Plant Leaves Disease Detection and Classification: Insights from Machine Learning and Deep Learning Approaches - A Review

Grace Thabitha J.[1], Dr. Ponnusamy R.[2]

Research Scholar, Department of Computer and Information Science, Annamalai University, Annamalai Nagar, Chidambaram,Tamilnadu, India
Email: *gracephd87[at]gmail.com*

Assistant Professor/Programmer, Department of Computer and Information Science, Faculty of Science, Annamalai University, Annamalai Nagar, Chidambaram, Tamilnadu, India
Email: *povi2006[at]gmail.com*

Abstract: ***Plant diseases pose a significant problem globally, greatly impacting crop quality and yield. This, in turn, affects global food security. Catching plant leaf diseases early and accurately is crucial for effective disease management strategies. Lately, machine learning (ML) and deep learning (DL) techniques have shown great promise in automating and improving the detection of plant diseases. This paper aims to provide a thorough review of current research on detecting and classifying plant leaf diseases using ML and DL algorithms. We begin by discussing the importance of early disease detection and the challenges linked with traditional methods. Then, we look into the key challenges and needs of plant disease detection systems. We also dive into existing studies that utilize ML and DL approaches for identifying plant leaf diseases. Additionally, we explore the evaluation methods, performance metrics, and datasets used to measure the effectiveness of these techniques. On top of that, we highlight emerging trends and recent advancements in this domain, such as image augmentation methods, transfer learning, and ensemble algorithms.***

Keywords: Plant disease, Leaf disease, Machine Learning, Deep Learning, Computer Vision

1. Introduction

Agriculture is the backbone of numerous economies, playing a crucial part in securing global food supplies. It supplies essential resources like food, fiber, and raw materials for various industries. However, plant diseases are a major threat to crop productivity and quality [1]. Particularly, plant leaf diseases are harmful. They directly impact photosynthesis, stunt growth, reduce yields, and can even cause total crop failure. Early and precise detection of these diseases is vital to minimize damage, enhance crop management, and ensure food sustainability. Identifying and classifying plant leaf diseases early helps stop their spread and allows farmers to apply the right treatments [2]. Traditional methods like visual inspections by experts can be slow, expensive, and error-prone. Machine learning (ML) and Deep learning (DL) are here. ML and DL have transformed plant disease detection by automating it. They offer greater accuracy, efficiency, and scalability. These technologies analyze large datasets, identify patterns, and predict outcomes accurately—even in complicated situations where traditional methods might fail [3].

Image processing plays a key role by turning leaf images into data that ML and DL models can analyze. It includes tasks like acquiring, enhancing, and segmenting images to extract features such as texture, color, and shape—essential for spotting disease symptoms. Detecting plant leaf diseases needs continuous crop monitoring which can be easier with automated systems [4]. Machine learning (ML) plays a big part in making these systems work. First, images of plant leaves were collected. Next, the images go through segmentation and pre-processing. After that, the features are extracted using different methods and fed into classification algorithms to find out which disease is present in the test images. Combined with ML and DL models, image processing helps create advanced systems that automatically classify and detect diseases in plant leaves with high precision [5]. This integration boosts the overall efficiency of disease management, benefiting both farmers and the agricultural sector broadly. Fig.1 depicts the process in the plant leaf disease detection system.

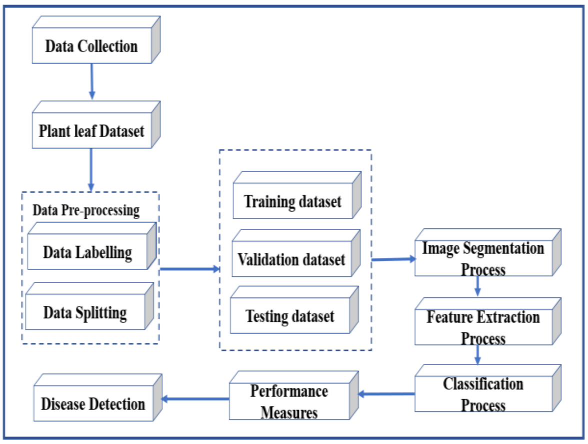

Figure 1: Steps involved in plant leaf disease detection and classification systems

