



# Recent Advances in Deep Learning-Based Disease Detection in Garlic Plants in Agriculture: A Review

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**Abstract**—AI and DL technologies have rapidly evolved and revolutionized modern farming practices, especially in automated plant disease detection and precision farming. This crop is economically and nutritionally significant and highly susceptible to diseases that affect yield, quality of bulbs and market value, including white rot, basal rot, purple blotch, downy mildew, rust and viral infections. Diagnosing disease promptly and correctly is very important for production losses and sustainable garlic production. Diagnosing diseases using conventional approaches that rely on human eye observation and experience can be challenging for large-scale agriculture due to their potential drawbacks, such as being costly, subjective, labor-intensive, and time-consuming. Automatic disease identification by image analysis using DL approaches has been more popular in the past few years. Finding diseases in garlic using Deep Learning (DL) techniques including YOLO, CNNs, Vision Transformers (ViT), hybrid CNN-ViT, and Generative Adversarial Networks (GAN) is the focus of this publication. Furthermore, the study discusses current research progress, key challenges, limitations, and future opportunities for developing accurate, scalable, and intelligent garlic disease detection systems for precision agriculture.

**Keywords**—Garlic Disease Detection, Deep Learning, Agriculture, Plant Disease Classification, Artificial Intelligence.

## I. INTRODUCTION

There is constant pressure on the agriculture sector to satisfy the needs of an expanding population. However, even though recent technical developments have enhanced agricultural output, the strategy has harmed the ecosystem and resulted in significant losses from weeds, pests, and diseases [1]. The Food and Agriculture Organization of the United Nations (FAO) reports that pests affecting various crops reduce agricultural productivity by an astounding 40% every year. Detecting pests and diseases in plants at an early stage is a huge challenge for farmers. Many nations rely heavily on agricultural production, which makes crop damage by pests and diseases all the more tragic. In agriculture, one of the most difficult jobs is to identify and categorize plant diseases and pests. The pest insects inflict major losses in crop production and classification can be difficult because of their complex anatomy and inter-dependencies between various species [2].

The agriculture sector has become an important part of the global economy as a significant number of developing world's population has relied on it for their livelihood and food security. The agricultural sector is facing pressure to improve crop productivity with the ever-growing population in the world, and food supply [3]. The development of these technologies along with intensive farming practices has led to higher yields, but has brought about certain challenges such as environmental degradation, climate change, pest and plant diseases etc. The FAO studies estimate that pests and plant diseases cause losses of 20-40% of global agricultural production each year, causing serious concerns for food security and economic sustainability. Early diagnosis and efficient control of plant diseases is now more critical to minimizing losses and ensuring crop production.

Garlic is an important food, medicinal, and commercial crop and is one of several crops cultivated in the world for food, medicinal, and commercial purposes. Garlic is widely known as a source of nutrition and therapeutic value including

antimicrobial and antioxidant properties and has an irreplaceable importance in food and healthcare systems. However, poor growing conditions, fungus, bacteria, and viruses can cause garlic to get sick. Rust, purple blotch, downy mildew, white rot, basal rot, and leaf blight are common diseases which cause severe losses in yield, bulb quality, and market value for farmers. The appearance of disease symptoms may occur on leaves and progress to the rest of the crop so the disease can be detected early to avoid general spread and loss of crop [4][5].

Farmers and agricultural specialists have traditionally been involved in subjectively-based and labor-intensive manual inspection to diagnose garlic diseases. Automated disease detection in plants has been a hot topic in recent years, thanks to developments in computer vision, AI, ML, and DL [6].

DL is a form of ML that automatically identifies patterns in the data and extracts valuable features from large volumes of data with minimal human effort. Several image classification, segmentation, and object recognition applications based on DL are being successful in agriculture; among them, the recognition of visual symptoms of plant diseases, where DL methods perform well [7]. Under varying environmental conditions, learning the symptoms of disease through leaf images has been accomplished with surprising accuracy, employing CNNs, transfer learning methods, and object recognition models such as YOLO. Techniques enable faster, more accurate and larger-scale detection of disease, thereby decreasing manual examination needed and allowing precision agriculture practices.

