Biotechnology Frontiers
An International Journal
OPEN ACCESS
ISSN 3117-5791
Popular Article
Check for updates

Application of Artificial Intelligence and Deep Learning in Early Detection of Crop Diseases

Sreedevi S. Chavan

Department of Plant Pathology, COA, University of Agricultural Sciences, Raichur, Karnataka, India

Corresponding author: **Sreedevi S. Chavan** | E-mail: **shrisatya19@gmail.com**

Citation: Sreedevi S. Chavan (2024). Application of Artificial Intelligence and Deep Learning in Early Detection of Crop Diseases. *Biotechnology Frontiers: An International Journal.* **DOI: https://doi.org/10.51470/BF.2024.4.2.01**

18 April 2024: Received | 11 May 2024: Revised | 14 June 2024: Accepted | 19 June 2024: Available Online

Abstract

The integration of Artificial Intelligence (AI) and Deep Learning (DL) in agriculture has revolutionized early disease detection and precision crop management. Timely diagnosis of crop diseases is critical for reducing yield losses, minimizing pesticide use, and ensuring food security. Traditional disease identification methods rely on visual inspection by experts, which is time-consuming, subjective, and often inaccurate at early stages. Recent advances in machine learning, computer vision, and neural networks have enabled automated, rapid, and accurate disease detection using image-based and sensor-based systems. This review discusses the principles of AI and deep learning, major architectures used in crop disease detection, data acquisition methods, performance evaluation, practical applications, challenges, and future prospects.

Keywords: *Artificial Intelligence, Deep Learning, Convolutional Neural Networks, Crop Disease Detection, Computer Vision, Precision Agriculture, Machine Learning, Smart Farming.*

Introduction

Global agricultural productivity is severely constrained by plant diseases, which account for significant annual yield losses worldwide. Early detection is essential to prevent epidemic spread and reduce economic damage. Conventional diagnosis depends on field scouting and laboratory-based pathogen identification, which are labor-intensive and require specialized expertise. The emergence of AI-driven technologies offers automated solutions capable of detecting diseases at early stages with high accuracy [1]. Deep learning, a subset of machine learning, has demonstrated remarkable performance in image recognition and classification tasks, making it particularly suitable for plant disease identification from leaf images. With the availability of smartphones, drones, and IoT-based sensors, AI systems can now be deployed directly in fields for real-time monitoring.

Table 1. Major Deep Learning Models Used for Early Crop Disease Detection

Model / Architecture	Type of Task	Key Features	Reported Accuracy Range (%)	Advantages	Limitations
Convolutional Neural Network (CNN)	Image classification	Automatic feature extraction from leaf images	90–98	High accuracy, efficient pattern recognition	Requires large labeled datasets
VGGNet (Transfer Learning)	Image classification	Deep architecture with small convolution filters	92–97	Improved performance with limited data	High computational cost
ResNet	Image classification	Residual connections to avoid vanishing gradients	94–99	Very deep network, stable training	Complex architecture
Inception (GoogLeNet)	Image classification	Multi-scale feature extraction	93–98	Efficient computation with high accuracy	Sensitive to image quality
MobileNet	Mobile-based detection	Lightweight architecture for smartphones	88–96	Low computational requirement, field deployment	Slightly lower accuracy than heavy models
YOLO (You Only Look Once)	Real-time object detection	Simultaneous detection and localization	85–95	Fast, real-time performance	May struggle with small lesions
U-Net	Semantic segmentation	Pixel-level disease region identification	90–97	Accurate severity estimation	Requires detailed annotated datasets

Fundamentals of AI and Deep Learning in Plant Pathology

Artificial Intelligence refers to computational systems that simulate human intelligence to perform tasks such as pattern recognition, classification, and prediction. Machine learning (ML) is a subset of AI that allows models to learn from data without explicit programming. Deep learning, a further subset of ML, uses artificial neural networks with multiple hidden layers to automatically extract hierarchical features from raw data.

Convolutional Neural Networks (CNNs) are the most widely used deep learning models for plant disease detection [2]. CNNs automatically extract features such as texture, color variation, and lesion patterns from images, eliminating the need for manual feature engineering. Other architectures such as Recurrent Neural Networks (RNNs), Long Short-Term Memory (LSTM) networks, and Transformer-based models are also being explored for temporal disease

© **Authors:** *Published in* ***Biotechnology Frontiers: An International Journal*** *under the CC BY-NC-ND 4.0 license (http://creativecommons.org/licenses/by-nc-nd/4.0/). No commercial use or modifications permitted.*

prediction and multi-spectral data analysis.

