AVE **Trends in Intelligent Informatics Reports**

Advances in Plant Disease Detection, Management, and Control: A Comprehensive Review

Aung Myint Myat[1,*], April Thet Su[2], Hlaing Htake Khaung Tin[3], M. R. Anitha[4], S. Sathya[5]

[1,2,3]Faculty of Information Science, University of Information Technology, Yangon, Myanmar.
[4]Department of Electronics and Communication Engineering, Dhaanish Ahmed College of Engineering, Chennai, Tamil Nadu, India.
[5]Department of Computer Science and Information Technology, School of Computing Sciences, Vels Institute of Science, Technology and Advanced Studies, Chennai, Tamil Nadu, India.
oungmyintmyat482@gmail.com[1], aprilthetsu@gmail.com[2], hlainghtakekhaungtin@gmail.com[3], anitha.m.r@dhaanishchennai.in[4], ssathya.scs@vistas.ac.in[5]

*Corresponding author

Abstract: Plant diseases continue to pose a serious risk to global food security and agricultural productivity, resulting in significant financial losses every year. If not identified and treated promptly, these diseases, caused by nematodes, bacteria, viruses, and fungi, reduce crop yield and quality. Although they are dependable, traditional diagnostic techniques such as visual inspection, microscopy, and culture-based methods are often labor-intensive and time-consuming. Rapid and precise pathogen identification has been enabled by recent advances in molecular biology, including next-generation sequencing, enzyme-linked immunosorbent assay (ELISA), and polymerase chain reaction (PCR). Simultaneously, scalable solutions for precision agriculture have been enabled by computational methods, particularly image processing, machine learning, and deep learning, which have become effective tools for early disease detection in plant images. Sustainable disease outbreak control has been achieved through integrated disease management strategies that combine biological, chemical, and cultural approaches. Despite these advances, challenges persist, including pathogen variability, resistance development, limited accessibility to advanced diagnostic tools, and environmental influences. This review provides an extensive summary of plant disease types, detection techniques, and management approaches. It emphasizes combining cutting-edge technology with conventional methods to improve early detection, reduce crop losses, and promote sustainable agriculture. Finally, future research directions for precision plant disease management are discussed.

Keywords: Plant Disease; Modern Technologies; Polymerase Chain Reaction; Plant Images; Agricultural Productivity; Deep Learning (DL); Image Processing; Disease Management.

Cite as: A. M. Myat, A. T. Su, H. H. K. Tin, M. R. Anitha, and S. Sathya, “Advances in Plant Disease Detection, Management, and Control: A Comprehensive Review,” *AVE Trends in Intelligent Informatics Reports*, vol. 1, no. 1, pp. 14–23, 2026.

Journal Homepage: https://www.avepubs.com/user/journals/details/ATIIR

Received on: 28/03/2025, **Revised on:** 13/05/2025, **Accepted on:** 16/07/2025, **Published on:** 01/03/2026

DOI: https://doi.org/10.64091/ATIIR.2026.000277

1. Introduction

Plant diseases pose serious threats to food security, farmer livelihoods, and the global economy, and they are a major factor limiting agricultural productivity globally. Crops are vulnerable to a wide range of pathogens, including fungi, bacteria, viruses, and nematodes, which can affect leaves, stems, roots, and fruits. These diseases can appear as minor discolorations, severe tissue necrosis, wilting, or plant death, and they often result in significant yield reductions. Early identification and effective management of plant diseases are therefore essential to mitigate losses and maintain sustainable agricultural production [2]. Plant pathology has long relied on conventional techniques for diagnosing plant diseases, including microscopic analysis, visual inspection of symptoms, and pathogen isolation in culture media [3]. Although these techniques are reliable, they often require a lot of work, take a long time, and require specialized knowledge. Misdiagnosis is common, particularly when symptoms are similar across several diseases or when infections start early and don't manifest. Developments in biotechnology and molecular biology have transformed the detection of plant diseases. Pathogens can be precisely identified at the genetic or protein level using methods such as next-generation sequencing, enzyme-linked immunosorbent assay (ELISA), and polymerase chain reaction (PCR).