### A. Structure of the Paper

This paper is organized into following sections. In Section II, an introduction to agriculture and sustainable food production and challenges from detection of plant diseases is introduced. Garlic culture and key issues with diseases are covered in Section III. A summary of diseases diagnostics

using deep learning techniques for garlic crops is provided in Section IV. In Section V, the existing literature is reviewed and any research gaps identified and in Section VI, the study is discussed and its implications for future research identified.

## II. AGRICULTURE AND PLANT DISEASE DETECTION: AN OVERVIEW

Sustainable Agriculture aims to produce food with a minimum impact on the environment, favoring biodiversity and improving the lives of farmers and society. Conventional agriculture relies on chemical inputs and monocultures while sustainable agriculture emphasizes soil health, pollution control, and strengthening agricultural systems to better withstand environmental challenges.

### A. Importance of Agriculture in Sustainable Food Production

Sustainable agriculture is a major component of sustainable food production, which tackles social, economic and environmental problems of the global food system. This is the way it helps:

#### 1) Soil Health And Fertility

Soil health is vital to agricultural production over the long haul. Crop Rotation, Cover Crops, and organic fertilizers are all examples of sustainable agricultural techniques that aid in keeping soil structure, fertility, and biodiversity intact. The healthy soils can offer resistance to Climate Change, increased crop yields and less fertilizer use.

#### 2) Water Conservation

Water scarcity is one of the major problems in the agriculture sector. To foster water conservation in sustainable agriculture, some of the drought-resistant crop types employed and rainwater harvesting and the application of drip irrigation are used. These techniques allow for access to water in the future, and decrease water consumption and water efficiency.

#### 3) Biodiversity Enhancement

Two pillars of sustainable agriculture are the incorporation of natural habitats into agricultural land and the cultivation of diverse crops [8]. Pollination, pest management, and nutrient cycling are just a few of the ecological functions that rely on this abundance. Agriculture systems that are more sustainable also have greater environmental shock resistance and lower risk of crop failures because of the increase in biodiversity.

#### 4) Climate Change Mitigation

A combination of causes and effects, climate change is having an impact on the agricultural sector. Carbon sequestration in plants and soils is another manner in which sustainable agricultural methods like organic farming, agroforestry, and reduced tillage contribute to the mitigation of climate change. The methods reduce the use of synthetic fertilizers and fossil fuels, as well as lower the amount of greenhouse gases released.

#### 5) Economic And Social Benefits

Sustainable agriculture contributes to financial security of farmers through better market access, reduced input costs, and opportunities to produce value-added products. Socially, it improves the standard of living in rural areas, enhances food security and creates ethical working practices.

### B. Challenges of Plant Disease Detection in Agriculture

Sustainable agriculture has a number of drawbacks despite its numerous advantages:

#### 1) Adoption Barriers

Conventional to sustainable farming transition can be challenging for farmers due to initial investments, lack of knowledge, and skill requirements [9]. Regulatory support for sustainable practice, and financial and knowledge resources to remove these barriers and promote the adoption of sustainable practice.

#### 2) Market Access and Consumer Demand

A potential difficulty in sustainable agriculture is the ability to sell the produce at competitive prices. To boost consumer demand for sustainable food, consumer education, certification and market development for sustainable production are all necessary.

#### 3) Policy And Regulatory Support

Governments play a vital role in promoting sustainable agriculture through research, subsidy and legislation. Policy frameworks which encourage sustainable agriculture and protect the rights of small-scale farmers are key to the widespread adoption of sustainable agriculture.

#### 4) Research and Innovation

Practices for sustainable agriculture require continuous research and invention. This includes examining the various types of crops, farming practices and technology that can provide a higher yield at a lower environmental cost.

