Agentic AI for Pathogen-Based Plant Disease Detection

*Asha Rani K P
Department of Computer Science and Engineering,
Dr. Ambedkar Institute of Technology,
Bengaluru – 560056, Karnataka, India.
Affiliated to Visvesvaraya Technological University, Belagavi – 590018, Karnataka, India
asharanikp.cs@drait.edu.in

Gowrishankar S
Department of Computer Science and Engineering,
Dr. Ambedkar Institute of Technology,
Bengaluru – 560056, Karnataka, India.
Affiliated to Visvesvaraya Technological University, Belagavi – 590018, Karnataka, India
gowrishankarnath@acm.org

2025 6th International Conference on Artificial Intelligence, Robotics and Control (AIRC) | 979-8-3315-4348-8/25/$31.00 ©2025 IEEE | DOI: 10.1109/AIRC64931.2025.11077524

***Abstract*— Plant disease detection is crucial for ensuring global food security and sustainable agriculture. Traditional methods rely on manual inspection, which is time consuming, error prone and requires expert knowledge. AI-driven approaches, particularly deep learning models have significantly improved disease classification and early detection. However existing AI models suffer from key limitations, including the need for large, annotated datasets, poor generalization across different crop varieties and environmental conditions, and limited adaptability to real-time dynamic scenarios. To address these challenges, we propose an Agentic AI framework for plant disease detection that goes beyond passive classification. Our approach integrates autonomous decision making, continuous learning and explainable AI, our system dynamically refines its predictions, reduces dependency on extensive labeled datasets and provides interpretable insights to farmers. Plant disease detection is being transformed by Agentic Artificial Intelligence (AAI), which offers proactive, self-governing, and accurate solutions to counteract pathogen-based risks. Plant disease problems can be effectively addressed by Agentic AI by combining real-time data gathering, pathogen detection models, decision-making procedures, and feedback mechanisms. This paper examines the vital role that artificial intelligence (AI) plays in agriculture, emphasizing its main features, benefits, and uses, including precision farming, crop yield optimization, and early disease detection. Its practical advantages are demonstrated through a case study on AI-powered disease detection in tomato crops, and its difficulties and moral implications are examined to guarantee responsible implementation. Finally, agentic AI's potential to revolutionize sustainable plant disease management techniques is highlighted by its promising future.**

Keywords—Agentic AI, Pathogen Detection, Plant Disease Management, Early Disease Diagnosis, Precision Agriculture, Crop Yield Optimization, Autonomous Systems, Sustainable Farming, Data Quality in AI, Real-Time Decision-Making, Feedback Mechanisms, Tomato Crop Case Study.

I. INTRODUCTION

Global agriculture is seriously threatened by pathogen-based plant diseases, which lead to large output losses, food shortages, and financial difficulties. Scale, speed, and precision are all constrained by traditional methods of plant disease identification, which frequently depend on manual inspection and reactive measures. In order to satisfy the increasing demand for sustainable agriculture, these constraints call for creative solutions.

A paradigm shift in the control of plant diseases is represented by agentic AI. Agentic AI, in contrast to traditional AI systems, has the capacity to see, determine, and act on its own, allowing for proactive and focused interventions. Agentic AI revolutionizes the identification and management of plant diseases by utilizing sophisticated pathogen detection models, real-time data collection, and decision-making algorithms. This study explores the processes of agentic AI, the significance of pathogen-based detection, and how it contributes to increased agricultural productivity.

With a case study on tomato crops demonstrating its usefulness, the conversation covers applications of agentic AI in precision agriculture, agricultural production optimization, and early disease diagnosis [1].

A. Introduction to Agentic AI Systems

Agentic Artificial Intelligence (AAI) systems function independently by combining elements that allow them to sense their surroundings, interpret data, decide, and carry out targeted actions. They start with perception and use technologies like computer vision, natural language processing, and speech recognition to gather data from sensors, APIs, or Internet of Things devices. Following that, this data is processed using techniques like knowledge graphs and feature extraction to produce a contextual understanding. Rule-based systems, reinforcement learning, or machine learning models are used in decision-making to choose the best course of action that is in line with preset objectives and is dynamically adaptive. These systems perform digital (like user answers) or physical (like robotic movements) tasks and employ feedback loops to improve performance. Constraints related to safety and ethics guarantee appropriate conduct [2].