Transfer learning (TL) is important for improving plant leaf disease detection and classification. It uses pre-trained models to tackle issues like limited labeled data and computational resources. These models, usually trained on big and varied datasets like ImageNet, can transfer learned features—such as shapes, textures, and patterns—to the plant disease area. This approach cuts down on the need for big, specialized datasets. The model can generalize better with fewer training samples. Also, transfer learning speeds up the training process by fine-tuning only the later layers of the model while keeping the earlier training's knowledge [6]. This method boosts accuracy by helping the model spot disease patterns well, even with smaller or unbalanced datasets. It can quickly adjust to identify new or upcoming plant diseases with just a bit of retraining. Additionally, transfer learning is cost-effective. It saves both the time and resources needed to create a solid model from the ground up. This makes it very useful in agriculture. Faster and more accurate disease detection helps stop crop loss. [7].

This survey paper aims to thoroughly study current research on plant leaf disease detection and classification using machine learning (ML) & deep learning (DL) algorithms. The paper discusses why early detection of plant diseases is important and points out the limits of traditional methods. Next, the challenges and requirements for building effective plant disease recognition systems are discussed. Also, we examine and assess the latest studies that use ML and DL techniques for detecting and classifying diseases in plant leaves. Finally, we also propose a model for plant leaf disease detection and classification, introducing the architecture and performance and explaining how it can be improved on current systems.

2. Preliminary Insights

Traditionally, methods based on human vision were employed to detect diseases in plant leaves. Yet, this approach tends to be costly & time-consuming. Besides, it depends a lot on the expertise of specialists or individuals, which often brings in subjectivity and variability in performance. On the flip side, automated systems for leaf disease detection make the diagnostic process smoother. Farmers can then make accurate decisions about their crops' health promptly. This improvement can lead to significantly better crop yields and help use resources more efficiently. Although using machine learning (ML) and deep learning (DL) algorithms for detecting diseases in various crops shows great promise, it hasn't been explored much. Even with its benefits, these techniques aren't widely adopted yet. Considering how often plant disease outbreaks happen, more research could help reduce losses and boost agricultural productivity. ML and DL could provide much better accuracy and efficiency in diagnosing leaf diseases.

3. Challenges Involved in Automatic plant leaf Disease Detection and Classification

- Variability in Disease Symptoms: Plant diseases present a broad range of symptoms, differing in color, shape, and texture. Environmental factors like light and humidity, with plant species, can change these symptoms. This variability makes standardizing disease detection tough.
- Data Quality and Availability: To build accurate disease detection models, large datasets of diseased plant leaf images are essential. However, high-quality labeled datasets are often rare, especially for uncommon diseases or crops. Furthermore, image quality may suffer due to noise, low resolution, or inconsistent lighting, affecting model performance.
- Similar Appearance of Symptoms: Many diseases display similar visual symptoms, such as yellowing or leaf spots. This similarity complicates the distinguishing between different diseases. Models need to detect small differences to classify correctly.
- Environmental Conditions: Environmental factors like lighting and weather can change a plant leaf's appearance. These variations impact the accuracy of image processing techniques. Thus, robust models must be able to generalize across different environments.
- Computational Resources: Training deep learning models on large datasets demands significant computational power, including high-performance GPUs. In many developing regions, access to such infrastructure may be limited.
- Complexity of Leaf Structures: Plant leaves vary in structure, shape, and size among species. This variation complicates automated systems because models need versatility to handle diverse plant types without losing accuracy.
- Real-Time Detection: Detecting diseases in real-time requires quick processing of large data volumes. Implementing real-time systems for field use like drones or mobile devices is challenging due to high processing demands.
- Generalization Across Crops: Developing models that perform well across diverse crops and diseases is difficult. Models trained on specific datasets might not work accurately on new crops or unseen diseases, limiting their scalability.

Addressing these challenges [9] calls for continued research and development in machine learning and scalable agricultural technologies to create robust, adaptable, and accessible plant disease detection systems.