### C. Role of Artificial Intelligence in Modern Agriculture

Organic farming, agroforestry, and precision agriculture are some of the sustainable agricultural approaches that are based on AI [10]. Soil conservation methods, drought-resistant crop varieties, and AI irrigation systems should all be promoted to promote efficient water use and soil health maintenance. More resilient crop varieties, increased harvest yields, and decreased disease incidence can all be achieved with the use of AI. These are explanations of the AI-based solutions displayed in Fig. 1:

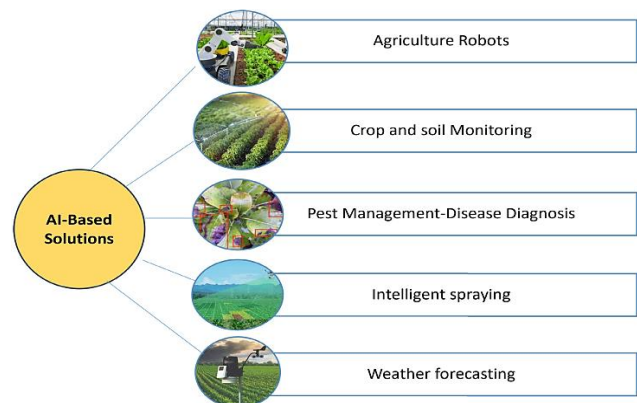


Fig. 1. AI based solutions

#### 1) Agriculture Robots

Agriculture robots, or agrobots and agri-bots as they are also known, have significantly improved and modernized various facets of the agricultural sector [11]. The sophisticated technology allows these robots to operate with little to no human input or control. The use of agricultural robots has the potential to improve crop development by precisely planting seeds in pre-determined sites, ensuring proper spacing and

depth. Robots fitted with sensors can assess the condition of soil and provide nutrients with precise localization, minimising any risk of misuse and environmental effects. Robots gather information about soil water, nitrogen, and other factors to enable farmers to make better decisions about water and fertilizer usage. Robots can be customized to suit the specific requirements of different crops, allowing for more effective and efficient harvesting.

#### 2) Crop and soil Monitoring

In modern agriculture, monitoring of the soil and crop is vital and involves keeping a constant eye on the condition of the soil and crop. This tracking helps farmers make smart choices, understand how resources are being used, and make their farms as productive as possible while having the least amount of damage to the environment. New technology can be used to take high-resolution photos of farmland, and satellites can be used to give information on crop health and growth trends. Drones fitted with sensors and cameras can collect information and produce high-quality images from various angles, allowing farmers to monitor their crops and soil more closely. The Internet of Things plays a crucial role in supporting farmers to optimize watering practices and avoid overwatering, as moisture sensors can be used to monitor soil conditions at various depths. Crop health sensors are used to measure the chlorophyll concentration and crop temperature to identify crop stress, disease or nutrient deficiency. By assessing the nutrient level of the soil, nutrient sensors can aid farmers to optimize plant nutrition.

#### 3) Pest Management-Disease Diagnosis

Plant disease diagnosis and pest management are important for agricultural production and health. It details methods and strategies for controlling and minimizing the impact of pests, including as weeds, insects, and other creatures that cause damage to crops. It is essential to check crops for evidence of pests and damage on a regular basis. It is critical to identify the particular pests that are generating issues and to learn about their life cycle. Some useful practices include Crop Rotation, Companion Planting, timing planting to interrupt pest life cycles, and reducing pest habitats via correct plant spacing and sanitation.

#### 4) Intelligent Spraying

Spraying with intelligence is often called precision spraying or variable-rate spraying. This cutting-edge method of farming makes use of state-of-the-art technology to maximize the efficacy of pesticides and other agricultural protection goods. Smart spraying is an approach of pest and disease management that seeks to reduce chemical use without sacrificing efficacy. Intelligent sprayers are equipped with sensors that allow them to detect and track field changes, such as the emergence of diseases, infestations of insects, and anomalies in plant health [12].

#### 5) Weather Forecasting

Present weather forecasts can be seen on a number of websites and apps for different places. These sensors can measure a wide range of environmental variables, allowing farmers to keep tabs on the weather every day or week. These websites (Weather Channel, AccuWeather, and meteorological.com) provide many people with their meteorological reports. The use of weather sensors can enable the collection of farm-specific, real-time weather information. The stations measure temperature, humidity, wind direction, precipitation and enable precise monitoring of field

conditions. Radar and satellite data not only help us understand weather patterns better, but they may also foretell when storms or heavy rains hit.