Example in Plant Disease Detection

A traditional AI model may classify a plant disease from an image, but an Agentic AI system goes beyond by actively requesting additional data, such as weather conditions and soil quality, to enhance accuracy. It continuously adjusts its recommendations based on farmer feedback and leverages reinforcement learning to refine its predictions over time. Unlike static models, it also provides explainability by linking symptoms to potential causes (e.g., "Yellowing leaves + high humidity → Likely fungal infection”). Moreover, it suggests proactive measures, such as increasing ventilation or applying organic fungicides, helping farmers take preventive action before the disease spreads.

B. Research Context

In order to maintain environmental sustainability and guarantee global food security, the agricultural sector must overcome increasing obstacles. With an estimated yearly crop loss of more than 20%, pathogen-based plant diseases are one of these difficulties. Climate change makes these losses much worse by fostering an environment that encourages the growth of plant diseases. Manual inspection and chemical treatments are two examples of traditional plant disease management techniques that are frequently reactive, resource-intensive, and inadequate to successfully reduce losses.

A promising remedy is offered by recent developments in artificial intelligence (AI), especially in the form of agentic AI systems. Agentic AI, in contrast to traditional AI, is intended to function independently, imitating proactive reactions and human-like decision-making. These systems provide quick and targeted interventions by combining automated action mechanisms, advanced pathogen detection algorithms, and real-time data collection. Precision agriculture, where early disease identification and resource optimization are essential to increasing productivity and reducing environmental impact, benefits greatly from such capabilities.

C. Motivation of Work

The goal of this study is to overcome the shortcomings of the present approaches for managing and detecting plant diseases. Key motivators consist of:

1. ***Global Food Security:*** In order to fulfil the growing demand for food, it is imperative to reduce crop losses as the world's population keeps increasing.
2. ***Environmental and Economic Sustainability:*** By enabling targeted treatments and reducing the usage of pesticides generally, agentic AI lowers input costs and crop losses.
3. ***Drawbacks of Manual Techniques:*** While AI-driven solutions guarantee constant accuracy, manual disease identification is time-consuming, prone to errors, and not scalable.
4. ***Technological viability:*** Intelligent decision-making and real-time analysis are made possible by developments in IoT, machine learning, and data accessibility.
5. ***Sustainability Objectives:*** By optimizing resource use, lowering chemical usage, and supporting global sustainability objectives, agentic AI promotes environmentally beneficial behaviours.

II. Literature Survey

The TABLE. 1 depicts literature survey of the recent works in agriculture and the field of deep learning.

TABLE I. Literature Survey

Paper Title	Authors	Key Findings	Reference
Artificial Intelligence: A Promising Tool for Application in Phytopathology	González-Rodríguez et.al	AI revolutionizes plant disease management with accurate detection, predictive modeling, and real-time monitoring.	[3]
Revolutionizing agriculture with artificial intelligence: plant disease detection methods, applications, and their limitations	Jafar, A. et.al	The study explores AI and IoT-based techniques for crop disease detection.	[4]
Hyperspectral Image Analysis and Machine Learning Techniques for Crop Disease Detection and Identification: A Review	García-Vera, Y. E., et.al	This review examines hyperspectral imaging with AI techniques for crop classification, disease detection, and monitoring.	[5]
Deep Learning for Plant Disease Detection	Khalid, M. M., et.al	This research demonstrates Deep Learning's potential, with CNNs, MobileNet, and GradCAM, for accurate plant disease detection.	[6]
An Artificial Intelligence Framework for Disease Detection in Potato Plants	Abbas, A., et.al	This study uses CNNs on the Plant Village dataset to achieve 98% accuracy in potato leaf disease detection.	[7]
Disaster Plant Pathology: Smart Solutions for Threats to Global Plant Health from Natural and Human-Driven Disasters	Etherton, et.al,	Disaster plant pathology examines how disasters impact plant diseases and highlights the need for smart management solutions.	[8]
Smartphone-Based Citizen Science Tool for Plant Disease and Insect Pest Detection Using Artificial Intelligence	Christakakis, P et.al	A smartphone-based AI tool detects plant diseases and pests, achieving 87% accuracy, supporting sustainable agriculture and Green Deal goals.	[9]
Integrating artificial intelligence and Internet of Things (IoT) for enhanced crop monitoring and management in precision agriculture	SharmaK et.al	AI and IoT are transforming precision agriculture with innovations in phenotyping, remote sensing, and AgroBots.	[10]
Custom Large Language Models Improve Accuracy: Comparing Retrieval Augmented Generation and Artificial Intelligence Agents to Noncustom Models for Evidence-Based Medicine	Woo et.al	This study highlights RAG and agentic augmentation in improving LLM accuracy for ACL injury information, achieving 95% accuracy and enhancing orthopedic decision-making.	[11]
Synergy between Artificial Intelligence and Hyperspectral Imaging—A Review	Khonina et.al	AI integration with hyperspectral imaging revolutionizes agriculture, environmental monitoring, and medical diagnostics,	[12]

