyphal formation in xylem components is possibly induced by the chemical and physical environment unique to the vascular system of trees (Pedrelli et al., 2024). So many host resistance mechanisms can restrict the distribution of *V. dahliae* in vascular tissues. In the defense mechanisms of infected plants, there are physical (entrapment and vascular constriction) and biochemical (phytoalexins) components. Conidia capture is achieved through the pattern function of the vessels' longitudinal and end walls. Gel plugs and tyloses are produced during immune-type interactions, which effectively block the lumen of the contaminated vessel just above the catching sites, thereby immobilizing the fungus. Finally, some secondary metabolites, such as oxidized polyphenols (tannins) and phytoalexins, produced by paratracheal parenchymatous cells, are mixed with gel plugs, tyloses, and adjacent cellular membranes. This induces a typical vascular disease sign: browning of vascular bundles. Polyphenols and phytoalexins confer tolerance to obstructing substances through their antibiotic activity. Dahliae in-vitro at a concentration mistrust in the wood below its hat present. Elemental sulfur (Su) and arjunolic acid appear to play a tolerance role in cocoa, even though they are found at fungitoxic concentrations in branches of affected resistant varieties (Cooper et al., 1996). In susceptible hosts, the protective responses are basically the same as in immune hosts; however, the rate, strength, or spatial arrangement of these responses is insufficient to suppress the pathogen. Subsequent efforts to limit the transmission of infections led to increased local blockage (Emechebe et al., 1974).

2.4 Factors Influencing Disease

Wilt attacks are most likely to happen in the early days of a plantation (3-10 years) in general. The disease is rare in mature peach and plum plants, although it can affect apricot, almond, and cherry plants of all sizes. Soil in apricot and almond trees can lead to a higher incidence of wilting. Intercropping with wilt-susceptible plants is a key factor in the occurrence of disease, as with other Verticillium wilts. Fifty percent more plants were influenced in a 4-year-old almond plantation in Italy than in the half that had not been intercropped. Like nematodes and soil cultivation, which contribute to root injury, high levels of soil nitrogen naturally led apricots to wilt (Spetik et al., 2024).

3 Disease Management

A variety of strategies and methods are used to control Verticillium wilt, including using resistant rootstocks, reducing the level of the fungus in the soil, suppressing the pathogen's spread, and other factors that affect the severity of the disease. To manage wilt in high-cost plants worldwide, soil disinfection with chemicals before planting is commonly used. In many regions, successful results have been recorded in reducing soil fungal populations through sunlight, particularly when growing plants under glass aas shown in Figure 2. This may also be used to control wilt by applying in situ treatments to crops (Pérez-Rodríguez *et al*., 2022). Lowering the fungal inoculum level in the soil also reduces the amount of plant residues. *V. dahliae* is also reduced temporarily by applying water through the flooding method. Soil is sterilized before use in areas where crops are grown under a protective environment. Nematodes are also managed because they cause severe disease in association with other pathogens; therefore, their management provides effective control of the fungus (Daranas *et al*., 2024). By solarizing the soil or fumigating with chloropicrin, the sites where plants are to be planted can be made free of microbes. Soils infected with varying levels of the pathogens, which may or may not defoliate plants, can be sterilized by solarization for about 1.5-2 months. The same management practices can be used for wilting of stone fruits, including: don't plant new plants at infected sites; disinfect the soil before planting; don't use susceptible plants as intercrops; use healthy nursery plants; and uproot and burn infected plants. The most effective way to manage wilt diseases is to use resistant cultivars, but their availability is limited. Grafting stone fruits is done on rootstocks; therefore, the rootstock should have the necessary resistance. Resistant rootstocks for stone fruits are not available at the commercial level. For high-value crops or trees, soil treatment with a disinfectant before planting is widely used worldwide (Hajji-Hedfi *et al*., 2024). Fungal inoculum can also be reduced by exposing the soil to solar radiation and by growing plants under greenhouse conditions, where soil temperature remains high for a longer period of time, and wilting of perennial crops can also be controlled using the above-mentioned methods (Navrátil *et al*., 2025). In apricot, wilt can be controlled by mulching the soil with a black or transparent polythene sheet, but this mulching can damage newly grown plants during summer days. Trees can recover from wilt by judiciously applying fertilizers and irrigating as needed. Proper strategy development is needed. It is very difficult to manage Verticillium wilt. The reasons it is tough to manage this are: the pathogen can persist in the soil for a long time; the fungus can feed on many plants; and pesticides cannot reach it because it is present in the xylem. Because the plants remain viable for a long time, the fungus persists with them, making it very difficult to manage. The integrated disease management approach is the most effective way to manage this disease; in this technique, management practices are applied before and after planting (Muñoz-Ramírez *et al*., 2024).