### III. GARLIC PLANTS AND DISEASE CHALLENGES IN AGRICULTURE

Garlic cultivation is a significant part of the agriculture as a crop of economic and nutritional importance. However, disease conditions severely affect the garlic plants which can be a serious issue in relation to crop quality, production, disease management and sustainable cultivation.

#### A. Importance and Cultivation of Garlic Plants

Garlic is a superfood and one of the most useful bulb crops in the world. It is a common food ingredient, medicine, and due to its medicinal properties and taste, it is used as raw material in various industries. Bioactive sulfur compounds such as alliin, ajoene and diallyl sulfides are responsible for the antibacterial, antifungal, antioxidant and anti-inflammatory properties of garlic. These functional properties have made garlic of major importance in the pharmaceutical, food processing and nutraceutical sectors, thus boosting the global agricultural demand for garlic.

Garlic is cultivated in different climatic and geographic regions including temperate and subtropical region and semi-arid regions. Good environmental conditions such as soil fertility, temperature, availability of irrigation water and disease management are very critical in garlic production. The ideal conditions for garlic are well-drained, loamy, organic-rich soils and moderate climate. Cloves are generally sown and not seeds to ensure uniformity of cultivar and increased productivity. However, the risk of garlic plants being infested with organisms causing disease increases with clonal propagation, particularly soil-borne and fungal organisms.

Garlic is cultivated for many reasons, and it is an important and valuable crop, but it has several agronomic problems such as environmental stress, nutrient imbalance, pests and disease outbreaks. Plant diseases continue to be a leading cause of yield and quality losses among them. In the most serious cases, infection can affect bulb size, storability, and marketability, resulting in substantial economic losses to growers and along the supply chain. Therefore, it is now more crucial than ever to have effective disease monitoring and management strategies to sustain garlic output.

#### B. Major Diseases Affecting Garlic Plants

There are several fungal, bacterial, viral, and nematode pathogens that attack garlic plants. The diseases have a considerable impact on growth, the quality of bulbs, yields and post-harvest storage. Disease is also promoted by environmental factors like over humid conditions, lack of soil drainage, temperature changes and a lack of proper crop management. The following are the major diseases of garlic plants:

- **White rot:** *Sclerotium cepivorum* is the source of white rot, one of the most damaging fungal infections that impair garlic production. It is primarily a root and basal plate disease of garlic which leads to a reduction in growth, wilting, yellowing of the leaves and rotting of the bulbs. The pathogen is very persistent in the soil, living there for several years in resistant fungal structures, making effective disease control very difficult and sometimes yield losses are significant.

- **Basal rot:** Basal rot is a fungal disease, primarily caused by *Fusarium* spp., especially *Fusarium oxysporum*. This disease targets the basal plate and root system, resulting in root rot, leaf yellowing and poor bulb quality. Infected bulbs have shorter storage life and impact marketability and profitability.
- **Purple blotch:** Purple blotch is a very common disease that occurs on the foliage of garlics and is caused by *Alternaria porri*. It does not appear to be a pest in Australia, though it is found as purple or brown elongated markings on leaves and stems, that enlarge and make photosynthesis less efficient. In severe infections, the plants are weakened, and the bulb development and plant productivity are significantly reduced.
- **Downy mildew:** Downy mildew occurs when the environment is cool and moist and is caused by *Peronospora destructor*. The disease consists of whitish spots on leaves followed by fungal growth and eventually plant wilting and weakness. Without control, downy mildew can quickly infest large areas of garlic crops and cause yields to drop.
- **Rust disease:** Garlic rust is caused by fungal pathogens of the *Puccinia* species. Symptoms are orange to brown pustules on the surface of leaves which decrease the plant's photosynthetic activity and growth performance. Extensive rust can cause early senescence and bulb yield.
- **Bacterial soft rot:** Bacterial soft rot is produced by bacterial pathogens including *Pectobacterium carotovorum*. The disease causes decomposition of the tissue, softening of bulbs and poor smell production, especially when stored. Garlic bulbs infected with the disease not keepable or marketable.
- **Garlic mosaic virus:** Garlic mosaic virus is a viral disease that produces mosaic pattern, distortion of leaves and yellow streaks. This disease hinders normal growth of the plant and seriously affects bulb size and crop productivity. Garlic is vegetatively propagated by the use of the clove and virus transmission is often accelerated by infected planting material.
- **Onion yellow dwarf virus:** Onion yellow dwarf virus is a common virus of garlic that infects it and causes yellowing of the leaves, stunted growth and poor bulb development. The disease causes plants to be less healthy and makes the plants less productive, particularly if infection is early.
- **Stem and bulb nematode infestation:** *Ditylenchus dipsaci* is a microscopic pest that enters the tissues of garlic and can cause damage to the bulbs, stems, and leaves. Symptoms include swelling, color change, deformation of the tissues and deterioration of the bulbs. Nematode infestations also affect the post-harvest storage quality as well as crop yield.
- **Black mold disease:** The fungus *Aspergillus niger* is the principal culprit responsible for black mold disease, which primarily affects garlic that has been preserved. The disease symptoms include black colored powdery fungal growth between the scales of the bulbs, causing spoilage and reducing bulb quality during storage and transit.