		providing precise, real-time insights.	
Comparison Study of Corn Leaf Disease Detection based on Deep Learning YOLO-v5 and YOLO-v8	Chitraningrum, N et.al	This study compares YOLO-v5 and YOLO-v8 for detecting infected corn leaves, with YOLO-v8 achieving superior accuracy and enhancing early disease detection.	[13]

III. ROLE OF AGENTIC AI IN PATHOGEN-BASED PLANT DISEASE DETECTION

Global agricultural output is greatly impacted by plant diseases brought on by pathogens such as bacteria, viruses, fungus and nematodes. In order to minimize losses, early detection and intervention are essential. With its capacity to gather, evaluate, and respond to environmental data on its own, agentic AI offers a viable way to detect pathogen-based diseases in crops.

Pathogen-Based Plant Disease Detection's Significance

Conventional disease detection techniques frequently depend on labour-intensive, error-prone hand inspection. By identifying the precise organisms causing the sickness, pathogen-based detection aims to reduce pesticide overuse and enable targeted therapies.

Key components of Agentic AI systems

The following features are included in agentic AI systems:

1. ***Sensors:*** Record data in real time, including environmental factors or pictures of leaves.
2. ***Machine learning models:*** Recognize pathogens and forecast the spread of disease.
3. ***Actuators:*** Start processes like applying pesticides or sending out alerts [14].

Advantages of Agentic AI in Disease Detection

1. ***Real-Time Monitoring:*** Crops are continuously observed.
2. ***Early Detection:*** Finding infections before symptoms show up.
3. ***Precision:*** Reduces needless interventions and false positives.

IV. MECHANISM OF AGENTIC AI IN PATHOGEN DETECTION

1. ***Data Collection and Perception***
   Drones, IoT sensors, and cameras are used by agentic AI systems to collect high-resolution plant images and track environmental variables like temperature and humidity. These elements are essential for comprehending the circumstances that promote the proliferation of pathogens and allow for the early identification of possible outbreaks [15].
2. ***Pathogen detection models***
   Convolutional Neural Networks (CNNs), in particular, are deep learning models used to interpret gathered data. To recognize powdery mildew symptoms in plant images, these models are trained on labeled datasets. For instance, a CNN can identify distinctive visual patterns, such as white powdery specks, to accurately detect powdery mildew, which is caused by the pathogen Podosphaera xanthii (for cucurbits) or Erysiphe necator (for grapes). These fungal pathogens thrive in warm, dry conditions and spread via airborne spores, severely impacting crop yield and quality if left untreated.
3. ***Decision Making Processes***
   The data is processed by AI algorithms to:
   i. Detect the presence of pathogens.
   ii. Determine the stage of infection.
   iii. Suggest the best possible intervention techniques, such as the use of focused therapies or alterations to the surrounding environment.
4. ***Action and Feedback Mechanism***
   i. After analysis, the system takes independent action, including:
   Utilizing messaging apps or platforms to provide farmers alerts and suggestions.
   ii. Turning on irrigation systems to control humidity or applying insecticides to specific areas.
   iii. Adjusting its models and tactics on a regular basis in response to input from activities taken in order to increase precision and efficacy over time.