These methods enable prompt intervention through early detection, even before outward symptoms manifest. Molecular techniques have also sped up plant pathology research by shedding light on host-pathogen interactions, pathogen diversity, and evolution [4]. Computational methods have become supplementary tools for monitoring and detecting plant diseases in recent years. Machine learning and deep learning algorithms enable image-based methods to accurately and automatically classify disease symptoms from photos of leaves, fruit, or stems. Because these methods can be combined with drones, mobile applications, and remote sensing platforms to provide real-time disease surveillance, they are especially useful for large-scale agricultural monitoring [5]. Integrated disease management (IDM), which combines biological, chemical, and cultural approaches, is frequently necessary for the effective control of plant diseases. Cultural practices include crop rotation, proper spacing, and sanitation measures to minimize the spread of pathogens. Although chemical treatments like fungicides and bactericides work well, they must be used sparingly to prevent environmental contamination and the emergence of resistance. Biological control techniques, such as the application of antagonistic microbes, offer sustainable substitutes [6]. Plant disease management continues to present difficulties despite technological advancements. Disease control efforts are complicated by pathogen variability, environmental fluctuations, the emergence of resistant strains, and limited access to sophisticated diagnostic tools in developing regions. As a result, current research is focused on combining conventional and contemporary methods to develop rapid, precise, and scalable solutions for sustainable agriculture [7].

2. Literature Review

2.1. Classification and Impact of Plant Diseases

Based on the type of pathogen, plant diseases can be broadly classified as bacterial, viral, fungal, or nematode-induced. Among the most prevalent and destructive fungi are powdery mildew, rust, and late blight, which often cause significant yield losses in fruit, vegetables, and cereals (Table 1).

Table 1: Common plant diseases, pathogens, and major crops

Disease	Pathogen	Major Crop	Symptoms
Late blight	Phytophthora infestans	Potato, Tomato	Leaf spots, stem lesions
Powdery mildew	Erysiphe spp.	Wheat, Grapes	White powdery growth on leaves
Bacterial wilt	Ralstonia solanacearum	Tomato, Potato	Wilting, yellowing
Tobacco mosaic	Tobacco mosaic virus	Tobacco	Mosaic patterns, stunted growth
Root-knot nematode	Meloidogyne spp.	Tomato, Carrot	Root galls, reduced nutrient uptake

Numerous crops are affected by bacterial diseases, such as bacterial wilt and bacterial leaf spot, which can spread quickly under favorable conditions. Stunted growth, discolored leaves, and reduced productivity are common outcomes of viral diseases such as tomato yellow leaf curl virus and tobacco mosaic virus. Crop performance is further reduced by nematodes, microscopic parasitic worms that attack roots and hinder nutrient uptake. Plant diseases cause 10–16% of annual crop losses worldwide, according to Agrios [1], underscoring the pressing need for efficient detection and control methods.

2.2. Traditional Detection Methods

Visual inspection remains widely used due to its simplicity and low cost, but it is subjective and prone to errors. Although it requires skilled workers, microscopy enables the visualization of pathogen structures, such as bacterial cells and fungal spores. By cultivating pathogens on selective media, culture-based techniques provide precise identification; however, they are time-consuming and not suitable for rapid screening.

2.3. Molecular Techniques

Molecular diagnostics offer early and accurate detection. For quick identification, PCR amplifies pathogen-specific DNA sequences. ELISA enables rapid field testing by detecting pathogen proteins or antigens. Comprehensive information about pathogen populations, including mixed infections and novel strains, can be obtained through next-generation sequencing. High-value crops, quarantine inspections, and research all make extensive use of these instruments.

2.4. Computational and Imaging Approaches

Plant disease monitoring has been transformed by image-based detection using deep learning (CNNs) and machine learning (SVM, Random Forest). CNNs achieve 95% accuracy in identifying intricate disease patterns in leaf photos. Real-time, comprehensive surveillance is enabled by integrating with satellites, drones, and mobile apps, thereby enhancing early intervention.

