NIU Journal of Health Sciences Copyright©2026
Nexus International University ISSN: 3136-6449; 12(2) 31-38

A Review of Fungal Infection on Plant

SARAH J. JALIL[1] , ZAINAB G. SADEQ[2]

[1] Iraq Natural History Research Centre and Museum, University of Baghdad, Iraq
Sarah.g@nhm.uobaghdad.edu.iq ORCID ID: 0009-0009-8903-8278
[2] Iraq Natural History Research Centre and Museum, University of Baghdad, Iraq
Zainab.g@nhm.uobaghdad.edu.iq. ORCID ID: https://orcid.org/0009-0004-2632-6575

Corresponding Author Email: sarah.g@nhm.uobaghdad.edu.iq

Abstract. The production and product quality of many plants are restricted by plant diseases. The interplay between pathogens, host plants, and ecological factors influences their development. The authors of this review summarize the infection processes, diagnostic methods, and strategies for managing diseases. Efforts to contain disease severity and resistance development have focused on biological control chemical management fungicide resistance and a range of other integrated measures. By correctly diagnosing the disease and integrating biological, cultural and chemical measures, disease can be sustainably managed.

Keywords: Fungal diseases; plant pathogens; fungal infection; disease diagnosis; biological control; fungicide resistance; integrated disease management.

1. Introduction

Fungal infections are still one of the most important biological limitations of agricultural production and limitation of yield quality and stability. Plant pathogenic fungi can harm various agricultural and horticultural crops and infect the roots, stems, leaves, flowers, fruits and seeds of plants. Besides causing visible disease symptoms, they can have adverse effects on photosynthesis, water and nutrient transport, reproductive development, and the commercial quality of harvested products. As also cited by Khan and Singh, harmful fungal diseases pose as a serious concern for agriculture production and food security.
A complex interaction of susceptible host virulent pathogen and favourable environmental conditions will help in the development of fungal disease.

The effectiveness with which pathogens survive, produce spores, and cause infection and diseases is considerably affected by the temperature, moisture, rainfall, soil condition, crop density and irrigation and agricultural practices. Such interactions are gaining paramount importance due to the new climate conditions, which may alter pathogen distribution, host susceptibility, and disease severity (Singh *et al*., 2023; Méndez *et al*., 2026).

Infection with a disease begins when a viable propagule arrives at a surface of the plant, which is susceptible. Infection occurs when a pathogen penetrates into the host due to a natural opening or wound. Infecting a host involves overcoming their defenses or manipulating the host. The interaction will be the result of fungal virulence mechanisms and the ability of the plants to induce structural biochemical and molecular defense mechanisms. (Khan, 2023; Aslam *et al*., 2024)

A critical diagnosis is essential for disease management. While part one of the note does not cover this sufficiently, the conventional diagnosis based on symptomatology, microscopy and pathogen isolation is still relevant, more so in laboratories that do not have high-throughput technologies to a larger extent. Despite showing similar symptoms, various pathogens or non-infectious stresses can be at work, making the symptom-based diagnosis alone inadequate in many cases. Researchers have developed molecular techniques that allow detecting pathogens more quickly and sensitively than ever before. These methods include PCR-based assays, isothermal amplification, biosensors and sequencing approaches (Sharma *et al*., 2024; Cotter *et al*., 2024).

Chemical fungicides are still important for crop protection. Due to the persistent dependence on specific mode of action fungicides, fungicide-resistant populations have come up. Target-site mutations, enhanced efflux, metabolic alterations or other adaptive regulators may all give rise to resistant strains. As a result, modern disease regulation includes a significant aspect of resistance management (Corkley *et al* 2022; Islam *et al* 2024).

Due to the limitations of using chemicals in a more intensive manner, there is an increased emphasis on biological control, host resistance, cultural practices, natural products and other compatible strategies. Microbial competitors including various Trichoderma, Bacillus and Pseudomonas species, and Paenibacillus species can kill pathogens using several ways. They compete for space and produce hydrolytic enzymes that can induce plant defence responses. Their mycoparasitic activity is due to antibiosis. (Yao *et al*. 2023; Galli *et al*. 2024; Dobrzyński and Naziębło 2024)

We can thus consider the implementation of integrated strategies that would prevent any fungal disease from appearing and affecting plants. Together, the results of the surveys enable researchers to assess R&D spending and scope. They also provide insight into new varieties needed in the future for results that grow better (Li *et al*, 2025).

