

**"FUNGAL THREATS: A GLOBAL ANALYSIS OF ECONOMIC, ENVIRONMENTAL,  
AND AGRICULTURAL IMPACTS ON PISTACHIO NUT PRODUCTION"***Odina Nazarova**PhD Research Institute of Forestry*

**Abstract:** Pistachio cultivation has become increasingly vulnerable to fungal diseases, with significant implications for farmers, markets, and ecosystems. Countries like the United States, Iran, and Turkey—together producing the vast majority of the world's pistachios—are facing growing challenges from pathogens such as *Aspergillus*, *Botryosphaeria*, *Fusarium*, and *Botrytis*. These fungi not only reduce yields and compromise nut quality, but also lead to economic losses due to contamination, particularly aflatoxins, which limit export potential. Environmental concerns are also mounting, as heavy reliance on chemical fungicides and monoculture practices reduce biodiversity and soil health. This review brings together recent studies to explore how climate change, pathogen evolution, and current agricultural practices are driving the spread and impact of these diseases. The article highlights the promise of integrated management strategies, including the use of biocontrol agents like *Trichoderma* and *Bacillus*, as sustainable alternatives. Ultimately, protecting pistachio production requires a coordinated global effort that combines scientific innovation with practical, region-specific solutions.

**Keywords:** Pistachio, fungal diseases, aflatoxins, climate change, integrated pest management, *Aspergillus*, biocontrol, *Botryosphaeria*, sustainable agriculture, monoculture

**Introduction.** The production of pistachio walnuts has attracted significant attention as a precious agricultural product, mainly due to its economic contributions and its nutritional benefits. This harvest, fundamental for diets of various cultures and a key ingredient in numerous culinary applications, is mainly cultivated in the United States, Iran and Turkey, which together represent a substantial share of global production. In 2022, these nations collectively produced about 98% of the pistachios in the world, underlining their critical role in local and international markets (Faostat, 2023). The importance of pistachios extends beyond the economy; They are recognized for their health benefits, containing high levels of unsaturated fats, proteins and vitamins and essential minerals. Despite their meaning, the cultivation of pistachios is increasingly in danger from various fungal diseases, which impose terrible threats to sell and quality.

**Methods.** This article is based on a systematic literature review. Peer-reviewed sources from academic databases such as ScienceDirect, Springer, and Scopus were analyzed. Key areas explored include:

- Epidemiology and ecology of fungal pathogens
  - Economic loss estimates from crop yield reductions and aflatoxin-related trade bans
  - Environmental effects of fungicide reliance and monocultural practices
  - Evaluation of sustainable disease management strategies including biocontrol agents
- The review includes findings from more than 20 primary and secondary sources published between 2015 and 2024.

**Results and discussion.**

Fungine pathogens, in particular those of the genres of *Botryosphaeria* and *Aspergillus*, have been identified as important contributions to the losses of crops in the pistachio sector (14; 8).

*Botryosphaeria spp.* They are famous for their ability to thrive in different environmental conditions and cause serious diseases of the trunk and branches that can lead to a reduction in the vigor and possible death of the trees if not managed effectively (fig. 1,2). *Aspergillus* species, more commonly associated with post-harvest problems, can produce mycotoxins that make pistachios unsafe for consumption and decrease their market value (table 1). Since these pathogenic agents proliferate, both the health of pre-harvested crops and post-harvest quality are compromised, placing a significant risk for the means of existence of farmers and the economic stability of the production of regions.

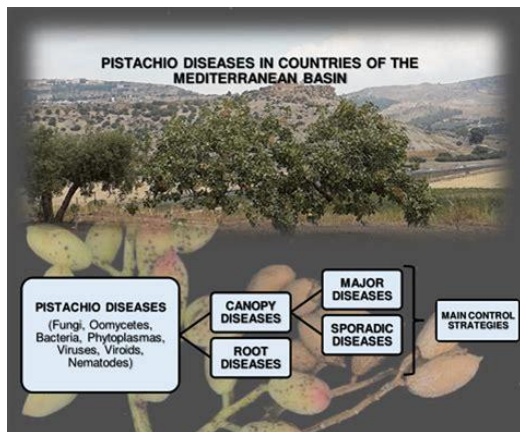


Figure 1. Pistachio diseases in countries of the Mediterranean basin — Wiley Online Library



Figure 2. Late season secondary leaf infections of *Botryosphaeria* panicle and shoot blight. Photo credit: Themis Michailides.

