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Review Article

Integrated management strategies for septoria leaf spot in pistachio (*Pistacia vera*): Challenges and advances

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Abstract:

Pistachios are economically important crops facing increasing threats from fungal diseases, particularly Septoria leaf spot, which has a significant global impact, causing substantial yield losses and economic damage worldwide. This review comprehensively examined existing literature on Septoria leaf spot of pistachio, including peer-reviewed articles, scientific reports, and relevant databases, to characterize the disease, assess its impact on pistachio production, and evaluate available management strategies. Septoria leaf spot is a significant foliar disease causing severe defoliation and yield reduction, prevalent in major pistachio-growing regions. Management strategies reviewed include cultural practices (proper irrigation, sanitation, and weed control), biological control (utilizing beneficial microorganisms), chemical control (employing fungicides strategically), and host resistance (utilizing resistant cultivars). Effective management requires an integrated approach combining multiple strategies, with continued research crucial to develop novel and sustainable control methods, such as improved fungicides and the identification and utilization of highly resistant cultivars. Implementing these strategies will enhance pistachio tree health, improve yield and quality, and ensure the long-term sustainability of pistachio production.

Keywords:

Management practices, *Pistacia vera*, *Septoria* spp., sustainability.

1. Introduction

Within the genus *Pistacia* of the family *Anacardiaceae*, only the *Pistacia vera* L. bears edible nuts (FAOSTAT, 2017; Gusella et al., 2022). Pistachio nuts have recorded a tremendous increase in global production (Mir-Makhamad et al., 2022). The wild type is native to western Asia and Asia Minor and found in parts of Africa, southern Europe, Turkey, Syria, Iran, Iraq, India, Lebanon, and Palestine (Mandalari et al., 2022). Pistachios belong to the category of drupes as classified by botanists. They thrive under long, hot summers and mild winters with at least 1000 hours below 7.2°C (Batovska and Inbar, 2024). They do well in various types of soils: saline, alkaline, fine sandy loams, and those high in lime (Benny et al., 2022). The recent discovery of new and existing pistachio diseases has reduced the yield and quality of fruit considerably. This emergence could be attributed to several factors, such as increased understanding of disease-causing agents, innovation in agricultural practices, and expansion of pistachio culture into diverse geographic regions under varying ecological conditions. Such changes must have influenced the prevalence and dissemination of certain pistachio diseases. Of these, Septoria Leaf Spot is considered to pose a serious threat both to yield and fruit quality. To this date, control of fungal infections has traditionally been carried out by the application of chemical fungicides. In recent times, however, interest has grown in more environmentally friendly control strategies, among which biological control measures are right at the forefront. Septoria leaf spot is a fungal disease affecting pistachio trees, primarily in Mediterranean climates. Caused by various Septoria species, it manifests as brown spots on leaves that can enlarge, leading to leaf drop and reduced fruit quality. The fungus overwinters on fallen leaves, and spores spread through wind and rain (Avenot et al., 2016; Guldur et al., 2011; López-Moral et al., 2022; Nazarova et al., 2023; Ozkiling & Kurt, 2017). The aim of this review was to discuss methodologies that may be used for the management of such harmful infections through various strategies. Further discussion will emphasize the virulence factors employed by these fungi in the process of pistachio infection and developing the disease. This review will also critically analyze the existing control methods, including chemical fungicides, cultural controls, and newer approaches involving biological control agents. The review is intended to present an overview of the pathogenicity of these fungal infections and assess various methods of management in pistachio production.

2. Septoria leaf spot of pistachio

2.1 Symptoms

The disease first appears as small, circular, or irregularly shaped necrotic areas belonging to dead tissues on either side of the leaf surface. They are usually confined within small veins, have small dimensions of about 1-2 mm in diameter, and with time keep the size small and sometimes even discrete by showing slow increase in size (Nazarova et al., 2023). In highly diseased leaves, hundreds of such spots may appear on them. As the disease progresses, larger sections of the leaf tissue turn brown (López-Moral et al., 2022). This often results in large infections causing early defoliation that reduces the photosynthetic capacity of the tree. That then leads to reduced carbohydrate production and storage of carbohydrates, and thus the general vigor and health of the tree decline (Figure 1) (Teviotdale et al., 2002).

2.2 Disease cycle

Overwintering of the fungal pathogen occurs in already infected leaves that fall on the orchard floor. These leaves serve as a reservoir for the pathogen during the winter months. During this stage, the fungus resides in a type of specialized structure called pycnidia, which is a spore-producing body. In the spring, after precipitation events such as rain or irrigation, pycnidia release the spores of the fungus. Wind or water droplets, thus facilitating their transmission to new, susceptible leaves, thereby initiating new infection cycles (Figure 2), can then disperse the spores (Chitzanidis, 1956; Eskalen et al., 2001; Gusella et al., 2021).