2. Fungal Pathogens and Their Importance in Crop Production

These fungi obtain their nourishment from the host plant and utilize different strategies to overcome the host plant. These organisms can live in a variety of ways. They can be biotrophic, which means that they keep the host tissue alive. On the other hand, they can be necrotrophic, which means that they kill the host cells and live on them. A pathogen that may invest in the first phase of the EARM-spectrum (disease strategy spectrum) and mutilate the host tissue later may be called a hemibiotroph (Maulenbay and Rsaliyev, 2024).

Some examples of fungi that are damaging to plants are sooty molds, smuts, and rusts. Other examples include genera of the fungi Alternaria, Botrytis, and Fusarium. There are significant variations among these pathogens regarding their hosts, infection process, means of survival, and endoparasite's environment requirements (Maulenbay and Rsaliyev, 2024; Aslam *et al*., 2024).

As capable of causing disease doesn't indicate the worth of any fungal pathogen as a whole. The epidemiological significance of an agent refers to its ability to survive, and between cropping seasons (i.e. grainless periods), to produce and disperse inoculum, to colonize susceptible plant tissues, and to adapt to variation in the environment. Plants absorb nutrients from the soil and, therefore, weeds compete for these resources. Herbicide works either by preventing the weed from absorbing nutrients and water or by killing the weed directly.

Post-harvest fungal diseases increase the loss due to diseases Pathogens such as Botrytis, Alternaria, and Colletotrichum serve as illustrations of rotting goods. It is essential that fungal disease control programs cover post-harvest protection effort as well as field production effort (Li *et al*.2025)

3. Infection Process and Disease Development

3.1 Spore Germination and Host Recognition

A fungal infection typically begins when spores or other infectious agents come into contact with a host's surface. Environmental conditions, especially temperature and moisture, are important factors for germination in addition to chemical and nutritional signals. The plant surface contracts after germination of fungal structure. Certain pathogens develop unique structures such as appressoria, which help them to enter host cells and / or break the host organisms' tissues (Khan, 2023).

3.2 Penetration and Colonization

The skin of a plant is the first line of defence against pests and pathogens and can be described as its first physical barrier. Fungal penetration is reduced by cuticle cell wall and other antifungal compounds. Colonization is limited due to defense mechanisms A successful pathogen can penetrate the tissues of a plant and disrupt its growth or even kill the plant. When a pathogen penetrates the host tissues, the fungal hyphae will either remain localized or disseminate through the host tissues. The extent to which the above takes place differs from one pathogen to another (Aslam *et al*., 2024).

3.3 Plant Defense Responses

Plants possess different kinds of defense against fungi. The identification of pathogen-related molecules could activate signaling that leads to the production of reactive oxygen species, antimicrobial agents, defence proteins and structural barriers. Structural modifications that occur as a result of pathogen invasion in plants are appressing and cell-wall reinforcement. Hormones such as salicylic acid, jasmonic acid, ethylene, and abscisic acid regulate the plant reaction(Yao *et al*., 2023; Aslam *et al*., 2024).

4. Symptoms and Consequences of Fungal Diseases

Symptom Presentation of Fungal Diseases Depending upon the pathogen and host infected, the symptoms caused by fungal diseases may vary. The symptoms of the plant diseases include leaf spots and blights, chlorosis and yellowing, necrosis, wilting, stem and branch cankers, damping-off, root and crown rot, vascular discoloration, fruit and seed rot, early defoliation and reduced growth and reproductive performance (Maulenbay and Rsaliyev, 2024).

Leaf diseases which damage functional leaf tissue can reduce photosynthetic capacity, whereas root and vascular tissue damage impairs water and nutrient acquisition. Diseases can reduce yields, affect quality, raise costs of production and reduce post-harvest shelf life with serious economic consequences.

Some fungal pathogens can also produce mycotoxins that cause food and feed safety problems (Singh *et al*., 2023; Li *et al*., 2025).

5. Environmental and Agricultural Factors Affecting Disease Development

The environmental factors and crop-management practices influence disease development.
Fungi's temperature alters how seed germinate and disease infects. All pathogens have a temperature range of optimum infection and any deviation from this temperature range may alter the disease development. (Singh *et al*., 2023)

Many leaf pathogens require moisture to thrive. Extended periods of leaf wetness can facilitate spore germination and penetration. High relative humidity may set the stage for sporulation.