To sum up, there are several garlic diseases with varying symptoms, causes, and severity. Accurate and timely diagnosis of diseases is crucial in order to reduce losses in the

agricultural sector and maintain sustainable garlic cultivation. But due to the similarity of the symptoms of the diseases, manual disease diagnosis is difficult and requires advanced method of disease detection for precision agriculture applications.

### C. Limitations of Traditional Garlic Disease Detection Methods

Manual inspection, symptom-based diagnosis, expert consultation and laboratory testing are traditional garlic disease detection methods used to identify plant infections and ensure crop health. In most cases farmers use visible signs like discoloration, lesions, wilting and fungal growth. But all of these methods are not always suitable for large farms, quick diagnosis, or precision farming. They have the following drawbacks:

- **Dependence on Human Expertise:** Accurate diagnosis is heavily reliant on the farmer or specialist. Because of limited access to plant pathologists in rural areas, this may result in misdiagnosis and ineffective treatment.
- **Difficulty in Early Detection:** Conventional methods are able to detect diseases only when visible symptoms occur, and then the infection spreads.
- **Time-Consuming and Labor-Intensive:** Manual inspection is time-consuming and labor-intensive, which can increase operational costs and decrease efficiency, particularly in large farms.
- **Lack of Real-Time Monitoring:** Traditional methods are not able to perform real-time monitoring, which delays preventive actions and disease control.
- **Subjective and Inconsistent Results:** Reliability is affected by diagnosis depending upon the skill of the observer and the environmental conditions under which the diagnosis is made.
- **Reduced Precision in Severity Assessment:** Disease severity is difficult to estimate, especially by visual inspection, which restricts effective disease management.

## IV. DEEP LEARNING TECHNIQUES FOR GARLIC PLANT DISEASE DETECTION

Automated plant disease identification using DL has become a popular AI strategy because of its capacity to identify intricate patterns from picture data. Unlike the traditional ML methods which rely on manually retrieved features, deep learning models can identify abnormalities of the leaf structure, color, texture, and lesions automatically. Early disease identification using DL methods is becoming more common in agriculture as a means to decrease crop losses and increase yield.

### A. Deep Learning Models for Disease Detection in Plants

#### 1) Convolutional Neural Networks (CNNs)

CNNs' exceptional capacity to autonomously learn the hierarchical and discriminative properties of raw picture data makes them the go-to DL model for plant leaf disease identification. To create categorization and geographic data, CNNs use a mix of pooling layers, fully linked layers, and Convolutional Layers. Earlier studies in plant disease diagnosis relied heavily on subjective characteristics such as color, texture, and shape; however, CNNs may learn features autonomously, eliminating the need for human feature engineers.