4. Machine Learning Techniques Plant Leaf Disease Detection and Classification

Machine learning (ML) techniques are crucial in the automatic detection and classification of plant leaf diseases. These methods analyze large sets of data, spot patterns, and make accurate predictions [10]. Several ML methods commonly used for this include:

- ***Support Vector Machines (SVM):***

SVM is a supervised learning algorithm that creates a hyperplane to separate data points into different classes. For plant disease detection, SVM classifies leaf diseases based on features like texture, color, and shape. It excels in binary classification tasks but can also handle multi-class issues.

- ***k-Nearest Neighbors (k-NN):***

K-NN is a straightforward algorithm that classifies data points by comparing their proximity to labeled instances. It's widely used in plant disease detection for its simplicity and effectiveness when given clear, labeled data. However, it can struggle with huge datasets & complex diseases.

- ***Decision Trees:***

Decision trees classify plant diseases by making a tree-like model of decisions based on feature splits. They are intuitive

Paper ID: SR241230211809 DOI: https://dx.doi.org/10.21275/SR241230211809

and easy to grasp but can overfit, especially when data is noisy or disease symptoms overlap.

- ***Random Forest:***

Random Forest is an ensemble learning method combining multiple decision trees to boost classification accuracy and reduce overfitting. It's applied to plant leaf disease detection because it handles noisy data and complex disease patterns effectively.

- ***Naive Bayes:***

This probabilistic classifier assumes features (like color & texture) are independent of each other. It's quick and simple but may underperform in complex scenarios where features are highly correlated, as often seen with plant leaves.

- ***K-Means Clustering:***

While primarily an unsupervised learning method, K-Means clustering sometimes helps in detecting diseased areas on leaves by grouping similar features into clusters. Though it doesn't classify on its own, it aids in identifying diseased regions.

- ***Principal Component Analysis (PCA):***

PCA is for dimensionality reduction—it helps cut down the number of features while keeping important information intact. Often used in pre-processing, it removes noise and improves classifier performance in plant disease detection.

These ML techniques are vital for advancing our ability to detect and treat plant diseases efficiently and accurately.

5. Deep Learning Techniques for Plant Leaf Disease Detection

Deep learning techniques have come a long way in enhancing the detection and classification of plant leaf diseases. They help by automating the extraction of features and boosting accuracy. These methods are now widely used in agricultural research [11]. Here are the primary deep-learning techniques involved in detecting and classifying plant leaf diseases:

- ***Convolutional Neural Networks (CNNs):***

CNNs are highly popular & effective for image-based detection of plant leaf diseases. They extract features like edges, textures, and shapes directly from leaf images, removing the need for manual feature engineering. CNNs consist of convolutional layers that apply filters to input images to identify disease patterns. Then there are pooling layers to cut down dimensionality and fully connected layers for classification.

- ***Transfer Learning***

Transfer learning uses pre-trained models (like VGG, ResNet, or Inception) that have been trained on extensive datasets (such as ImageNet). These models are then fine-tuned for specific tasks like plant disease detection. This method is especially helpful when the dataset for plant leaf diseases is small. By using knowledge already gained from larger datasets, transfer learning can achieve great accuracy with less training data & computational effort.

- ***Recurrent Neural Networks (RNNs):***

RNNs mostly handle sequential data like time series, but they can be adapted for disease detection where temporal data is available—such as tracking disease symptoms over time on leaves. Long Short-Term Memory (LSTM), a type of RNN, aids in tracking and predicting disease spread based on previous observations. However, RNNs are less commonly applied than CNNs in this field.

- ***Generative Adversarial Networks (GANs):***

GANs consist of two neural networks—a generator and a discriminator—that work together to create synthetic images resembling real ones. For plant leaf disease detection, GANs can be utilized to expand the dataset by generating realistic additional leaf images, including those with disease symptoms. This helps address the issue of limited training data, particularly for rare diseases.