The growing prevalence of these fungal diseases can be connected to various factors, including inadequate management practices and the evolution nature of the pathogens themselves. In addition, climate change is expected to exacerbate this situation, potentially expanding the geographical distribution and increasing the severity of fungal infections that affect pistachios. Warm temperatures, altered precipitation models and increase in humidity create favorable environments for growth and sporting fungal, undermining efforts to control their diffusion. For example, high temperatures can alter the phenology of pistachio trees, making them potentially more susceptible to specific pathogens in the critical development phases. While global warming continues to influence agricultural landscapes, the understanding of the dynamics of these fungal diseases in relation to climatic variability becomes imperative to mitigate their impact.

**Table 1**  
**Pistachio Fungal Pathogens Impact**

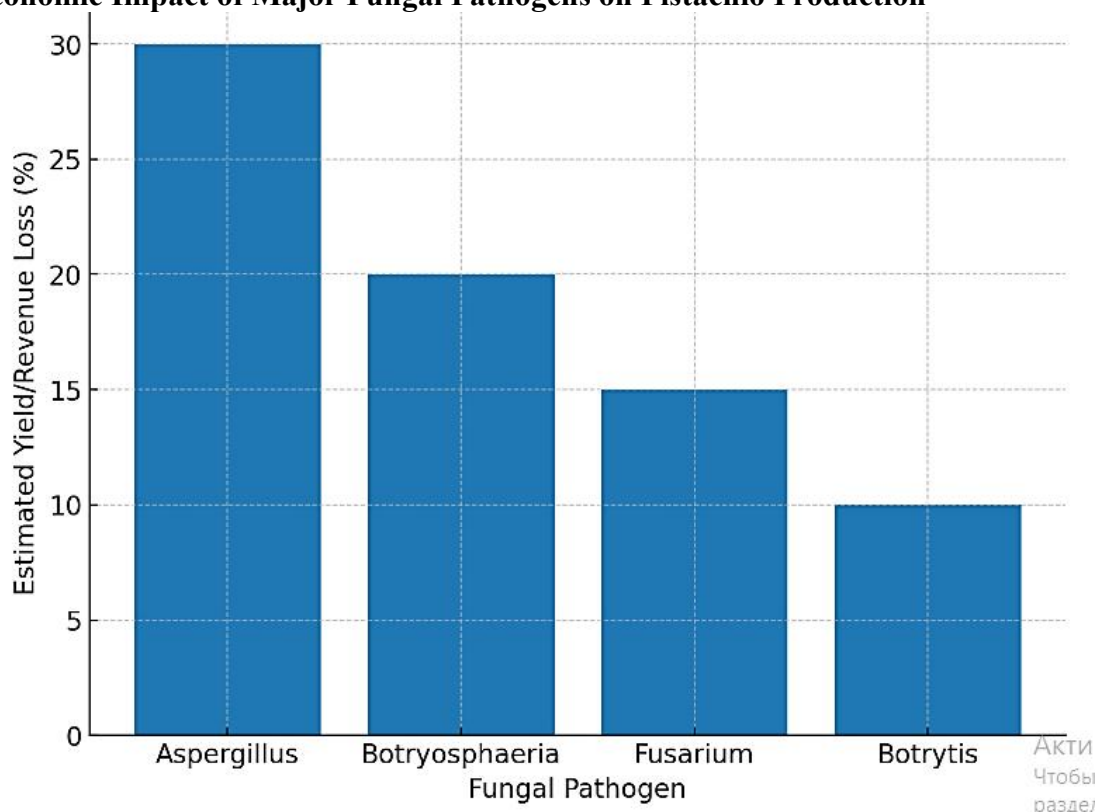
Nº	Fungal pathogen	Main effect	Economic impact
1.	<i>Aspergillus</i>	Aflatoxin contamination, nut quality loss	Up to 30% yield loss; export bans due to aflatoxin
2.	<i>Botryosphaeria</i>	Canker, shoot blight, tree decline	Reduced vigor, possible tree death
3.	<i>Fusarium</i>	Crown rot, stem canker	Reduced productivity and tree survival
4.	<i>Botrytis</i>	Fruit rot, post-harvest	Increased costs for

		spoilage	fungicide management
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In light of these challenges, the integrated management of fungal diseases through sustainable agricultural practices is essential to preserve the production of pistachios. Global branches of decreases not only influence local economies, but also have strategic implications for global food safety, given the critical role of pistachios as a high value walnut with significant health benefits. Continuing research on the epidemiology of these diseases and the development of effective management strategies will be crucial to safeguard the future of this vital crop., Fungal diseases, particularly those caused by opportunistic pathogens, such as *Aspergillus* species, represent a significant economic threat to the production of pistachio nuts globally. The incidence of pistachio aflatoxin contamination is particularly worrying, as aflatoxins directly influence marketing and consumer safety perceptions. Recent studies indicate that contamination of Aflatoxin can substantially reduce the annual pistachio crop yield, with losses reported to reach up to 30% in severely affected regions (4). Such losses reflect not only the amount of nuts produced, but also the quality, as contamination can make whole lots, thus inflicting direct financial losses to farmers (fig.3). The economic impact extends beyond local producers; Reverberate through the international market, influencing price structures and commercial dynamics. For example, a significant outbreak of Aflatoxin may lead to export of prohibitions, as important countries apply rigorous quality controls. This may result in reduced market access to produce nations, exemplifying how localized fungal infections can interrupt global supply chains and economic stability (2).