Rain can disperse pathogenic through splash dispersal and run off, while overhead irrigation can increase wetness duration of leaves possibly increasing the risk of disease in susceptible crops. Densely packed plants can make a great environment for fungal growth, due to humid conditions (Khan, 2023).

By minimizing the consistent presence of susceptible hosts, crop rotation has the ability to interrupt pathogen life cycles. Appropriate management of infected residues may reduce pathogen survival between years growing (Khan, 2023).
Changing climate conditions have been complicating disease epidemiology through changes in temperature precipitation water availability pathogen distribution and host physiology. A systematic review of 106 studies found that 61% of the studies showed an increase in disease severity under the climate-related conditions investigated. However, the responses varied among different crops and pathogens (Méndez *et al*. 2026).

6. Diagnosis of Fungal Plant Diseases

An accurate diagnosis forms the basis of rational disease management.

6.1 Symptom-Based Diagnosis

Spotting a Disease Is the First Sign of Illness The lesion structure and symptoms and appearance of organ involvement and visible fungal element can signal useful preliminary information. Symptoms can be misleading, since they cannot help to distinguish pathogens, or infectious and non-infectious disorder (Sharma *et al*., 2024).

6.2 Microscopy and Culture

Observation under microscope can show fungal hyphae. Culturing the pathogen in proper media allows us to identify them further. These methods are useful but take time and expert knowledge (Sharma *et al*., 2024).

6.3 Molecular Diagnosis

The detection of pathogens has benefited from the improved sensitivity and specificity made possible by PCR, quantitative PCR, loop-mediated isothermal amplification, recombinase polymerase amplification, sequencing, and biosensor-based technologies. A review of diagnostics earlier has identified novel molecular methods that can potentially be very useful for detecting fungal and oomycete plant pathogens before disease establishment (Sharma *et al*., 2024; Cotter *et al*., 2024).

6.4 Imaging and Remote Sensing

More and more researchers are looking into optical hyperspectral thermal and other type of s en s ing for early detection of diseases. These methods allow for non-destructive information that can monitor large crop areas. Nonetheless, the necessity for assessment under changing field conditions will always be there as measured in controlled conditions may not be the same in farming time (Pereira *et al*., 2025; George *et al*., 2025).

7. Chemical Control and Fungicide Resistance

Fungicides are important for protecting crops from disease. The effectiveness of fungicides relies on factors like chemical composition, mode of action, timing, and dose sensitivity (Islam *et al*, 2024).

Using several fungicides with similar action modes will impose selection pressure on the pathogen population. Strains that develop during treatment can propagate and spread resistance. Resistance to efflux target-site mutations can involve altered metabolism and other mechanism. As a result, it is apt for current and future-resistant management, to enhance the diversification of modes of action, limit unnecessary applications, offer sound dose, and integrate with non-chemical means (Corkley *et al*., 2022; Naqvi *et al*., 2024).

8. Biological Control

Biological control refers to the strategy of employing beneficial microorganisms in inhibiting plant pathogens. The method is increasingly used in pest control, as there are concerns of chemical residues, environmental pollution, resistance development and sustainability (of the method) (Galli *et al*., 2024; Madlhophe *et al*., 2025). Microbes employed for biocontrol can assist with competition for nutrients and niches, antibiosis, mycoparasitism, production of hydrolytic enzymes, production of antimicrobial metabolites, competition for iron and other elements, as well as stimulation of plant defence mechanisms (Yao *et al*., 2023; Dobrzyński and Naziębło, 2024).

8.1 Trichoderma spp.

Trichoderma species have been thoroughly studied and shown to be effective fungal biocontrol agents. Yao et al., 2023, reported that this activity can also be mycoparasitism, competition antibiosis, enzyme production and induction of systemic resistance in plants. Recent studies on formulations based on Trichoderma are being used against soil-borne and foliar and post-harvest diseases. Despite being efficacious, field performance may differ with strains, environmental conditions, formulation stability and application method (Li et al, 2025; Pérez-Pizá et al, 2025).