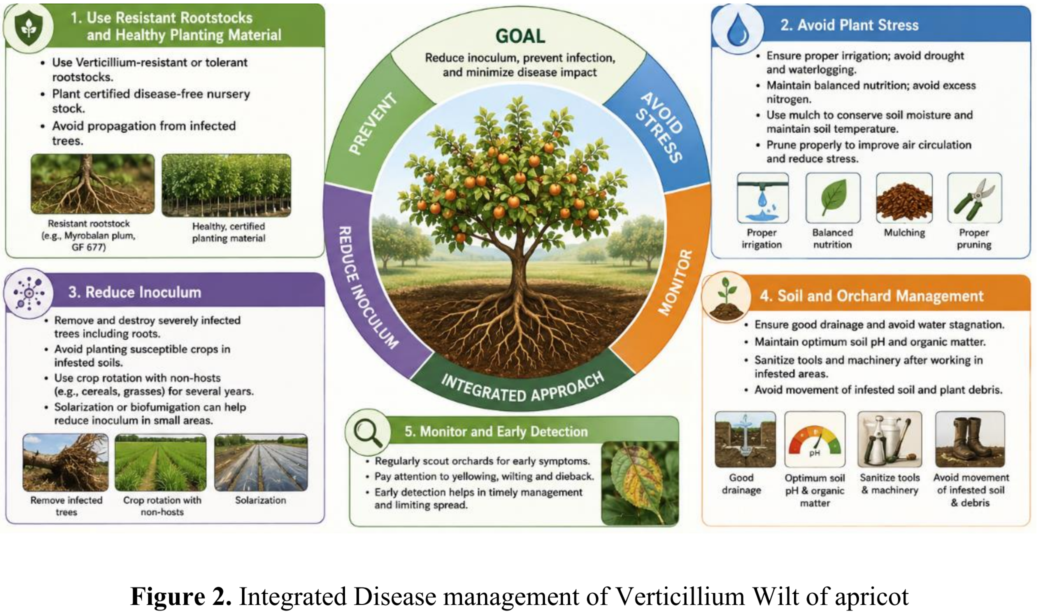

Figure 2. Integrated Disease management of Verticillium Wilt of apricot

4 Control Measures before Planting

4.1 Choice of a proper planting site

This helps prevent the inclusion of soils with *V. dahliae* inoculant rates within a hazardous range. The thresholds might change with the plant's sensitivity and the virulence factors of the dominant pathotype(s), a matter of particular significance for the defoliating species. Info on past crop rotations at accessible planting sites may provide an idea of the wilt threat; however, the only way to determine site location is to quantify the fungus in a soil sample (Khafri et al., 2024).

4.2 Disinfection of soil

By decreasing the amount of fungus in the soil, plants can be planted in the infected soil, and healthy plants can be maintained there. For this purpose, various methods are used, such as physical methods (sterilizing the soil with solar rays) and chemical methods (methan-Na, chloropicrin, methyl bromide, formalin). For single plants or a large number of plants, these techniques can be successfully employed. When sunlight is available for a longer period of time, wet soil is covered with polythene sheets, through which the soil becomes sterilized by the heat generated. For maximum efficacy, the soil should have sufficient moisture. A clear reduction in the microsclerotia in soil because of solarization. Some organisms, such as Talaromyces flavus and Aspergillus terreus, which act antagonistically to *V. dahliae*, are favored by solarization (Ram and Bhardwaj, 2004).

4.3 Use of *V. dahliae* free planting Material

In some nursery plants, the fungus doesn't develop symptoms, but it is present; therefore, care should be taken while selecting plants for new plantations, and these plants should not contain any infectious agent attached to them. That has significant implications when the planting site is completely free of *V. dahlia* (Luo *et al*., 2022).

4.4 Use of resistant cultivars or rootstocks

In various tree species, the presence of resistance should be taken seriously because it provides the most effective and long-term control of the fungus. The rootstocks should be resistant to the fungus because, through grafting, the plants are grafted onto them. There should be complete resistance in the rootstock, because if it has partial resistance, the fungus may pass into the scion and grow there. Tolerant cultivars can also be used to minimize losses if resistant cultivars are unavailable. But there will be an increase in the fungus population in the soil due to tolerant cultivars (Mendelné Pászti et al., 2023).