Figure 3.

**Economic Impact of Major Fungal Pathogens on Pistachio Production**



In addition, the financial burden associated with fungal disease management is considerable. Farmers face increased costs due to the need for more intensive monitoring, fungicide applications and other preventive measures. The complexity of Aflatoxin challenges management requires a comprehensive approach, as simplistic management strategies are usually not in control effectively. Rhouma et al. (18) emphasize the importance of integrated management strategies that combine cultural practices, chemical controls and crop rotation, thus reducing the risk of fungal proliferation and minimizing economic losses. Such strategies not only help mitigate the immediate start of fungal diseases, but also promote long-term sustainability and resilience in pistachio production.

The correlation between fungal infections and reduced incomes highlights a fundamental issue for pistachio export-dependent economies. Like countries to cultivate, such as Iran, the United States and Turkey, face varied levels of fungal threats, economic implications can differ significantly. In regions where farmers cannot implement comprehensive management practices, income reductions and quality deficiencies translate directly into economic instability. Economic analyzes indicate that these losses can accumulate billions of revenue in global scale, affecting subsistence means, employment and rural economies. In addition, the threat of fungal diseases has broader implications for investment in infrastructure and agricultural research as stakeholders reconsider their financial commitments in the light of potential uncertainties and management complexities.

Addressing the economic consequences of fungal diseases in pistachio production requires a multifaceted approach that is not only responsible for direct financial losses, but also considers the broader economic scenario that includes trade relations, market access and farmers' subsistence means. Continuous research on effective management strategies, along with international collaboration, is essential to protect the economic viability of the pistachio industry in a rapidly evolving agricultural landscape, characterized by emerging fungal threats. The environmental impacts of fungal diseases on pistachio orchards extend well beyond the immediate effects on the surrender and quality of crops; They also induce significant changes in biodiversity and health of ecosystems. Funge infections can seriously compromise the health of pistachio trees, making them more vulnerable to a series of other parasites and diseases. This weakened state increases the probability of infestation by phytophagous insects, which can start a cascade series of ecological interruptions. As divided into the results of Saaiman (19), the interaction between insects and pathogenic mushrooms is particularly fundamental, since many mushrooms exploit the physiological stress inflicted by the food of insects. In this context, an infected tree can exhibit reduced vigor and resilience, thus reducing mutual relationships that often exist in healthy ecosystems, such as those between trees, soil microbes and beneficial insects.

In addition, the monoculture practices prevalent in the main pistachio producing countries have exacerbated the susceptibility of the orchards to fungal diseases. As highlighted by Gusella et al. (6), the cultivation of a single harvest on large areas decreases genetic diversity, thus limiting the ability of the ecosystem to respond adaptively to diseases and environmental changes. This lack of genetic heterogeneity not only compromises the innate defenses of the individual trees, but also removes the associated flora and fauna that depend on these orchards. These practices can lead to a significant decline in local biodiversity and create an environment in which specific fungal pathogens are prosperous, establishing a vicious circle of environmental degradation.

The implications of these interactions extend to the wider agricultural panorama, in which excessive dependence on fungicides and other chemical treatments, often adopted in response

to the increase in fungal prevalence, can further compromise the health of ecosystems. The application of these chemicals can lead to the leaching of toxic substances in the ground and waterways, negatively influencing the non-target species and interrupting local ecosystems. This chemical management is particularly alarming in the regions in which agricultural intensification is already linked to the loss of biodiversity and the destruction of the habitat.

The research underlines that the monoculture of pistachios not only surrenders the resilience of the orchards themselves, but also has repercussions for adjacent ecosystems, since the decline of trees health can lead to a reduced coverage of the canopy, altered microclimates and movements in the composition of the soil. This instability can lead to the loss of avian populations that are based on pistachio trees for nesting and nutrition, thus leading to wider branches for the ecosystem services provided by these species.