2.5. Disease Management Strategies

Biological control (antagonistic microorganisms such as Bacillus subtilis or Trichoderma spp.), chemical control (fungicides, bactericides), and cultural practices (crop rotation, sanitation, and appropriate spacing) are examples of management strategies. These tactics are combined in Integrated Disease Management (IDM) for long-term control.

2.6. Challenges

Pathogen evolution, the emergence of resistance, environmental factors, and restricted access to cutting-edge instruments are among the difficulties. AI-based detection requires large, annotated datasets and high-quality images. It is still difficult to integrate computational, visual, and molecular approaches into an economic framework.

2.7. Emerging Trends and Future Directions

Future studies will focus on multimodal detection for predictive disease management using IoT, sensors, and AI. Proactive disease control requires open-access worldwide databases, drones for surveillance, and the breeding of disease-resistant cultivars. Food security and sustainable agriculture are promised by combining traditional, computational, and molecular methods.

3. Plant Disease Detection Methods

From conventional field-based techniques to molecular and computational approaches, plant disease detection has significantly improved. Preventing crop losses, guaranteeing sustainable production, and improving food security all depend on early and precise detection. Detection techniques fall into three categories: computational, molecular, and traditional (Figure 1).

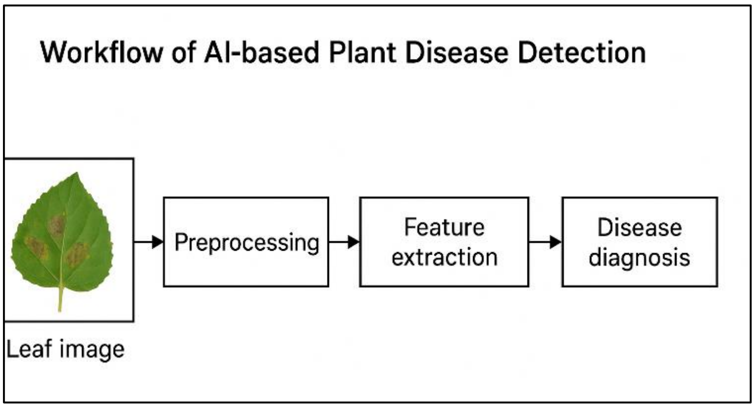

Figure 1: Workflow of AI-based plant disease detection

3.1. Traditional Methods

- **Visual Inspection:** The most basic and popular technique relies on spotting telltale signs such as discoloration, wilting, and leaf spots. Although economical, this approach is arbitrary and may not identify latent or early infections.

- **Microscopy:** Direct observation of bacterial cells, viral inclusion bodies, or fungal spores is possible. Although this method takes more time and requires skilled personnel, it offers a more reliable identification than visual inspection.
- **Culture Techniques:** Fungi, bacteria, and other microorganisms can be precisely identified by isolating them in selective media. Culture-based methods are slow and labor-intensive, limiting their use for rapid or large-scale diagnosis despite their high accuracy.

3.2. Molecular Methods

Molecular methods have revolutionized plant pathology by providing highly accurate, rapid, and sensitive tools for pathogen detection. These techniques allow researchers to identify pathogens at the DNA, RNA, or protein level, facilitating early diagnosis, disease management, and a deeper understanding of pathogen biology. Table 2 summarizes some commonly used molecular methods, highlighting their applications and advantages.

Table 2: Molecular methods

Polymerase Chain Reaction (PCR)	PCR is a highly sensitive and specific technique for detecting pathogen DNA or RNA. It enables early diagnosis even before symptoms appear, making it invaluable for managing viral, bacterial, and fungal diseases.
Enzyme-Linked Immunosorbent Assay (ELISA)	ELISA detects pathogen-specific proteins or antigens, providing rapid and quantitative results. It is widely used to detect viruses and bacteria in crops.
Next-Generation Sequencing (NGS)	NGS allows comprehensive identification of known and novel pathogens at the genomic level. It provides insights into pathogen diversity, evolution, and interactions with host plants.