5 Control Measures After Planting

5.1 Cultural practices

It is discussed there how cultural operations are important for the management of *Verticillium* wilt. For this purpose, following methods are used for managing the disease: don't intercrop with the susceptible plants, control the weeds through the chemicals and don't use those cultural operations through which roots of the plants are damaged, don't use the equipment in the healthy field which is already used in the infected field, for reducing the spread of the fungus irrigate the plants through drip irrigation method not through flood or furrow irrigation, the diseased plants or their parts should be removed from the field and try to burn or destroy the diseased parts to avoid the contamination of soil through microscelrotia. In irrigated orchards, soil solarization is mostly used to manage wilt (Khan et al., 2021). The advantage of soil solarization is that it prevents infection by wilt and enhances recovery from wilt, as reported in many plants. If the sun's radiation is at its maximum, then soil solarization is performed. Before solarization, the weeds are removed from the area, and the infested branches are pruned to ensure proper exposure of the soil to solar radiation. At a proper level of saturation, the plants are moistened at the soil level. After that, the soil, equal to or greater than the plants' foliage area, is covered with polyethylene sheets. It is important to anchor the plastic tightly. No fungicides are available that are highly effective against Verticillium wilt of trees, despite extensive work by pesticide companies and many scientists, which provides either protective or curative control. For proper management of the fungus, systemic fungicides are needed because it is present within plant tissues (Adaskaveg & Förster, 2022). Carbendazim and carbendazim-releasing from the benzimidazoles and thiophanates are somewhat effective against this fungus. Against strawberry wilt, little progress has been made in herbaceous crops, but for proper management, frequent applications at high water rates are needed. Ineffectiveness has been observed with woody species unless the application method is used. C. Fimbriata was mainly a pathogen of xylem. Infection usually occurred in Theobroma, Mangifera, and Prunus trees via new injuries, while root disorders were also prevalent (Dhar et al., 2020). Mycelium and spores reached the injuries and spread via ray parenchymatous cells into the xylem within water-conducting vessels. The fungus produced deep-brown or black staining throughout the xylem, ranging from dark reddish-brown to purple. That stain spread up the stem of the plant and through the branches many meters from the base. The staining across the bends provided a unique wedge-shaped or starburst-like appearance when damaged limbs or trunks were cut into cross-section (Song et al., 2020). Cankers formed along regions of xylem decoloration upon the surface of its trunk or stems, and gum exuded from the cankers. Branch and trunk cancers were prevalent (Acharya et al., 2020), while wilting also occurred in the absence of cancer growth. Usually, leaves that were wilted were dried and curled very abruptly, but for many weeks, they stayed connected to the branch. Interveinal yellowing of leaves and death of the tissues, possibly related, were shown by individual leaves on damaged branches with toxins produced by the fungus (Palanga et al., 2021). Through the grafts of the roots, *C. fimbriata* moves from one plant to another plant (Daayf, 2015). The fungus enters the plant through wounds in the roots (Fradin and Thomma, 2006). Because of pathogens present in the soil, the mangifera plants become diseased from the roots (Kowalska, 2021). Air is not the main source of spore dispersal; insects are. Aiborne was not the dispersal agent for the conidia, but there was in the insect's frass. There was no documentation of conidia spread through rainwater. The tapping panel is infected by *C. fimbriata* on the rubber, resulting in a pale grey panel due to mould, and, below the surface, the color changes to a darker shade (Luo et al., 2014). Via injured roots or branches, the fungus enters the host and causes rot of roots or seedlings, or it moves through the xylem. As a result, the xylem becomes discolored, and the plant wilts rapidly (Zhang et al., 2022).

6 Conclusion and Future Aspects

Verticillium wilt is a vascular disease among the most destructive of apricot and other stone fruit crops worldwide. The disease is primarily caused by Verticillium dahliae, and is known to persist in the soil for several years via microsclerotia and to spread rapidly under favorable environmental conditions. The xylem vessels are plugged during infection, causing orchards to wilt, turn yellow, defoliate, and lose branches, and to lose productivity. The pathogen has a broad host range and a long survival in soil, making its management challenging. Susceptible rootstock, intercropping, root injury, soil temperature, and soil moisture all play significant roles in disease development. The most effective strategies to reduce the incidence of disease are currently integrated disease management (IDM) practices, such as soil solarization, crop sanitation, use of healthy planting material, cultural practices, and resistant rootstocks. But chemical control has been ineffective so far because it cannot be protected within the plant's vascular tissues. Advanced breeding and biotechnological studies should be conducted to develop rootstocks and cultivars that are resistant or tolerant in the future. Research into molecular interactions between host plants and the pathogen can lead to the identification of resistance genes and to more accurate disease forecasting systems. In addition, biological control agents and eco-friendly soil treatments should be considered to sustainably control the disease. In addition, better nursery certification systems, improved rapid diagnostic methods, and farmer awareness programs are critical to stopping the spread. Modern research, integrated management practices, and sustainable agricultural techniques will be important elements in reducing losses from Verticillium wilt in apricots and stone fruits.

Author Contributions

Sadia Basheer, Sonum Bashir, Rida Fatima, Naureen Anwar, Muti Ur Rehman, Iram Bilqees, Muhammad Awais Fareed, Lubna Shahzadi, Muhammad Usman Ghani, and Judith J. Kiptoo contributed to the conceptualization, literature search, investigation of the relevant plant-pathology literature, synthesis and interpretation of evidence, organization of the scientific content, and preparation of the manuscript. All authors contributed to writing—original draft and writing—review and editing. All authors read and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

Conflict of Interest

The authors declare that they have no financial, professional, commercial, institutional, or personal conflicts of interest that could have influenced the content or conclusions of this article.

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Data Availability

No new experimental or field dataset was generated or analysed for this study. All information supporting the review was derived from the published scientific literature cited in the article.

Informed Consent

Not applicable. The study did not involve human participants or the collection of personal information.

Use of Generative AI

The authors declare that no generative artificial intelligence tools were used to generate the scientific content, conduct the literature analysis, interpret the evidence, or formulate the conclusions presented in this article.

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