2.3 Conditions for disease

Septoria pistaciarum, the fungal agent of Septoria leaf spot, exhibits a distinct host range and overwintering habit. Thus, this pathogen infects only pistachio trees (Crous et al., 2013). At the close of any growing season, leaves of diseased trees infected with the fungus from the previous year fall to the ground. The diseased leaves serve as a reservoir for the pathogen to survive the winter months (Nazarova et al., 2023). Specialized fruiting structures, called pycnidia, form within the fallen, infected leaves in late winter and early spring. The pycnidia serves as spore-producing bodies, carrying the fungal spores that initiate new infections. With

rainfall, spores are liberated from the pycnidia (Eskalen et al., 2001). Rain and wind help in the spread of spores toward healthy pistachio leaves. The spores can germinate and then directly penetrate the leaves to establish new infections and perpetuate the disease cycle upon landing on susceptible leaf tissue (Crous et al., 2013).

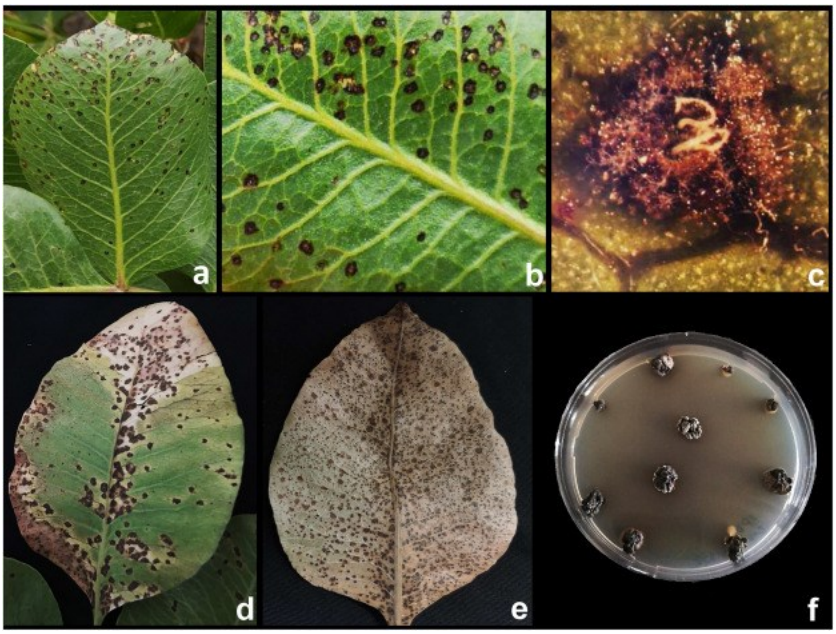

Figure 1: *Septoria pistaciarum* is a causative agent of pistachio leaf spot. a. Field symptoms (June); b. Leaf spot details; c. Crystalline cirrus exuding from a lesion; d. End-of-July symptoms (coalesced lesions resulting in necrotic patches); e. Senescent fallen leaf symptoms (November); f. Isolation results showing constant presence of the same Septoria-like colony (Gusella et al., 2021; Gusella et al., 2022).

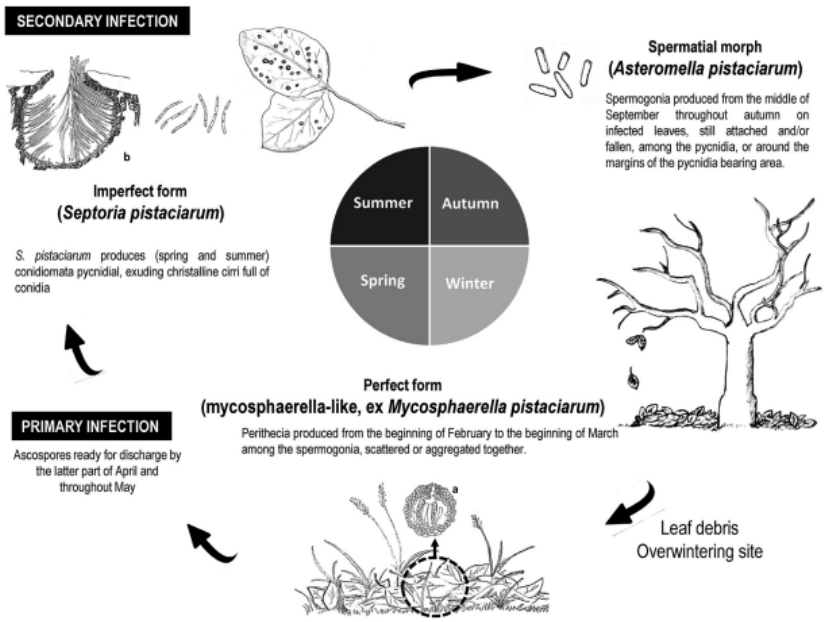

Figure 2: Cycle of *Septoria pistaciarum*. Seasons details, perithecium with asci (a) and pycnidium with pycnidiospores (b) (Chitzanidis, 1956; Gusella et al., 2021; Gusella et al., 2022).