3.3. Computational and Imaging Techniques

Computational and imaging techniques have emerged as powerful tools for rapid and accurate detection of plant diseases and crop stress. Digital image processing enables detailed analysis of leaf symptoms, such as chlorosis, necrosis, and lesions, reducing the time and labor required by traditional inspection methods. Advanced machine learning and deep learning models, including convolutional neural networks (CNNs), enable high-accuracy automated classification of diseases from images, enabling scalable monitoring across large agricultural areas.

Table 3: Computational and imaging techniques

Image Processing	Digital image analysis of leaves enables rapid detection of symptoms such as chlorosis, necrosis, and lesions. This approach reduces the time and labor associated with traditional methods.
Machine Learning and Deep Learning	Convolutional Neural Networks (CNNs) and other AI models classify diseases from images with high accuracy. These models can be scaled for automated monitoring in large agricultural areas.
Remote Sensing	Drones, satellites, and multispectral sensors detect crop stress and disease over large fields by measuring variations in vegetation indices. This facilitates early intervention and precision agriculture practices.

Additionally, remote sensing technologies—such as drones, satellites, and multispectral sensors—provide comprehensive field-level surveillance by detecting variations in vegetation indices, supporting early intervention and precision agriculture practices. These techniques are summarized in Table 3.

4. Disease Management and Control Strategies

Effective disease management requires a combination of preventive, curative, and sustainable strategies. The selection of an appropriate method depends on pathogen type, environmental conditions, and resource availability.

4.1. Cultural Practices

Cultural practices are essential agronomic strategies designed to reduce the occurrence and spread of plant pathogens by creating conditions less favorable to disease development. Crop rotation, for example, alternates susceptible crops with non-host species to prevent pathogen buildup in the soil. Proper spacing between plants improves air circulation, reducing humidity and the likelihood of disease transmission.

Table 4: Cultural practices

Crop Rotation	Alternating crops with non-host species reduces pathogen buildup in the soil.
Proper Spacing	Adequate plant spacing improves air circulation, lowering humidity and the risk of disease spreading.
Sanitation	Removing infected plant debris and controlling weeds minimizes pathogen reservoirs.
Water and Nutrient Management	Proper irrigation and balanced fertilization enhance plant health and resistance to infections.

Sanitation practices, such as removing infected plant debris and controlling weeds, help minimize reservoirs of pathogens, while careful water and nutrient management strengthen plant health and resistance to infections. These key cultural practices are summarized in Table 4.

4.2. Chemical Control

Chemical control involves the targeted application of fungicides, bactericides, or pesticides to manage plant diseases effectively. Treatments should be applied based on accurate disease identification and infection severity to maximize efficacy. Implementing resistance management strategies, such as rotating chemical agents with different modes of action, helps prevent the development of pathogen resistance.

Table 5: Chemical control

Targeted Use	Chemicals should be applied based on disease identification and severity.
Resistance Management	Rotating chemical agents with different modes of action prevents pathogen resistance.
Safety Considerations	Proper handling, adherence to guidelines, and minimal environmental impact are critical.

Additionally, safety considerations—including proper handling, strict adherence to guidelines, and minimizing environmental impact—are essential for responsible chemical use. These important practices are summarized in Table 5.

4.3. Biological Control

Biological methods employ living organisms to suppress plant pathogens and enhance crop health. Antagonistic microorganisms, such as beneficial bacteria, fungi, or viruses, inhibit pathogen growth through competition or the production of antimicrobial compounds.

Table 6: Biological control

Antagonistic Microorganisms	Beneficial bacteria, fungi, or viruses inhibit pathogen growth through competition or antimicrobial production.
Mycorrhizal Associations	Symbiotic fungi improve nutrient uptake and enhance disease resistance.
Biopesticides	Formulated microbial agents can be applied to seeds, soil, or foliage to reduce disease incidence.