- ***Fully Convolutional Networks (FCNs):***

FCNs are a variant of CNNs aimed at pixel-wise classification in tasks like semantic segmentation. In detecting plant leaf diseases, FCNs can pinpoint and segment diseased regions on a leaf, offering more detail than simply classifying the entire image. This is particularly useful for determining precisely how much damage the disease has caused on a leaf.

- ***Autoencoders:***

Autoencoders are models used without labeled data and are very effective for identifying anomalies. In terms of plant leaf diseases, autoencoders can be trained to recreate healthy leaf images. Any considerable deviation between the input and the recreated image may indicate a disease's presence—helping detect subtle symptoms not easily seen by the human eye.

- ***Deep Belief Networks (DBNs):***

DBNs are another type of unsupervised deep learning model used for feature extraction and classification. For plant leaf disease detection, DBNs can learn hierarchical features from input data and enhance classification accuracy by spotting complex patterns in disease symptoms.

- ***Region-Based Convolutional Neural Networks (R-CNN):***

R-CNN models and their improved versions like Fast R-CNN & Faster R-CNN combine CNNs with region proposals for object detection tasks. In detecting plant diseases, R-CNN can detect & localize diseased regions on leaves, allowing both classification and localization of diseases—especially useful when precise identification is necessary.

- ***You Only Look Once (YOLO):***

YOLO is a real-time object detection model that splits an image into a grid & predicts bounding boxes plus class probabilities for objects in them. For detecting diseases on plant leaves, YOLO can spot diseased areas or spots quickly & efficiently in real-time—making it ideal for field environments.

6. Related Works

a) *Machine Learning-Based Detection Methods*

In [12], the author does a comparative study of three models: Support Vector Machines (SVM), K-Nearest Neighbor (KNN), & Convolutional Neural Networks (CNN). These models are tested for their skill in spotting eight different leaf diseases. In [13], the author brings in a new convolutional neural network (CNN) model to classify common rice leaf diseases. In [14], they used a machine learning technique to spot grape leaf disease early. This helped them tell the difference between various disease types accurately. In [15], the "PlantVillage" dataset was used to classify various plant diseases across 12 crop species employing machine learning techniques like SVM. K-means clustering was instrumental in disease detection, reaching 99% accuracy for rice, 98% for apples, and 94-97% for tomatoes.

A system for recognizing leaf stages, using K-means clustering, was created to improve the detection of leaf diseases [16]. In another study [17], the author suggested four pre-processing steps to reduce the noise in leaf image datasets. In [18] traditional methods such as K-nearest neighbor (KNN) algorithms classified plant leaves based on features like color, intensity, and size. The author [19] turned leaf colors into LAB color space and then used clustering methods to analyze those colors. In [20], the author proposed an automatic background removal to find mildew in cherry leaves. Authors [21] used color transformation to spot seed regions in leaf analysis.

Different methods in precision farming have been looked at [22], but getting high classification accuracy in leaf spot detection is still tough for many machine-learning techniques. The author [23] explored tomato leaf disease classification by experimenting with and comparing different methods. The author used traditional machine learning tools such as random forest (RF), support vector machines (SVM), and naïve Bayes (NB). On top of that, the author tried out a deep learning convolutional neural network (CNN) and ended up hitting 95% accuracy.

In [24], a selection of support vector machine (SVM) based multi-class image processing algorithms has been proposed for diagnosing and classifying grape leaf diseases, such as black measles, black rot, and leaf blight. RiceNet [25], was proposed to analyze and classify four rice diseases. YoloX has the highest accuracy in detecting the diseased parts (95.58% mAP) and Siamese Network is the most accurate in distinguishing the disease patches (99.03% accuracy), surpassing other models. The paper [26] suggests that machine learning models could be used for predictive analyses at the leaf disease level. The working of disease detection system using OpenCV and CNN in precision agriculture is a four-step leaf-disease detection framework that takes camera input, processes it through computer vision and image segmentation, extracts features from the images and then finally detects the disease present with machine learning on extracted features. Fig. 2 depicts the sample plant leaf images which are used in the existing works.