Agentic AI offers a comprehensive, self-sufficient approach to agricultural pathogen identification and control by combining various principles [16][17].

V. AGENTIC AI IN AGRICULTURE

Agentic AI framework for agriculture is shown in Figure 1. Different stages in the framework are as follows.

1. Farmer/User Input
Users provide images, soil data, and weather conditions for disease detection.

2. Multi-Modal Data Fusion
Combines image, sensor, and weather data to improve accuracy.

3. Preprocessing Layer
Performs noise removal and feature extraction to clean input data.

4. AI Model (CNN + RNN) – Initial Classification
Uses CNN for spatial features and RNN for sequential data to classify plant diseases.

5. Reinforcement Learning Module
Learns from ground truth data to enhance accuracy over time.

6. Active Learning Module
Engages human experts for difficult cases to improve model decisions.

7. Explainable AI (XAI) Module
Visualizes the model's reasoning, making AI predictions transparent.

8. Final Disease Prediction and Adaptive Recommendation System
Provides refined disease classification and adaptive treatment suggestions.

9. Autonomous Decision Making
Suggests treatment and prevention strategies for precision farming [18][19].

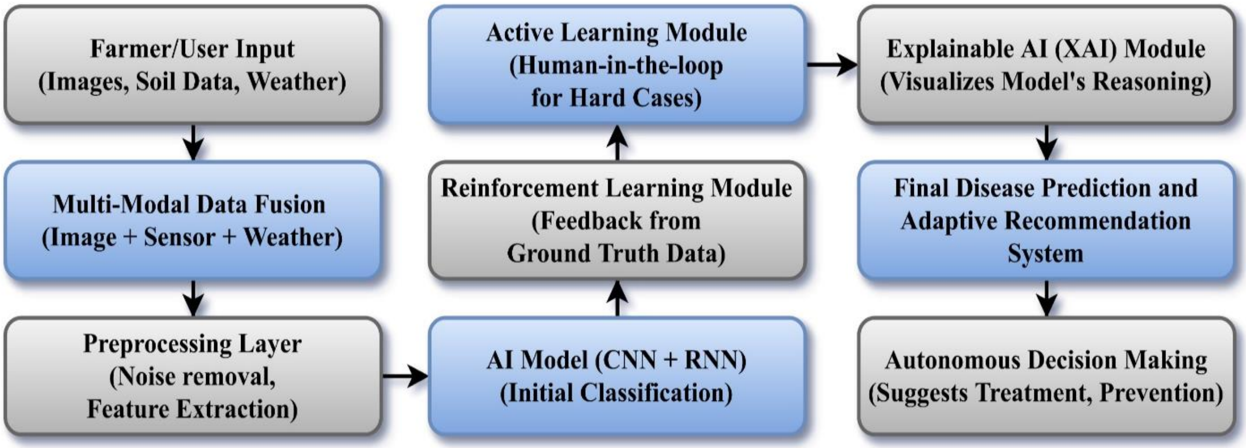

Fig. 1. Agentic AI framework for Agriculture

VI. CASESTUDY: AI POWERED DISEASE DETECTION IN TOMATO CROPS

Bacterial spot disease, caused by the pathogen Xanthomonas campestris pv. vesicatoria, poses a significant threat to tomato crops, leading to severe yield losses if not effectively managed. This bacterial pathogen thrives in warm, humid conditions and spreads through water splashes, contaminated tools, and infected plant debris. Traditional detection methods rely on manual field inspections, which are labor-intensive, costly, and often involve environmentally harmful broad-spectrum pesticide applications. In this case study, we explore how integrating agentic AI with drone-mounted sensors revolutionized disease diagnosis and management in tomato fields, enabling real-time, precise detection and targeted intervention strategies [20].