2.4 Management approaches

The literature indicates a lack of substantial scientific research and published data specifically on this plant disease affecting pistachio trees. This scarcity could stem from limited research conducted, limited publication of existing findings, or the dispersion of information across various sources. This limited information poses significant challenges, including difficulties in managing the disease effectively for growers due to insufficient guidance, limited understanding of the disease's underlying causes hindering the development of effective control measures, and obstacles for researchers in building upon existing knowledge due to the limited availability of reliable data (López-Moral et al., 2022; Nazarova et al., 2023). The management of Septoria leaf spot in orchards requires an integrated approach. The basis of this is good sanitation practice. This approach directly targets the inoculums, those infective propagules responsible for the next growing season. They include raking and destroying fallen leaves, pruning dead and dying branches, and removing weeds within and surrounding the orchard area. This sanitation practice removes the inoculum harbored in host plant materials over winter, thereby reducing by a great magnitude the inoculum levels that would have otherwise been available to initiate new infections the following spring (Drais et al., 2023). Where *S. pistaciarum* has been identified to be an existing problem in pistachio orchards, preventive fungicide applications may be a complementary control measure. Predictive timing of the fungicide application is crucial for effective disease management. Applications must be conducted based on predictive models or when environmental conditions are identified that signal favorability for the disease development, such as frequent rain or high humidity. This targeted approach will limit the rate of fungicide application to the appropriate amount, thus contributing to maximizing efficiency in the control of fungal diseases (Sarpkaya, 2014). A few fungicides with different modes of action are registered for managing Septoria leaf spot in pistachio orchards. Azoxystrobin and trifloxystrobin are classes of strobilurin fungicides. Both interfere with the fungal respiratory chain by disrupting the production of the high-energy electron carriers within the pathogen. Copper hydroxide interferes with the fungal cell membrane and protein synthesis due to its non-specific mode of action. Potassium bicarbonate interferes with fungal growth by changing cellular pH and offering uninhabitable environments. Chlorothalonil inhibits all types of metabolic processes in the fungal pathogens, thus impeding their growth and ability to infect plant tissues (Luo et al., 2007). In this vein, if pistachio growers were allowed to practice good sanitation and apply fungicides as targeted applications when the environmental conditions favored the development of the disease, this would manage the disease Septoria leaf spot and, by such consideration, protect health in crops (Çat, 2022). Limited commercial pistachio cultivars with host resistance necessitate the exploration of alternative strategies for inducing systemic acquired resistance (SAR). Synthetic, natural, and peptide-based compounds are being investigated for the management of Septoria leaf spot. K-carrageenan, a sulfated polysaccharide derived from *Kappaphycus alvarezii* (marine red seaweed), has demonstrated SAR induction in susceptible tomato cultivars, enhancing their tolerance to infection by *Solanum lycopersici* (Mani et al. 2021). Furthermore, many study evaluated the efficacy of botanicals traditionally used in indigenous technical knowledge for plant disease control (Hajji-Hedfi et al., 2024a; Hajji-Hedfi et al., 2024b; Matrood and Rhouma, 2021). Biological control agents (BCAs) are favored by some growers due to their generally high toxicological safety profile and reduced environmental impact compared to conventional chemical pesticides. These agents have been successfully employed in the management of various plant diseases. For example, the application of *Metarhizium* spp. and *Beauveria bassiana* to seedlings has demonstrated significant efficacy in suppressing several soilborne diseases, including Damping-Off, Root Rot, and Fusarium wilt (Rhouma et al., 2024a; Rhouma et al., 2024b). Additionally, *Trichoderma* spp. and *Pseudomonas* spp., which are also recognized as prominent BCAs, have proven effective in controlling gray mold disease (Hajji-Hedfi et al., 2023).

3. Conclusion

Septoria leaf spot in pistachio necessitates the development and implementation of innovative disease management strategies beyond traditional fungicides. Short-term efforts should focus on optimizing existing technologies through refined integrated pest management (IPM) approaches. This includes incorporating biological control agents, implementing cultural control measures, and judiciously utilizing fungicides. Simultaneously, research efforts should

prioritize developing efficient and accessible methods for phenotyping Septoria leaf spot resistance and expanding the search for resistant germplasm. To overcome current limitations in developing durable resistance, mid-term strategies should emphasize the application of advanced plant breeding technologies, such as CRISPR-Cas9 and genomic selection. Collaborative research initiatives are crucial to enhance our understanding of host-pathogen interactions, identify novel resistance mechanisms, and develop effective disease management strategies for a broader range of diseases and abiotic stresses. The long-term objective is to fully integrate durable resistance into pistachio production systems. This requires the establishment of robust and adaptable IPM frameworks that combine biological, botanical, and sustainable agronomic practices with host resistance. Continuous monitoring and adjustments of these systems are essential to address the evolving challenges posed by pathogen populations, environmental stresses, and climate change. The successful implementation of these strategies will require the development of predictive models and the integration of artificial intelligence-driven decision-making tools. A multidisciplinary approach that prioritizes ecological sustainability, farmer engagement, and scientific innovation is crucial for effective Septoria leaf spot management and the long-term sustainability of the pistachio industry.

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