b) *Deep Learning-Based Detection Methods*

As per [27], DL-based insect detection in soybean crops reached high accuracy using transfer learning models. YoloV5 was the best performer with an accuracy rate of 98.75% and 53 fps, making it ideal for real-time detection, while InceptionV3 and CNN achieved 97% accuracy. The study simplified the process and lowered the producer's workload using a varied insect dataset. In [28] the author proposed a DL-based system to spot and classify plant leaf diseases using the PlantVillage dataset. They used Convolutional Neural Networks (CNN) to sort 15 types, including 12 disease kinds and 3 healthy leaf groups like bacterial and fungal. The system scored 98.29% in training and 98.03% in testing with all datasets included. In [29], a method for identifying rice plant diseases by analyzing lesion size, shape, & color is presented. The proposed model utilizes Otsu's global threshold technique for image binarization, effectively removing background noise. Trained on 4000 samples of diseased and healthy rice leaves, the fully connected CNN achieved an impressive 99.7% accuracy in identifying three distinct rice diseases. In [30], the author uses four deep learning models—AlexNet, a simple sequential model, MobileNet, & Inception-v3—for detecting leaf diseases. In [31], they came up with a hybrid optimization algorithm. This algorithm combines the Rider Optimization Algorithm (ROA) & Henry Gas Solubility Optimization (HGSO), and it's used to classify plant diseases.

In [32], the author used a deep convolutional neural network (Deep CNN) to propose a new way to detect leaf diseases. In [33], the author looks at three deep learning models—CNN, VGG16, and VGG19 to spot plant diseases. In [34], the author introduced CottonLeafNet. Here the author used a nearly balanced dataset that featured 22 different leaf disease types. These included bacterial, fungal, viral, and nutrient deficiency diseases. To boost model performance, they applied data augmentation. In [35], the author suggests using an enhanced deep-learning algorithm to classify potato leaves into five categories based on their visual. Author [36], presented a system based on computer vision using machine learning and deep learning techniques for the detection of rice plant diseases. This method tends to be less reliant on the traditional procedure of crop protection against bacterial leaf blight, false smut, brown leaf spot, rice blast, and sheath rot which affects Indian paddy crops thereby being able to detect all five major diseases with an accuracy rate of 91%.

A VGG-16 transfer learning model along with Faster R-CNN architecture was employed for the feature extraction [37]. Random forest was used for the classification of extracted features that gave 97.3% accuracy. In [38], the writer proposes a deep learning-based disease detection and classification method by applying Ant Colony Optimization to a Convolutional Neural Network, which achieved 99.98% accuracy. Using a residual channel attention block (RCAB), feedback block (FB), and elliptic metric learning (EML) based integrated deep learning approach called RFE-CNN for wheat leaf disease detection in wheat crop, the author [39] achieved an accuracy of 98.83%. In [40], a hybrid deep learning framework for real-time detection of multiple diseases on the same guava leaf analysis naturally captures an accuracy of 92.41%.