A. *Deployment of Agentic AI systems*

1) Data Acquisition

a) Drone-Based Monitoring

- High-resolution cameras mounted on drones systematically captured detailed images of tomato plants across vast farmlands.
- Advanced multispectral imaging sensors detected crucial plant health markers, such as chlorophyll concentration and early stress indicators which are often imperceptible to the human eye.

b) IoT-Enabled Smart Sensing

- A network of environmental sensors continuously tracked key variables such as humidity, temperature, and soil moisture which are critical for bacterial spot outbreaks.

2) Real-Time Processing and Analysis

a) AI-Powered Disease Detection

- Captured images and sensor data were processed on a cloud-based platform using Convolutional Neural Networks (CNNs) and other deep learning models.
- The AI system identified early signs of bacterial spot infections by detecting subtle changes in leaf color, texture, and stress indicators, allowing for intervention before visible symptoms appeared.

3) Intelligent Decision-Making and Targeted Recommendations

a) Actionable Insights for Farmers

- The system not only detected diseases but also assessed their severity, providing farmers with tailored recommendations.
- Mapping of infected regions enabled precision treatment, eliminating the need for widespread pesticide use and reducing unnecessary chemical applications.

B. Key *Achievements*

1) Enhanced Early Detection Accuracy

- The AI system significantly improves the accuracy of early disease detection, allowing for timely intervention.
- Farmers could take preventive action before visible symptoms emerged, curbing disease spread and safeguarding healthy crops.

2) Drastic Reduction in Pesticide Dependency

- By pinpointing infected zones, the system enabled targeted pesticide spraying, minimizing the use of chemicals.
- This precision approach not only cut down on environmental pollution but also reduced costs for farmers, making disease management more sustainable.

C. *Impact and Benefits*

1) Economic Advantages

a) Cost Efficiency

By avoiding unnecessary pesticide applications, farmers experience a significant reduction in chemical expenses.

b) Increased Crop Yields

Early detection and intervention preserved plant health, leading to higher-quality tomatoes and increased overall yield.

2) Promoting Environmental Sustainability

a) Minimizing Chemical Contamination

The reduced dependence on pesticides helps protect soil, water sources, and surrounding ecosystems.

b) Optimized Resource Utilization

AI-driven insights facilitates efficient use of water, fertilizers, and disease control measures, promoting sustainable farming practices.

VII. Versatility of Agentic AI Systems

Agentic AI is a self-learning, adaptive system designed for plant disease detection across various crops and pathogens. Unlike conventional models that require extensive retraining, it leverages transfer learning to apply knowledge from one crop to another, reducing the need for large datasets. With active and reinforcement learning, the AI continuously refines itself based on new pathogen symptoms. Multi-modal data fusion—integrating imaging, climate data, and soil conditions—enhances accuracy in disease identification. Furthermore, the system adapts to regional variations by learning from real-time feedback and seamlessly operates on both edge devices and cloud platforms. Its self-learning ability enables rapid response to emerging agricultural threats, making it a scalable and intelligent solution for real-time, data-driven precision farming.

VIII. Implementation Setup of Agentic AI System for Pathogen Based Plant Disease Detecton

Integration of computer vision, internet of things sensors, and autonomous decision making is necessary to implement an agentic AI system for pathogen-based plant disease detection. This allows for real-time monitoring and disease control. The system uses drones, cameras and sensors to collect real-time environmental data and infected plant image. Deep learning models trained on plant disease datasets analyzes the data, .AI systems will categorize diseases and provide remedies and initiates self directed actions such as alerts or pest control. With a dashboard user interface for farmers, the system can be setup on edge devices or through cloud-based API's. Future enhancement includes swarm robotics for extensive monitoring, blockchain for traceability, and federated learning.

IX. Conclusion

Agentic AI is revolutionizing plant disease management, offering unmatched accuracy, efficiency, and scalability. By integrating autonomous systems capable of real-time perception, analysis, and response, this technology addresses critical agricultural challenges while boosting productivity and sustainability. The case study on tomato crops highlights the practical impact of this innovation, demonstrating its ability to optimize crop health and pathogen based disease control. However, for widespread adoption, challenges related to data quality, ethical considerations, and equitable access must be addressed. As agriculture embraces a tech-driven future, Agentic AI will play a pivotal role in ensuring food security, environmental sustainability, and smarter farming practices worldwide.

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