Several well-known CNN structures have been successfully used for the problem of plant leaf disease categorization [13]. Despite their great computational complexity, VGG networks are known for their simplicity and depth, which allows them to effectively extract information. In order to successfully train deeper networks, ResNet topologies use residual connections to solve the vanishing gradient issue. Lightweight CNN models like MobileNet and EfficientNet are ideal for smart agricultural applications because they are parameter-efficient, work well on mobile and edge devices, and are relatively tiny in size. The ideal flow of gradients and learning is achieved via DenseNet's interconnection of layers, which further improves feature reuse.

## 2) Vision Transformer (ViT)

With the replacement of convolutional processes with self-attention mechanisms, ViTs represent a new generation in image-based plant disease diagnosis. A visual image transform (ViT) is based on transformer models in natural language processing; it flattens and projects an input picture with fixed-size patches to a matrix of embeddings. Transformer encoders have multiple layers of multi-head self-attention to learn relationships between these embedded picture patches [14]. The ability to capture long-range correlations, along with global contextual information, is often essential when aiming to identify disease patterns across leaf surfaces, which is where ViTs truly excel. ViTs look at the entire image, and thus can more effectively distinguish between healthy and diseased areas than CNNs, which are better suited to image local features.

## 3) Hybrid CNN-ViT Models

Hybrid CNN-ViT models combine the strengths of vision transformers and convolutional neural networks, which could make them more effective than either approach alone. It is common practice in these systems to employ CNNs for low- and mid-level feature extraction in order to detect local spatial patterns (e.g., edges, textures, lesion boundaries, etc.). To encode global contextual interactions dependent on self-attention, these attributes can be added or removed from ViT modules. Superior performance compared to single CNN or ViT models has been shown by PlantXViT, SLViT, and

ensemble CNN ViT models. IoT smart agricultural systems and edge devices may benefit from these hybrid designs since they are both computationally efficient and more precise. By using CNN feature extraction and reducing the number of transformer parameters, hybrid models significantly reduce training time and memory requirements.

## 4) GANs

A new deep learning approach for improving plant disease datasets is the Generative Adversarial Network (GAN). A GAN's generator network makes fake pictures, and the GAN's discriminator network tries to distinguish fake pictures from genuine ones [15]. The generator improves with time as it learns. In plant disease identification, GANs are used to address the issue of data shortage. By generating synthetic images of diseased plants, GANs can augment existing datasets, providing deep learning models with more diverse examples. Researchers have successfully used GANs to generate synthetic images of diseased leaves for crops such as grapes, apples, and tomatoes, significantly improving the accuracy of disease detection models.

## 5) Object Detection and Super-Resolution Models

Object identification and super-resolution, in addition to picture classification, may play a significant role in enhancing the process of real-world plant leaf disease diagnosis. Real-time localization and identification of the sick parts of leaves can be achieved with object detection models, especially YOLO family models, in leaf images [16]. There are many real-time applications where YOLO-based designs could be very useful, such as mobile disease diagnostic systems and drone-based crop monitoring. In the field, many of the images are captured at low resolution and quality, and super-resolution models are used to correct these problems. Under certain conditions, such as when the image is distorted, noisy or compressed into an artifact, the models can make better diagnoses of the disease.

Table I presents a comparative analysis of major DL models used in plant disease detection, highlighting their working principles, advantages, limitations, architectures, and agricultural applications for effective disease diagnosis.