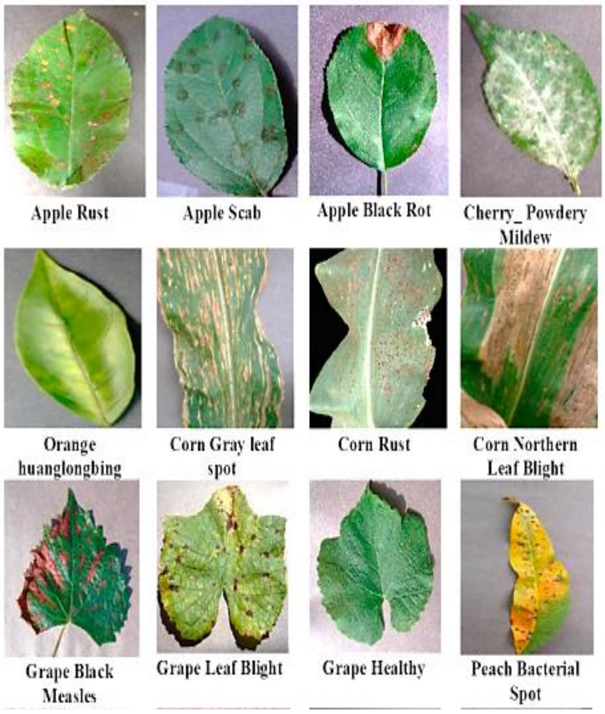

Figure 2: Sample Plant Leaf images

Table 1: Review of Present Plant Leaf Disease Detection and Classification

References	Crops/ Leaves Used	Techniques used	Accuracy (%)
[12]	Plant leaves	SVM, KNN, CNN	90%
[13]	Rice Leaf	CNN	93.5%
[14]	Grape Leaf	SVM, CNN	92%
[15]	Rice leaf, Apple leaf, tomato leaf	SVM, KNN	99%, 98%,94-97% respectively
[16]	Plant Leaves	KNN	93%
[17]	Plant Leaves	Four step pre-processing	90.07%
[18]	Plant Leaves	KNN	92.07%
[19]	Plant Leaves	Clustering method	90.05%
[20]	Cherry Leaf	Automatic background removal	-
[21]	Plant Leaves	Color transformation	95.69%
[22]	Plant Leaves	ML techniques	95.7%
[23]	Tomato Leaf	RF, SVM, NB, CNN	95%
[24]	Grape Leaf	SVM	95%
[25]	Rice Leaf	YoloX, Siamese Network	95.58%, 99.03% respectively
[26]	Plant Leaves	Machine Learning models	-
[27]	Soybean crop	Inception V3, CNN, YoloV5	98.75%
[28]	Plant Leaves	CNN, DL Methods	98.29%
[29]	Rice Leaf	DL methods, CNN	99.07%
[30]	Plant Leaves	AlexNet, MobileNet, Inception V3	-

7. Conclusion

Over the last decade, these plant leaf disease detection systems have been significantly improved by advancements in machine learning (ML) and deep learning (DL), providing greater accuracy of classification with high efficiency than previous methods. Such technologies help farmers with quick and accurate diagnosis provided by automated systems, which results in better cultivation practices, high yields, and minimum losses. ML models such as SVM, k-NN, and random forests have been among the most thoroughly researched models, with DL ones especially CNNs and transfer learning impressing by far on

large datasets indicating diseases. Still, difficulties like heterogeneous symptoms, data quality, and computational resource constraints persist. It is equally crucial to address these challenges with further research and development to move toward both feasible and scalable solutions. As automated detection systems evolve, they hold the potential to revolutionize agriculture, making it more sustainable, efficient, and resilient in the face of disease outbreaks.

References

[1] P. A. Nazarov, D. N. Baleev, M. I. Ivanova, L. M. Sokolova, and M. V. Karakozova, “Infectious plant diseases: etiology, current status, problems and prospects in plant protection,” Acta Naturae, vol. 12, no. 3, p. 46, 2020.

[2] S. Rathi, H. McFeeters, R. L. McFeeters, and M. R. Davis, “Purification and phytotoxic analysis of botrytis

cinerea virulence factors: new avenues for crop protection," Agriculture, vol. 2, no. 3, pp. 154–164, 2012.

[3] N. Bodenhausen, M. W. Horton, and J. Bergelson, "Bacterial communities associated with the leaves and the roots of Arabidopsis thaliana," PLoS One, vol. 8, no. 2, Article ID e56329, 2013.

[4] H. El-Ramady, P. Hajd´u, G. Torős, et al., "Plant nutrition for ¨human health: a pictorial review on plant bioactive compounds for sustainable agriculture," Sustainability, vol. 14, no. 14, p. 8329, 2022.

[5] O. Calicioglu, A. Flammini, S. Bracco, L. Bell`u, and R. Sims, "Te future challenges of food and agriculture: an integrated analysis of trends and solutions," Sustainability, vol. 11, no. 1, p. 222, 2019.

[6] T. P. Dodiya, G. D. Patel, N. K. Patel, D. A. Patel, and A. D. Gadhiya, "Economics of different intercropping systems in jasmine (Jasminum sambac l.) var. baramasi," Advances in Life Sciences, vol. 10, pp. 6896–6898, 2016.