Data Acquisition and Image Processing Techniques

AI-based disease detection systems rely heavily on high-quality datasets. Images are typically collected using smartphones, digital cameras, drones, or hyperspectral sensors. Public datasets such as PlantVillage have significantly accelerated research in this domain. Preprocessing steps include image resizing, normalization, noise removal, background segmentation, and data augmentation techniques such as rotation, flipping, and scaling to improve model robustness [3]. Advanced systems integrate multispectral and hyperspectral imaging to detect physiological stress before visible symptoms appear. Thermal imaging and chlorophyll fluorescence analysis are also used for early disease diagnosis.

Deep Learning Architectures for Disease Detection

Several deep learning models have shown high performance in crop disease detection:

- **Convolutional Neural Networks (CNNs):** Efficient for image classification and feature extraction.
- **Transfer Learning Models:** Pre-trained architectures such as VGGNet, ResNet, Inception, and MobileNet reduce training time and improve accuracy.
- **Object Detection Models:** YOLO (You Only Look Once) and Faster R-CNN enable real-time detection and localization of infected areas.
- **Semantic Segmentation Models:** U-Net and Mask R-CNN help identify disease severity by segmenting infected regions.

Accuracy levels often exceed 90–98% under controlled conditions, though field-level performance may vary due to environmental variability.

Applications in Early Disease Detection

AI-driven systems are applied in multiple ways:

1. Smartphone-based diagnostic apps for farmers.
2. Drone-assisted large-scale disease surveillance.
3. IoT-based smart farming systems integrating weather and soil sensors.
4. Automated greenhouse monitoring systems.
5. Decision-support systems for targeted pesticide application.

Early detection allows precise and reduced chemical usage, contributing to sustainable agriculture and environmental protection.

Advantages of AI-Based Disease Detection

AI-based detection systems provide rapid, non-destructive, and scalable diagnostic solutions. They reduce dependency on expert pathologists and enable continuous field monitoring. Integration with cloud computing and mobile platforms ensures accessibility even in remote areas [4]. Furthermore, predictive analytics can forecast disease outbreaks based on climatic conditions.

Challenges and Limitations

Despite significant progress, several challenges remain. Models trained under controlled conditions often struggle in real-field environments due to lighting variation, occlusion, mixed infections, and background noise. Limited availability of diverse annotated datasets restricts generalization [5-6]. High computational requirements and lack of digital literacy among farmers may hinder adoption. Ethical concerns regarding data privacy and accessibility also require attention.

Future Prospects

Future research should focus on developing robust models capable of handling real-world variability. Integration of AI with Internet of Things (IoT), edge computing, and blockchain technologies may enhance traceability and real-time decision-making. Explainable AI (XAI) approaches will improve transparency and trust among users. Development of lightweight mobile-based models can ensure widespread adoption in developing countries. AI-powered predictive disease modeling combined with climate forecasting may revolutionize plant disease management strategies.

Conclusion

The application of AI and deep learning has transformed early crop disease detection, offering rapid, accurate, and scalable diagnostic solutions. While challenges related to dataset diversity and field variability remain, continuous advancements in computer vision, sensor technologies, and computational power are enhancing system reliability. The integration of AI-based tools into precision agriculture systems holds immense potential for improving crop health, reducing yield losses, and ensuring sustainable food production in the future.

References

1. Mohanty, S. P., Hughes, D. P., & Salathé, M. (2016). Using deep learning for image-based plant disease detection. Frontiers in Plant Science, 7, 1419.
2. Sladojevic, S., Arsenovic, M., Anderla, A., Culibrk, D., & Stefanovic, D. (2016). Deep neural networks based recognition of plant diseases by leaf image classification. Computational Intelligence and Neuroscience, 2016, 3289801.
3. Ferentinos, K. P. (2018). Deep learning models for plant disease detection and diagnosis. Computers and Electronics in Agriculture, 145, 311–318.
4. Too, E. C., Yujian, L., Njuki, S., & Yingchun, L. (2019). A comparative study of fine-tuning deep learning models for plant disease identification. Computers and Electronics in Agriculture, 161, 272–279.
5. Kamilaris, A., & Prenafeta-Boldú, F. X. (2018). Deep learning in agriculture: A survey. Computers and Electronics in Agriculture, 147, 70–90.
6. Boulent, J., Foucher, S., Théau, J., & St-Charles, P. L. (2019). Convolutional neural networks for the automatic identification of plant diseases. Frontiers in Plant Science, 10, 941.