In summary, the interaction between fungal diseases, agriculture of monoculture and health of ecosystems highlights a complex network of environmental consequences deriving from the threats to the production of pistachio walnuts. The vulnerability of these crops to fungal infections not only has immediate agricultural challenges, but also places long-term risks for the ecological integrity of the regions in which they are cultivated. Therefore, the understanding of these dynamics is crucial for the development of integrated management strategies that can improve both agricultural productivity and environmental sustainability. Fungal diseases significantly affect agricultural practices within pistachio cultivation, presenting a variety of challenges that farmers should navigate to maintain productivity. One of the main difficulties is the greatest dependence on fungicides to handle such diseases. The implementation of frequent fungicide applications, necessary for the increase in the incidents of pathogenic fungi such as *Fusarium* and *Botrytis*, leads to inflated production costs (Morality et al., 2017). In addition, the application of chemical interventions is aggravating the problems related to soil health. As the agrochemical load, traditional soil management practices, such as crop rotation and organic amendments increases, may negatively affect the quality of soil and microbial diversity (10). This change towards chemical weight approaches not only increases operating expenses, but also raises risks to environmental integrity, which underlines the need for integrated pest management strategies (IPM) that prioritize sustainability.

In response to these growing pressures, the exploration of biocontrol agents has become a promising way to manage fungal pathogens in pistachio orchards while adheres to sustainable agricultural principles. Research on these biocontrol agents, such as specific strains of *trichoderma* and *bacillus*, provides information about their mechanisms of action, which often include direct antagonism of pathogens, competition for resources and induction of systemic resistance in guest plants (17). These biological control methods represent a paradigm shift, which allows farmers to reduce their dependence on chemical fungicides and mitigate negative environmental impacts associated with their use. Effectively, biocontrol agents could improve the resilience of pistachio crops against fungal diseases, while decreases input costs over time.

In addition, the integration of biocontrol into conventional agricultural practices can improve soil health by promoting various microbial communities that contribute to the nutrient cycle and the decomposition of organic matter. As such, the dual benefits of cost reduction through the use of diminished fungicides and the improvement of ecosystem services present biocontrol agents as a critical component in the future of sustainable pistachio production (7). In spite of the promising advances, the challenges in the deployment of biocontrol strategies remain, including the variability of the effectiveness of the agent in various climatic conditions and edaphics that are found in the key countries producing pistachio. Therefore, ongoing research is

essential to adapt biocontrol applications to specific regional contexts, ensuring a robust and consistent management of fungal pathogens.

Sustainable agricultural practices require an integral framework that not only addresses immediate threats raised by fungal diseases, but also feels the basis for long-term viability in pistachio cultivation. The exploration of integrating approaches, which combines biocontrol with traditional agricultural practices, has the potential to improve both performance and sustainability. Doing so will require collaboration between researchers, agricultural agencies and farmers to facilitate knowledge exchange and implement evidence-based strategies. Such cooperative efforts are essential to forge roads towards an agricultural ecosystem that equitably balances economic viability with environmental administration against fungal disease challenges. The intricate relationship between economic, environmental and agricultural dimensions in the context of fungal diseases that affect the production of pistachio nuts emphasize the multifaceted challenges faced by major cultivating countries. Economic repercussions manifest in both reduced income and increased costs associated with management practices designed to mitigate the impact of these diseases. The financial viability of pistachio farms is compromised, leading to broader implications for rural economies that depend on nut production as a primary source of income (5). In addition, the potential for commercial limitations linked to fungal contamination further exacerbates the economic pressures that can scribble through global markets, interrupting supply chains and boosting fluctuations in pistachio prices.

From an environmental perspective, the use of chemical fungicides to combat fungal pathogens raises concerns about ecological health and sustainability. The potential for flow and degradation of the soil associated with the application of pesticides poses risks not only for the immediate agricultural landscape, but also for surrounding ecosystems. This impact can lead to a decline in biodiversity and contribute to the greater issue of environmental degradation, further complicating cultivation of cultures that require healthy soil and balanced ecosystems (14). Such environmental restrictions highlight the critical need for integrated agricultural practices that prioritize ecological integrity while addressing the threats represented by fungal diseases.

Agriculture, cultivating countries such as Iran, the United States and Türkiye must face a pressing imperative: the adoption of innovative management strategies that incorporate traditional practices and modern technology. The development and dissemination of disease-resistant pistachio varieties, along with advances in monitoring technologies, can enable farmers to anticipate and better mitigate the impacts of fungal threats (12). In addition, collaborative research initiatives that unite agricultural scientists, industry stakeholders and policy formulators are essential to promote an environment of knowledge and shared resources, increasing resilience against evolutionary challenges placed by fungal pathogens.

Given the dynamic nature of fungal diseases and their potential to adapt quickly, continuous monitoring and adaptive management practices are fundamental to protecting pistachio production. Regular assessments of the prevalence of pathogens and the effectiveness of control measures will allow producers to respond proactively to emerging threats (9). By promoting international partnerships in research institutions and agricultural communities, a comprehensive approach can be developed to address the economic, environmental and agricultural impacts interconnected from fungal diseases. This collaborative effort, based on the principles of innovation and sustainability, is vital to ensure the long-term viability of pistachio nut production, in the light of a global change landscape affected by climate change and evolving fungal pathogens.

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