[7] K. Hemanandhini, A. Muthukumar, A. K. Reetha, R. Udhayakumar, and R. Logeshwari, "Effect of different media on growth and cultural characteristics of Alternaria jasmini causing jasmine leaf blight," Plant Archives, vol. 19, no. 2, pp. 2220–2224, 2019.

[8] I. Kamenova, S. Adkins, and D. Achor, "Identification of Tomato Mosaic Virus Infection in Jasmine," 2006, https:// www.actahort.org/books/722/722_34.htm.

[9] M. Nivedha, E. G. Ebenezar, K. Kalpana, and A. Kumar, "In vitro antifungal evaluation of various plant extracts against leaf blight disease of Jasminum grandiforum caused by Alternaria alternata (fr.) keissler," Journal of Pharmacognosy and Phytochemistry, vol. 8, no. 3, pp. 2143–2147, 2019.

[10] R. Sanoubar and L. Barbanti, "Fungal diseases on tomato plant under greenhouse condition," European Journal of BiologicalResearch, vol. 7, no. 4, pp. 299–308, 2017.

[11] H. Durmus¸, E. O. G¨unes¸, and M. Kırcı, "Disease detection on the leaves of the tomato plants by using deep learning," in Proceedings of the 2017 6th International Conference on agro geoinformatics, IEEE, Fairfax, VA, USA, August 2017.

[12] Nikith, B. V., et al. "Leaf disease detection and classification." Procedia Computer Science 218 (2023): 291-300.

[13] Kulkarni, Priyanka, and Swaroopa Shastri. "Rice leaf diseases detection using machine learning." Journal of Scientific Research and Technology (2024): 17-22.

[14] Shantkumari, M., Uma, S.V. Grape leaf image classification based on machine learning technique for accurate leaf disease detection. Multimed Tools Appl 82, 1477–1487 (2023). https://doi.org/10.1007/s11042-022-12976-z.

[15] Ahmed I, Yadav PK. A systematic analysis of machine learning and deep learning-based approaches for identifying and diagnosing plant diseases. Sustain Oper Comput. 2023;4:96–104. https://doi.org/10.1016/j.susoc.2023.03.001.

[16] S. S. Harakannanavar, J. M. Rudagi, V. I. Puranikmath, A. Siddiqua, R. Pramodhini, and R. Pramodhini, "Plant leaf disease detection using computer vision and machine learning algorithms," Global Transitions Proceedings, vol. 3, no. 1, pp. 305–310, 2022.

[17] G. Geetha, S. Samundeswari, G. Saranya, K. Meenakshi, and M. Nithya, "Plant leaf disease classifcation and detection system using machine learning," Journal of Physics: Conference Series, vol. 1712, Article ID 012012, 2020.

[18] L. S. P. Annabel, T. Annapoorani, and P. Deepalakshmi, "Machine learning for plant leaf disease detection and classifcation–a review," in Proceedings of the 2019 international conference on communication and signal processing (ICCSP), IEEE, Chennai, India, April 2019.

[19] R. P. Narmadha and G. Arulvadivu, "Detection and measurement of paddy leaf disease symptoms using image processing," in Proceedings of the 2017 International Conference on Computer Communication and Informatics (ICCCI), pp. 1–4, IEEE, Coimbatore, India, January 2017.

[20] V. Gupta, N. Sengar, M. K. Dutta, C. M. Travieso, and J. B. Alonso, "Automated segmentation of powdery mildew disease from cherry leaves using image processing," in Proceedings of the 2017 International Conference and Workshop on Bioinspired Intelligence (IWOBI), IEEE, Funchal, Portugal, July 2017.

[21] Y. Kurmi and S. Gangwar, "A leaf image localization based algorithm for different crops disease classifcation," Information Processing in Agriculture, vol. 9, no. 3, pp. 456–474, 2022.

[22] G. S. Nagaraja, K. Vanishree, and F. Azam, "Novel framework for secure data aggregation in precision agriculture with extensive energy efficiency," Journal of Computer Networks and Communications, vol. 2023, Article ID 5926294, 11 pages, 2023.