Symbiotic mycorrhizal associations improve nutrient uptake and strengthen plant resistance to diseases. Additionally, biopesticides—formulated microbial agents applied to seeds, soil, or foliage—help reduce disease incidence in crops. These key biological control strategies are summarized in Table 6.

4.4. Integrated Disease Management (IDM)

Integrated Disease Management (IDM) combines multiple strategies to achieve sustainable and effective control of plant diseases. Monitoring and early detection through molecular diagnostics, field scouting, and AI-based tools allow timely interventions to prevent disease spread.

Table 7: Integrated disease management

Monitoring and Early Detection	Molecular diagnostics, field scouting, and AI-based tools enable timely interventions.

Combination of Control Measures	Leveraging the strengths of cultural, chemical, and biological methods minimizes reliance on chemicals.
Adaptation to Local Conditions	Strategies are tailored to crop type, pathogen prevalence, climate, and available resources.
Sustainability Focus	Promotes long-term productivity and environmental safety.

IDM leverages the strengths of cultural, chemical, and biological control measures, minimizing over-reliance on chemical treatments. Strategies are adapted to local conditions, considering crop type, pathogen prevalence, climate, and available resources, while maintaining a focus on long-term productivity and environmental safety. These principles of IDM are summarized in Table 7.

4.5. Comparison of Methods

The effective management of plant diseases relies on a diverse range of detection and control methods, each with distinct principles, advantages, and limitations. Traditional detection methods, such as visual inspection, microscopy, and culture techniques, are simple and cost-effective but may miss latent infections or require specialized expertise. Molecular techniques—including PCR, ELISA, and next-generation sequencing—offer high specificity and early detection capabilities, although they require laboratory facilities and can be expensive. Computational and imaging approaches, such as image processing, machine learning, and remote sensing, provide fast, scalable, and automated disease monitoring, but their effectiveness depends on data quality and technical expertise.

Table 8: Comparison of plant disease detection and management methods, highlighting their principles, advantages, limitations, and representative references

Method Category	Specific Method	Principle	Advantages	Limitations	Representative References
Traditional Detection	Visual Inspection	Observing disease symptoms on the plant	Simple, low cost, rapid	Subjective, misses latent infections	Akhtar et al. [11]
	Microscopy	Observing spores and bacterial cells under a microscope	Direct observation of the pathogen	Time-consuming, requires expertise	Akhtar et al. [11]
	Culture Techniques	Isolating pathogens on selective media	Accurate identification	Slow, labor-intensive	Akhtar et al. [11]
Molecular Detection	PCR	Amplification of pathogen DNA	High specificity, detects early infections	Requires lab, expensive	Cubero et al. [13]
	ELISA	Detects pathogen proteins/antigens	Rapid, quantitative	Limited to known pathogens	Cubero et al. [13]
	Next-Generation Sequencing	High-throughput pathogen genome sequencing	Comprehensive detection identifies new pathogens	Expensive, complex data analysis	Cubero et al. [13]
Computational and Imaging	Image Processing	Analyzes leaf images for symptoms	Fast, scalable	Sensitive to image quality	Jackulin and Murugavalli [12]
	Machine Learning / Deep Learning	AI models classify diseases from images	High accuracy, automation	Require large datasets	Jackulin and Murugavalli [12]
	Remote Sensing	Drone or satellite imaging of crops	Monitors large areas for early detection	Expensive technical expertise needed	Yang [10]
Cultural Control	Crop rotation, spacing and sanitation	Reduces pathogen survival and spread	Eco-friendly, cost-effective	Labor-intensive, slow-acting	Etesami [9]
Chemical Control	Fungicides, bactericides, pesticides	Chemical suppression of pathogens	Fast-acting, effective	Resistance development, environmental hazard	Babu et al. [8]