8.2 Bacterial Biocontrol Agents

The fungal pathogens have been proved to be controlled biologically by Bacillus, Pseudomonas and Paenibacillus species. Mechanisms may involve the production secretion of enzymes activation of host defenses biofilm formation and more. The genus Paenibacillus is of special interest as a potential biocontrol agent other than P. polymyxa (Dobrzyński and Naziębło, 2024).

8.3 Arbuscular Mycorrhizal Fungi

Mycorrhizal fungi can prevent plant diseases and help plants obtain nutrients and water. They may change plant nutrition, hormonal signaling, root structure, defence responses, and so on. Scientists have recently found out that they can help manage disease and promote vigour(Galli *et al*., 2024).

9. Botanical and Natural Products

Another potential group of substitutes for synthetic fungicides are plant. The activity of phenolics, flavonoids, terpenoids, alkaloids, and essential-oil components in inhibiting the growth of fungi can be attributed to their action on membrane integrity, enzyme activity, and spore germination (Calefi *et al*., 2025).
Recent reviews indicate that plant-based products can be useful against many pathogens, especially in organic systems. But this is a serious hindrance because of the variability of chemical composition stability formulation phytotoxicity and field efficacy. For real-life use in agriculture, promising compounds will need to be formulated in standard way and field validated (Calefi *et al*., 2025; Monteiro *et al*., 2026).

10. Emerging and Advanced Approaches

Advancements in plant pathology have created a whole new range of disease-management choices. Researchers are evaluating approaches like genomic editing, molecular diagnostics, and nanotechnology to enhance disease management. Despite the regulatory, ecological, economic, and technical constraints which still exist, Ogwu and Izah (2025) and Monteiro *et al*. (2026) concluded that these technologies have the potential of improving pathogen specificity and minimizing environmental exposure.
These methods are the additions to the already-established disease-management principles (Keykhasaber *et al*., 2026).
.

11. Integrated Disease Management

The different methods for integrated disease management are compatible and among them reduce diseases' intensity. The aim is to avoid heavy dependence on any one method. A practical program can employ resistant or tolerant cultivars, pathogen-free planting material, incorporate crop rotation, ensure proper irrigation and drainage, include handling sanitation and residues, monitor the crop, make an early and accurate diagnosis, practice biological control, use validated botanicals, use fungicide judiciously and rotate the mode of action of fungicide (Khan, 2023; Galli *et al*., 2024).

The main advantage of integration is that various components act via various means. This technique can help in improving disease suppression and decreasing the selection pressure for fungicide resistance. As per the recent reviews, it has endorsed integrated frameworks which combine cultural practices, host resistance, bio-control, use of natural products, and targeted application of chemicals. (Galli *et al*. 2024 Monteiro *et al*. 2026).

12. Current Challenges and Future Perspectives

Fungal diseases face many challenges that hinder their effective management. Populations of pathogens are genetically varied and adaptable. Fungicide resistance threatens the long-term effectiveness of chemical control. Variable performance shown in the field despite positive laboratory results experienced by a range of biological control agents (Corkley *et al*., 2022; Pérez-Pizá *et al*., 2025).

The uncertainty added by climate change stems from alterations in the distribution of pathogens, environmental suitability, host physiology and disease outcomes. The effects are not uniform across the pathosystems indicating

that we require disease-specific forecasts making them more specialised than generalised assumptions (Singh *et al*., 2023; Méndez *et al*., 2026).
As a result of this, future research focus needs to be on field validation, better formulation of biological agents, standardization of diagnostics, resistance monitoring and combination of complementary disease-management strategies (Keykhasaber *et al*., 2026; Monteiro *et al*. 2026).
.

Table 1: Major fungal pathogens, associated diseases, symptoms, and main affected plant organs.

Fungal pathogen/group	Representative disease	Major symptoms	Main affected organs
Fusarium spp.	Fusarium wilt/root rot	Wilting, vascular discoloration, root decay	Roots, stems
Alternaria spp.	Leaf spot/blight	Necrotic spots, concentric lesions	Leaves, fruits
Botrytis cinerea	Gray mold	Soft rot, gray sporulation	Flowers, fruits
Colletotrichum spp.	Anthracnose	Sunken necrotic lesions	Leaves, stems, fruits
Rhizoctonia spp.	Root/crown rot	Damping-off, root and stem lesions	Roots, stems
Sclerotinia spp.	White mold	Soft rot, white mycelium	Stems, fruits
Verticillium spp.	Vascular wilt	Wilting, vascular browning	Roots, vascular tissues
Magnaporthe spp.	Blast disease	Lesions and tissue necrosis	Leaves, stems, reproductive tissues

Table 2: Comparison of major fungal disease-management strategies.