TABLE I. COMPARATIVE ANALYSIS OF DEEP LEARNING MODELS FOR PLANT DISEASE DETECTION IN AGRICULTURE

Model	Working Principle	Key Advantages	Limitations	Applications
Convolutional Neural Networks (CNNs)	Automatically extracts hierarchical spatial features from plant photos using convolutional, pooling, and fully connected layers.	High classification accuracy, automatic feature extraction, strong performance on image-based tasks.	High computational cost for deep architectures; may struggle with global contextual relationships.	Leaf disease classification, disease severity estimation, mobile-based crop diagnosis systems.
Vision Transformer (ViT)	Using transformer-based self-attention mechanisms, it divides images into patches and learns the relationships between them.	Captures global contextual information, effective for complex disease patterns, strong feature representation.	Requires large datasets and high computational resources; training complexity is higher than CNNs.	Identification of distributed disease symptoms across leaf surfaces and complex disease classification.
Hybrid CNN-ViT Models	Integrates CNN-based local feature extraction with transformer-based global attention algorithms.	Higher accuracy, improved feature learning, computational efficiency compared to standalone ViT.	More complex architecture design and integration process.	Smart agriculture systems, precision disease detection, IoT-enabled monitoring.
Generative Adversarial Networks (GANs)	Uses a generator-discriminator framework to generate synthetic plant disease images for dataset augmentation.	Solves data scarcity issues, improves model generalization, increases dataset diversity.	Training instability, high computational requirements, possibility of unrealistic image generation.	Data augmentation for rare plant diseases, synthetic diseased leaf generation, improving classification performance.
Object Detection Models	Detects and localizes diseased regions in plant images using bounding boxes and classification mechanisms.	Real-time disease localization, high detection speed, suitable for field deployment.	Sensitive to image quality and environmental variations.	Real-time crop monitoring, drone-based disease surveillance, mobile diagnosis systems.

Super-Resolution Models	Enhances low-resolution or noisy images to improve disease visibility and classification accuracy.	Improves image quality, better performance under poor field conditions, reduces noise effects.	Additional computational overhead; dependent on input image quality.	Enhancing field-acquired plant images for accurate disease recognition.
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V. LITERATURE REVIEW

The literature highlights significant advances in deep learning-based garlic disease detection, emphasizing CNNs, YOLO, federated learning, imaging techniques, challenges, and future improvements.

Nurulita et al. (2026) created RT-PCR tests that can detect all of the most prevalent garlic-associated viruses. Sequences that were accessible on GenBank were used to conduct an in silico examination of primer specificity. Next, the tests were tested using viral isolates that were known to be infected. Then, forty different garlic cultivars were tested, drawn from a large germplasm collection at a government research station in South-east Queensland [17].

Gao et al. (2026) proposed YOLOv11n to achieve automated detection of damage in garlic. By adopting the ADown structure to replace the conventional convolution structure, the model decreased both the number of parameters and the computational complexity. The application of SimAM as an attention mechanism made the detection of damages more accurate, and the adoption of BiFPN architecture helped the model with multi-scale feature fusion. Experiments conducted with a self-built dataset showed that the proposed model outperformed other methods by achieving better parameters and computational cost performance, as well as faster inference speed and higher detection accuracy [18].

Liu et al. (2025) present a DL framework using a modified ResNet18 with RTCB attention for garlic leaf disease identification. This framework has increased computational performance by incorporating partial convolution and improved the feature extraction process using triplet attention. These results have shown that the presented approach can be employed in automated disease identification, edge computing, and intelligent agriculture for garlic leaf diseases [19].

Mehta and Bhardwaj (2024) proposed a federated learning (FL) and Convolutional Neural Network (CNN)-based framework for diagnosing garlic leaf disease severity across four severity classes: mild, moderate, severe, and critical. The model was trained using data collected from four different agricultural clients, where federated learning aggregated local

model updates to develop a globally applicable and privacy-preserving disease detection system. The results demonstrated high diagnostic accuracy across all clients using federated averaging. Performance evaluation based on Macro Average, Weighted Average, and Micro Average showed consistently high accuracy, with client performances exceeding 97%. Client dq\_2 achieved the highest accuracy of 98.84%, indicating the effectiveness of the FL-CNN approach in classifying garlic disease severity [20].

Acang et al. (2023) the garlic disease detection systems use state-of-the-art ML and image analysis methods to guarantee early identification and classification of potential diseases. The weather forecasting apps utilize sophisticated algorithms that incorporate historical weather data, soil conditions, and pest and disease occurrences to assist in the strategic allocation of resources and the meticulous management of irrigation schedules. The technological marvels have brought about a promising era for garlic agriculture, one that emphasizes sustainability and efficiency, ultimately bolstering global food security through the optimization of garlic cultivation practices [21].