Biological Control	Antagonistic microbes, biopesticides	Suppression via natural enemies	Environmentally friendly	Variable efficacy, may be slow	Babu et al. [8]
Integrated Disease Management (IDM)	A combination of the above methods	Combines cultural, chemical and biological approaches	Sustainable, reduces chemical use	Requires monitoring and expertise	Kumar et al. [14]

Cultural, chemical, and biological control strategies target pathogen suppression through agronomic practices, chemical treatments, or living organisms, each with benefits and potential drawbacks. Integrated Disease Management (IDM) combines these approaches to achieve sustainable, environmentally friendly disease control while reducing reliance on chemicals. A comparative overview of these methods, including their principles, advantages, limitations, and representative references, is summarized in Table 8.

4.6. Performance Comparison

Evaluating the performance of plant disease detection and management methods is essential for selecting appropriate strategies in different agricultural contexts. Methods vary in accuracy, speed, cost, scalability, and applicability depending on their underlying principles. Traditional approaches such as visual inspection, microscopy, and culture techniques are generally low to moderate in terms of speed and scalability, though culture methods offer high accuracy for pathogen identification. Molecular techniques, including PCR, ELISA, and next-generation sequencing (NGS), offer high specificity and early detection capabilities, albeit at higher costs and often requiring laboratory facilities.

Table 9: Performance comparison of plant disease detection and management methods, including accuracy, speed, cost, scalability, and practical applicability

Method	Reviewer / Source	Accuracy	Speed	Cost	Scalability	Applicability / Notes
Visual Inspection	Akhtar et al. [11]	Low–Moderate	Fast	Low	Limited	Good for field-level preliminary assessment; misses latent infections
Microscopy	Akhtar et al. [11]	Moderate	Slow	Low–Moderate	Limited	Requires expertise; useful for direct pathogen observation
Culture Techniques	Akhtar et al. [11]	High	Slow	Moderate	Limited	Accurate but labor-intensive; not suitable for rapid large-scale screening
PCR	Cubero et al. [13]	High	Moderate	High	Moderate	Early detection of pathogens; lab-based; sensitive to sample quality
ELISA	Cubero et al. [13]	Moderate–High	Fast	Moderate	Moderate	Rapid detection of known pathogens; less effective for novel pathogens
Next-Generation Sequencing (NGS)	Cubero et al. [13]	Very High	Moderate–Slow	Very High	Moderate	Comprehensive pathogen identification; useful for research and outbreak studies
Image Processing	Jackulin and Murugavalli [12]	Moderate	Fast	Low–Moderate	High	Efficient for controlled environments; sensitive to image quality and lighting
Machine Learning / Deep Learning	Jackulin and Murugavalli [12]	High	Fast	Moderate	High	High automation potential; requires large labeled datasets
Remote Sensing (Drones / Satellites)	Yang [10]	Moderate	Fast	High	Very High	Suitable for large-area monitoring; early stress detection; technical expertise needed

Cultural Practices	Etesami [9]	Moderate	Slow	Low	High	Preventive approach; long-term benefit; labor-intensive
Chemical Control	Babu et al. [8]	High	Fast	Moderate–High	Moderate	Immediate effect, risk of resistance and environmental concerns
Biological Control	Babu et al. [8]	Moderate	Moderate	Moderate	Moderate	Sustainable and eco-friendly; efficacy may vary
Integrated Disease Management (IDM)	Kumar et al. [14]	High	Moderate	Moderate	High	Combines multiple approaches for sustainability and effectiveness

Computational and imaging methods—such as image processing, machine learning, and remote sensing—enable fast, scalable, and automated monitoring, though they may require high-quality data and technical expertise. Control strategies, including cultural, chemical, and biological methods, differ in speed, cost, and environmental impact, while Integrated Disease Management (IDM) combines multiple approaches to achieve sustainable and effective disease suppression. A detailed comparison of these methods, highlighting their performance metrics and practical considerations, is presented in Table 9.