Strategy	Main mechanism	Major advantage	Major limitation	Sustainability
Chemical control	Direct inhibition of pathogen growth	Rapid and often effective	Resistance and environmental concerns	Moderate
Host resistance	Restricts infection or disease development	Long-term and relatively low input	Pathogen adaptation may overcome resistance	High
Crop rotation	Interrupts pathogen life cycle	Low cost and preventive	Less effective against broad-host pathogens	High
Biological control	Competition, antibiosis, mycoparasitism, induced resistance	Environmentally compatible	Variable field performance	High
Botanical products	Antifungal natural compounds	Potentially biodegradable	Stability and standardization problems	Potentially high
Integrated management	Combines complementary methods	More robust disease suppression	Requires monitoring and planning	Very high

Figure 1: *Conceptual framework for fungal disease development and integrated management.*

Pathogen survival and dissemination
↓
Spore deposition / pathogen contact with host
↓
Germination and host recognition
↓
Penetration and colonization
↓
Host defense–pathogen interaction
↓
Disease development and symptom expression
↓
Early diagnosis and disease monitoring
↓
Integrated management: Cultural practices | Host resistance | Biological control | Botanical products | Judicious chemical control | Resistance management

13. Conclusion

Fungal diseases are a huge challenge for sustainable crop production and food security. The development of pathogens happens as a result of many factors including pathogen biology. Accurate diagnosis and early intervention are essential for effective management of diseases (Khan, 2023; Singh *et al*., 2023).

Even with the availability of chemical fungicides, the rising resistance and increasing environmental concerns necessitate the incorporation of host resistance, cultural practices, biological control, natural products and use of chemical fungicides options. Future studies need to increase the reliability of biological and diagnostic technologies under field conditions and explore complementary strategies for effective disease suppression that mitigates environmental impacts (Corkley *et al*., 2022; Galli *et al*., 2024; Monteiro *et al*., 2026).

References

Khan, R. A. A. (2023). Advances in integrated disease management (IDM) for soil-borne plant pathogens: innovative approaches and underlying action mechanism at molecular level. *Frontiers in Plant Science, 14,* 1256979. https://doi.org/10.3389/fpls.2023.1256979 .

Yao, X., Guo, H., Zhang, K., Zhao, M., Ruan, J., & Chen, J. (2023). Trichoderma and its role in biological control of plant fungal and nematode disease. *Frontiers in Microbiology*, 14, 1160551. https://doi.org/10.3389/fmicb.2023.1160551 .

Madlhophe, S., Ogugua, U. V., Makhubu, F. N., & Figlan, S. (2025). Use of biological control agents for managing fungal pathogens in Solanaceae crops: progress and future perspectives—a review. *Discover Applied Sciences, 7,* 83. https://doi.org/10.1007/s42452-025-06500-9 .

Galli, M., Feldmann, F., Vogler, U. K., et al. (2024). Can biocontrol be the game-changer in integrated pest management? A review of definitions, methods and strategies. *Journal of Plant Diseases and Protection, 131,* 265–291. https://doi.org/10.1007/s41348-024-00878-1 .

Corkley, I., Fraaije, B., & Hawkins, N. (2022). Fungicide resistance: Progress in understanding mechanism, monitoring, and management. *Phytopathology, 112*.

Sharma, G., Dwibedi, V., Seth, C. S., et al. (2024). Direct and indirect technical guide for the early detection and management of fungal plant diseases. Current Research in Microbial Sciences, 7, 100276. https://doi.org/10.1016/j.crmicr.2024.100276 .

Cotter, A., Dracatos, P., Beddoe, T., & Johnson, K. (2024). Isothermal detection methods for fungal pathogens in closed environment agriculture. *Journal of Fungi, 10,* 851. https://doi.org/10.3390/jof10120851 .

Maulenbay, A., & Rsaliyev, A. (2024). Fungal disease tolerance with a focus on wheat: A review. *Journal of Fungi, 10,* 482. https://doi.org/10.3390/jof10070482 .