[23] Sagar, Sanjeela, and Jaswinder Singh. "An experimental study of tomato viral leaf diseases detection using machine learning classification techniques." Bulletin of Electrical Engineering and Informatics 12.1 (2023): 451-461.

[24] Javidan, Seyed Mohamad, et al. "Diagnosis of grape leaf diseases using automatic K-means clustering and machine learning." Smart Agricultural Technology 3 (2023): 100081.

[25] Pan, Jinchao, Tengyu Wang, and Qiufeng Wu. "RiceNet: A two-stage machine learning method for rice disease identification." Biosystems Engineering 225 (2023): 25-40.

[26] Endait, Gauri, et al. "Hybrid Model to Predict Leaf Disease Prediction Using Ensembling Machine Learning Approach." 2023 World Conference on Communication & Computing (WCONF). IEEE, 2023.

[27] Tirkey D, Singh KK, Tripathi S. Performance analysis of AI-based solutions for crop disease identification detection, and classification. Smart Agric Technol. 2023. https://doi.org/10.1016/j.atech.2023.100238.

[28] Jasim MA, Al-Tuwaijari JM. Plant leaf diseases detection and classifcation using image processing and deep learning techniques. Int Comput Sci Soft Eng Conf. 2020. https://doi.org/10.1109/CSASE48920.2020.9142097.

[29] Upadhyay SK, Kumar A. A novel approach for rice plant disease classification with deep convolutional neural network. Int J Inf Technol. 2022;14(1):185–99. https://doi.org/10.1007/s41870-021-00817-5.

[30] Binnar, V., Sharma, S. (2023). Plant Leaf Diseases Detection Using Deep Learning Algorithms. In: Doriya, R., Soni, B., Shukla, A., Gao, XZ. (eds) Machine Learning, Image Processing, Network Security and Data Sciences. Lecture Notes in Electrical Engineering, vol 946. Springer, Singapore. https://doi.org/10.1007/978-981-19-5868-7_17.

[31] Daniya, T., and S. Vigneshwari. "Rice Plant Leaf Disease Detection and Classification Using Optimization Enabled Deep Learning." Journal of Environmental Informatics 42.1 (2023).

[32] Towfek, S. K., and Nima Khodadadi. "Deep convolutional neural network and metaheuristic optimization for disease detection in plant leaves." Journal of Intelligent Systems and Internet of Things 10.1 (2023): 66-75.

[33] Shivaprasad, Kelothu, and Ankita Wadhawan. "Deep learning-based plant leaf disease detection." 2023 7th international conference on intelligent computing and control systems (ICICCS). IEEE, 2023.

[34] Singh, Paramjeet, et al. "CottonLeafNet: cotton plant leaf disease detection using deep neural networks." Multim. Tools Appl. 82.24 (2023): 37151-37176.

[35] Mahum, Rabbia, et al. "A novel framework for potato leaf disease detection using an efficient deep learning model." Human and Ecological Risk Assessment: An International Journal 29.2 (2023): 303-326.

[36] Haridasan, Amritha, Jeena Thomas, and Ebin Deni Raj. "Deep learning system for paddy plant disease detection and classification." Environmental monitoring and assessment 195.1 (2023): 120.

[37] Rajpoot, Vikram, Akhilesh Tiwari, and Anand Singh Jalal. "Automatic early detection of rice leaf diseases using hybrid deep learning and machine learning methods." Multimedia Tools and Applications 82.23 (2023): 36091-36117.

[38] Abd Algani, Yousef Methkal, et al. "Leaf disease identification and classification using optimized deep learning." Measurement: Sensors 25 (2023): 100643.

[39] Xu, Laixiang, et al. "Wheat leaf disease identification based on deep learning algorithms." Physiological and Molecular Plant Pathology 123 (2023): 101940.

[40] Rashid, Javed, et al. "Real-Time Multiple Guava Leaf Disease Detection from a Single Leaf Using Hybrid Deep Learning Technique." Computers, Materials & Continua 74.1 (2023).