4.7. Challenges in Plant Disease Management

Several obstacles still exist despite methodological and technological advancements:

- **Emergence of New Pathogens:** Outbreaks can be caused by novel or mutated pathogens that evade current control measures.
- **Chemical Resistance:** Overuse of chemicals can lead to strains that become resistant to them, reducing the effectiveness of treatment.
- **Limited Access to Molecular Tools:** Accurate diagnosis may be delayed in developing regions due to a lack of PCR or NGS facilities.
- **Variability in Field Conditions:** AI-based detection systems' performance is influenced by the microclimate, soil, and management techniques.
- **Impact of Climate Change:** Changes in temperature, rainfall, and extreme weather affect pathogen distribution and disease dynamics.
- **Financial Limitations:** Smallholder farmers may lack the funds to adopt integrated management techniques.

5. Conclusion

The control of plant diseases is a key problem for agriculture worldwide. Traditional, molecular and computational detection methods each have their own strengths and weaknesses. The integration of these techniques into sustainable approaches enhances early detection, strengthens control strategies and reduces crop losses. Future progress in AI, IoT, biocontrol and worldwide surveillance will improve precision management and contribute to long-term food security. To effectively implement these techniques to build resilient and sustainable agricultural systems, researchers, policymakers, and farmers need to collaborate. Plant diseases affect agricultural output, quality and farmer income significantly in both developing and developed nations. The conventional methods of detection, such as visual inspection, are straightforward and inexpensive, but they often fail to detect diseases in the early stages. Molecular procedures are highly accurate and sensitive, but they are expensive and require specialized equipment. Computational methods like machine learning and deep learning enable fast, automated identification but require vast datasets and robust technology infrastructure. Integrating various methodologies into a single system improves disease diagnosis and facilitates early intervention. Using remote sensing, drones and smart sensors, it is possible to monitor and treat in real time, thereby reducing the overuse of pesticides and environmental damage. Advances in AI and IoT improve predictive capabilities, enabling farmers to anticipate epidemics and take preventive measures. To achieve sustainable, efficient and resilient agricultural practices, collaborative efforts across stakeholders and continuous investment in research and technology adoption will be needed.

5.1. Future Directions

To create resilient agricultural systems, future plant disease management strategies will increasingly concentrate on combining sustainability and technological innovation. Real-time detection devices, such as Internet of Things sensors and intelligent monitoring tools, will enable continuous crop health surveillance and early warning of disease outbreaks. Predictive analytics will be greatly enhanced by sophisticated AI models that combine image analysis with data on weather, soil, and crop physiology. This will enable proactive interventions. The creation of disease-resistant crop varieties, microbial consortia, and natural biopesticides is an example of sustainable strategies that will simultaneously lessen reliance on chemical pesticides. To improve early warning systems and data-driven preventive measures across regions, global disease databases will act as centralized platforms for information sharing. Tools for precision agriculture, such as GPS mapping, drone-based imagery, and AI-driven analytics, will enable targeted interventions, ensuring efficient resource use and minimal environmental impact. Agronomists and farmers will be empowered to implement integrated disease management techniques through education and capacity-building initiatives, which are equally important. This will increase efficacy and support long-term agricultural sustainability.

Acknowledgment: The authors sincerely express their gratitude to the University of Information Technology, Dhaanish Ahmed College of Engineering, and Vels Institute of Science, Technology, and Advanced Studies for their continuous support, guidance, and resources throughout this work.

Data Availability Statement: The authors collectively confirm that the dataset used in this study is derived from published literature on advances in plant disease detection, management, and control. All data supporting the findings of this research are available in the cited sources, and no new datasets were generated or analyzed during this study.

Funding Statement: The authors confirm that no external financial support was received for the preparation of this manuscript and the related research work.

Conflicts of Interest Statement: The authors declare that there are no conflicts of interest related to this study, and all referenced information has been properly cited.

Ethics and Consent Statement: Ethical approval and participant consent were obtained during data collection, along with permission from the relevant organization and the individuals involved.