Aslam, H. M. U., Chikh-Ali, M., Zhou, X.-G., et al. (2024). Epigenetic modulation of fungal pathogens: a focus on *Magnaporthe oryzae. Frontiers in Microbiology*, 15, 1463987. *https://doi.org/10.3389/fmicb.2024.1463987*.

Naqvi, S. A. H., Farhan, M., Ahmad, M., et al. (2024). Deciphering fungicide resistance in Phytophthora: mechanisms, prevalence, and sustainable management approaches. *World Journal of Microbiology and Biotechnology, 40, 302.* https://doi.org/10.1007/s11274-024-04108-6 .

Dobrzyński, J., & Naziębło, A. (2024). *Paenibacillus* as a biocontrol agent for fungal phytopathogens: Is P. polymyxa the only one worth attention? *Microbial Ecology, 87, 134. https://doi.org/10.1007/s00248-024-02450-8* .

Galli, M., Sede, A., Heinlein, M., et al. (2025). A biocontrol perspective on mycoviruses in fungal pathogen management. Journal of Plant Diseases and Protection, 132, 43. https://doi.org/10.1007/s41348-024-01006-9 .

Li, X., Liao, Q., Zeng, S., Wang, Y., & Liu, J. (2025). The use of *Trichoderma* species for the biocontrol of postharvest fungal decay in fruits and vegetables: Challenges and opportunities. *Postharvest Biology and Technology*, 219, 113236. *https://doi.org/10.1016/j.postharvbio.2024.113236*

Pérez-Pizá, M. C., et al. (2025). Quick and effective evaluation methods for biocontrol agents and biostimulants against phytopathogenic fungi relevant for various cropping systems. Plant Pathology. https://doi.org/10.1111/ppa.14064

Ogwu, M. C., & Izah, S. C. (2025). Nanotechnology for fungal pathogen control in crops: innovations, public health impacts, and disease prevention. Frontiers in Fungal Biology, 6, 1653214. https://doi.org/10.3389/ffunb.2025.1653214.

Keykhasaber, M., Tzelepis, G., & Rafiei, V. (2026). Converging technologies for next-generation plant protection: an integrated framework for fungal disease management. Frontiers in Agronomy, 8, 1760693. https://doi.org/10.3389/fagro.2026.1760693.

Monteiro, F., et al. (2026). Non-chemical control of fungal pathogens in crops: a one-health perspective on strategies, mechanisms, and future directions. Frontiers in Plant Science. https://doi.org/10.3389/fpls.2025.1746521.

George, R., Thuseethan, S., Ragel, R. G., et al. (2025). Past, present and future of deep plant leaf disease recognition: A survey. Computers and Electronics in Agriculture, 234, 110128. 10.1016/j.compag.2025.110128.

Méndez, I., et al. (2026). Does climate change increase disease severity caused by crop pathogens? A systematic review. Plant Disease, 110, 2556–2571. https://doi.org/10.1094/PDIS-03-25-0573-SR.

Islam, T., Danishuddin, Tabassum Tamanna, N., Matin, M. N., Barai, H. R., & Haque, M. A. (2024). Resistance mechanisms of plant pathogenic fungi to fungicide, environmental impacts of fungicides, and sustainable solutions. Plants, 13, 2737. https://doi.org/10.3390/plants13192737 .
Calefi, G. G., Silva, N. B. S., Alhatlani, B. Y., & Abdallah, E. M. (2025). Harnessing nature's arsenal: sustainable plant-based strategies for phytopathogen control. *Frontiers in Microbiology, 16,* 1588462. https://doi.org/10.3389/fmicb.2025.1588462.
Pereira, M. R., Tosin, R., dos Santos, F. N., Tavares, F., & Cunha, M. (2025). Digital assessment of plant diseases: A critical review and analysis of optical sensing technologies for early plant disease diagnosis. Computers and Electronics in Agriculture, 236, 110443. 10.1016/j.compag.2025.110443.
Singh, B. K., Delgado-Baquerizo, M., Egidi, E., Guirado, E., Leach, J. E., Liu, H., & Trivedi, P. (2023). Climate change impacts on plant pathogens, food security and paths forward. *Nature Reviews Microbiology, 21,* 640–656. https://www.nature.com/articles/s41579-023-00900-7 .