Ryu, Wi and Lee (2023) developed a heat stress detection model for southern-type garlic using snapshot-based multispectral imaging and deep learning techniques. Images of garlic crops were captured during the bulb enlargement stage in both Vis and NIR regions. After preprocessing, a 38-wavelength spectral dataset was generated and used to train models such as PLS-DA, LS-SVM, DNN, and RP-CNN. The findings demonstrated that multispectral imaging combined with AI models can effectively monitor stress-induced changes in garlic plants and support early crop health assessment. This study highlights the potential of advanced imaging and ML techniques for improving garlic crop monitoring and precision agriculture [22].

Table II summarizes recent studies on garlic disease detection, highlighting their focus areas, challenges, limitations, and research gaps. It shows that while AI and deep learning methods have improved disease detection, further work is needed in real-time monitoring, larger datasets, and integrated smart agriculture solutions.

TABLE II. COMPARATIVE ANALYSIS OF EXISTING STUDIES AND RESEARCH GAPS IN GARLIC DISEASE DETECTION

Authors	Focus Area	Challenges	Limitations	Research Gap	Future Work
Nurulita et al., (2026)	RT-PCR assays for garlic virus detection	Ensuring primer specificity and validation across multiple viruses	Focused only on laboratory-based virus diagnosis; no AI or image-based detection	Lack of integration with automated deep learning-based disease detection systems	Combine molecular diagnostics with AI-based image analysis for real-time field detection
Gao et al., (2026)	Garlic-YOLO-DD for garlic damage detection using lightweight YOLO	Balancing detection accuracy with computational efficiency	The dataset was self-built and may lack diversity; focused on damage rather than disease severity	Limited validation under varying environmental and field conditions	Develop larger datasets and test models in real-time agricultural environments
Liu et al., (2025)	Deep learning model (Modified ResNet18 with RTCB) for garlic leaf disease identification	Improving feature extraction and computational performance	Limited disease categories and dependence on image quality	Lack of generalized and explainable models suitable for different garlic diseases	Develop explainable AI and multi-disease classification systems for field deployment
Mehta and Bhardwaj, (2024)	Federated Learning and CNN for garlic disease severity classification	Privacy-preserving model training across multiple clients	Requires distributed infrastructure and high communication efficiency	Limited studies on FL-based garlic disease diagnosis and scalability	Optimize FL communication and expand datasets from diverse regions

Acang et al., (2023)	Knowledge-driven decision support system for pest and disease management	Integrating environmental and agricultural data	Relies on predefined rules and historical information	Limited use of adaptive AI and real-time learning mechanisms	Develop intelligent AI-driven decision support systems with predictive analytics
Ryu, Wi and Lee, (2023)	Multispectral imaging and AI for heat stress detection	Detecting stress symptoms at early growth stages	Focused on abiotic stress rather than disease classification	Insufficient integration of stress and disease monitoring systems	Develop unified models for both stress and disease detection in garlic crops

## VI. CONCLUSION AND FUTURE WORK

The use of DL has revolutionized the identification of illnesses in garlic plants. These diseases can now be quickly and accurately identified via automation, which greatly improves crop quality and yield. Delays in diagnosis, subjectivity, and insufficiency to handle large-scale agricultural settings are common problems with traditional disease detection methods that depend primarily on visual examination and expert knowledge. The recent advancements during the past few years, particularly those based on DL techniques such as CNNs, ViTs and hybrid CNN-ViT models, GANs, and object detection frameworks like YOLO for garlic disease detection, which offer better precision and less manual effort, have proven to be highly promising. The strategies facilitate early detection, continuous monitoring, and appropriate crop management, contributing to precision agriculture and reducing farmer-induced economic losses. However, a number of problems remain: variability in the environment, the complexity of the models, the applicability of the models in less developed agricultural situations, and lack of good information on garlic diseases. Future research is needed in the following areas: large-scale annotated datasets, explainable AI frameworks, lightweight AI models for use on the edge, and multimodal systems that combine imaging, IoT sensor data, and weather data. Moreover, the federated learning and real-time mobile applications can enhance the scalable, privacy-preserving and intelligent garlic disease management system further.

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