References

1. G. N. Agrios, “Plant Pathology,” 5th ed., *Elsevier Academic Press*, Amsterdam, Netherlands, 2005.
2. H. D. Lin, Z. Y. Zhang, and C. H. Lin, “Smart Image-Based Deep Learning System for Automated Quality Grading of Phalaenopsis Seedlings in Outsourced Production,” *Sensors*, vol. 25, no. 24, p. 7502, 2025.
3. A. K. Mahlein, “Plant Disease Detection by Imaging Sensors – Parallels and Specific Demands for Precision Agriculture and Plant Phenotyping,” *The American Phytopathological Society*, vol. 100, no. 2, pp. 241–251, 2016.
4. K. Lagos-Ortiz, J. Medina-Moreira, A. Alarcón-Salvatierra, M. F. Morán, J. Del Cioppo-Morstadt, and R. Valencia-García, “Decision support system for the control and monitoring of crops,” in Proc. 2nd Int. Conf. ICTs in Agronomy and Environment, *Springer International Publishing*, Cham, Switzerland, 2018.
5. H. F. Pardede, E. Suryawati, D. Krisnandi, R. S. Yuwana, and V. Zilvan, “Machine Learning Based Plant Diseases Detection: A Review,” in *Proc. Int. Conf. Radar, Antenna, Microwave, Electronics, and Telecommunications (ICRAMET)*, Tangerang, Indonesia, 2020.
6. R. N. Strange and P. R. Scott, “Plant disease: A threat to global food security,” *Annual Review of Phytopathology*, vol. 43, no. 1, pp. 83–116, 2005.
7. T. Rumpf, A. K. Mahlein, U. Steiner, E. C. Oerke, H. W. Dehne, and L. Plümer, “Early detection and classification of plant diseases with Support Vector Machines based on hyperspectral reflectance,” *Computers and Electronics in Agriculture*, vol. 74, no. 1, pp. 91–99, 2010.
8. S. Babu, B. R. Sahu, S. A. Basha, S. Mohapatra, P. Kumar, D. Patyal, B. S. Maheswari, P. Yeliya, and A. Tutlani, “Advances in Chemical Protection for Plant Disease Management in Agriculture: From Traditional Practices to Modern Innovations,” *Journal of Scientific Research and Reports*, vol. 31, no. 10, pp. 824–839, 2025.
9. H. Etesami, “Enhancing crop disease management through integrating biocontrol bacteria and silicon fertilizers: Challenges and opportunities,” *Journal of Environmental Management*, vol. 371, no. 12, p. 123102, 2024.
10. C. Yang, “Remote Sensing and Precision Agriculture Technologies for Crop Disease Detection and Management with a Practical Application Example,” *Engineering*, vol. 6, no. 5, pp. 528–532, 2020.
11. H. Akhtar, M. Usman, R. Binyamin, A. Hameed, S. F. Arshad, H. M. U. Aslam, I. A. Khan, M. Abbas, H. E. M. Zaki, G. Ondrasek, and M. S. Shahid, “Traditional Strategies and Cutting-Edge Technologies Used for Plant Disease Management: A Comprehensive Overview,” *Agronomy*, vol. 14, no. 9, p. 2175, 2024.
12. C. Jackulin and S. Murugavalli, “A comprehensive review on detection of plant disease using machine learning and deep learning approaches,” *Measurement: Sensors*, vol. 24, no. 12, p. 100441, 2022.

13. J. Cubero, P. J. Zarco-Tejada, S. Cuesta-Morrondo, A. Palacio-Bielsa, J. A. Navas-Cortés, P. Sabuquillo, T. Poblete, B. B. Landa, and J. Garita-Cambronero, "New Approaches to Plant Pathogen Detection and Disease Diagnosis," *The American Phytopathological Society*, vol. 114, no. 9, pp. 1989–2006, 2022.
14. N. Kumar, S. Kumar, R. Singh, and M. Lal, "Integrated disease management is a holistic approach in modern agriculture," *Journal of Pharmacognosy and Phytochemistry*, vol. 8, no. S4, pp. 98–101, 2019.