Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Economics and Finance 00 (2012) 000–000

Procedia
Economics and Finance

www.elsevier.com/locate/procedia

Exploring The Evolution of Deep Learning Techniques in Plant Diseases: A Systematic Literature Review

Ummi Farihah Abd Wahid, Nuramira Shafinaz Zulailee, Yovi Pratama*

[a]*First affiliation, Address, City and Postcode, Country*
[b]*Second affiliation, Address, City and Postcode, Country*

Abstract

The systematic literature review explores the evolution of deep learning methods for plant disease identification and techniques and the development of essential approaches in this methodology that have transformed this field. The traditional methods of plant disease detection, which rely on manual inspections, are increasingly being replaced with advances in deep learning approaches, such as convolutional neural network (CNN) and transfer learning are used due to their higher accuracy and speed can be made scalable. By examining the comprehensive range of studies on learning approaches in plant pathology, this paper aims to outline trends, advances, and limitations by incorporating multiple studies on deep learning approaches. The findings emphasize the importance of enhancing disease identification effectiveness and the potential of these schemes in transforming agriculture practices. At the same time, it highlights the existing limitations and proposes directions to improve the robustness and utilization of deep learning for such an essential section.

Keywords: Deep Learning, Plant Disease.

1. Introduction

In recent years, agriculture industries have witnessed tremendous improvement due to the deployment of deep learning methods in diagnosing and treating plant disease. These technologies in the agriculture

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: author@institute.xxx .

industries significantly impact how they matter around plant disease diagnosis and treatment of various plant health issues. It's unfortunate to mention that plant disease severely threatens global food security, the economy, and countless farmers around the globe. Traditional disease detection methods often rely on manual inspections involving physical examination and laboratory analysis of biological samples, giving high levels of variability and low accuracy, and can take a lot of time and resources (Saleem et al., 2022). Most existing conventional machine learning models depend on the nature of extrinsic features usually chosen by humans, such as Colour, Edge, and Texture features(Doutoum & Tugrul, 2023a). This usually demands added understanding and focus of the features most suitable for classifying plant diseases(Gong & Zhang, 2023a). Advanced techniques using deep learning, a type of artificial intelligence, can provide revolutionary solutions because of their ability to investigate and analyze data patterns and provide precise disease diagnosis and categorization.

The systematic literature review explores the evolution of deep learning methods to identify plant diseases, including an overview of the current research, methodologies, and applications. By reviewing the advancements made in the past year, this review will highlight the strengths and weaknesses of available strategies, illustrate trends and novelties, and influence the potential development of further research in this vital field. The first review discusses the conceptual background of deep learning and its applicability to image analysis and pattern recognition, specifically in studying plant diseases. It then outlines various imaging techniques employed in this field, including hyperspectral, thermal, and RGB imaging, which are essential when designing effective deep-learning models. A Convolutional Neural Network (CNN) is a type of deep learning model particularly well-suited for processing structured grid data, such as images (R. Albogamy, 2021).The evolution of convolutional neural networks (CNNs), recurrent neural networks (RNNs), and other architectures in enhancing the accuracy of disease detection, with significant achievements and advancements illustrated(Xu et al., 2023a).

In the context of deep learning, real-world agricultural settings include automated disease diagnosis systems and mobile applications that can be used in the field and are compatible with integrating Internet of Things (IoT) devices for ongoing surveillance. Specified case studies and pilot projects from various regions show examples of advantages and overcoming the difficulties encountered while implementing those technologies in various agricultural climate conditions. The performance of deep learning models heavily relies on the quality and quantity of the training data. Limited datasets can lead to overfitting, where the model performs well on training data but poorly on unseen data (Alwan Fauzi et al., 2023). The challenge that farmers might face is a lack of expertise, as many farmers do not have the necessary training or expertise to identify various plant diseases (S. Omer et al., 2023).

The review outlines future research directions, including integrating with other fields, developing more generalizable and transformable frameworks, and exploiting deep learning with other novel technologies such as blockchain and edge computing. In fulfilling the aforementioned objectives of the review, the current study will employ a review of existing literature as well as an extrapolation of future trends in deep learning applications that help authorities, researchers, and practitioners in the agricultural sector employ deep learning for optimal sustainable farming practices and efficient plant health management. For all these reasons, this systematic review of developments in deep learning approaches for plant diseases demonstrates the revolutionaries of these technologies. It points the way to future research and application that will help humanity meet food security challenges in the world and enhance sustainable agricultural production.

1.1 *Problem Statement*

Some diseases that affect plants are caused by pathogens like fungi, bacteria, viruses, and nematodes, which are destructive to food crops across the globe and threaten plant productivity and agricultural food security worldwide. The loss of crop yields and their earnings can negatively impact the financial well-being of these farmers and cause issues in the provision of food across the globe. Have traditionally involved non-molecular techniques that involve observation and identification of diseases and their severity by qualified personnel after observing typical symptoms on plants. However, this approach is commonly slow, requiring much effort, and will be influenced by human errors as the first signs of a disease may go unnoticed, especially when diseases are in the early stages, with many types of plants and numerous pathogens.

Despite many traditional methods, artificial intelligence, especially deep learning, has been seen as the ultimate way of improving plant disease diagnosis. As seen in the figure, using rich computational models and an extensive, diverse collection of images, deep learning algorithms can enhance the capability of machines to diagnose plant diseases with only a trim level of error and a short amount of time. They can spot disease at its early stage, help take necessary measures on time, and aid in long-term agricultural practices.

Nevertheless, fast advancements in deep learning frameworks, higher variability of plant species and diseases being diagnosed, and the fluctuations of imaging and data acquisition environments in the existing studies create obstacles to integrating the most up-to-date algorithms. Therefore, a well-structured systematic literature review that effectively evaluates deep learning literature’s advancement, issues, and opportunities for plant disease identification is crucial since the recent studies involve methodologies, datasets, and numerous assessment approaches.

This review would help understand various deep learning architectures, data preprocessing and augmentation techniques, transfer learning benchmarks, and model evaluation protocols for plant disease detection. It would also highlight areas for further study, sources of possible bias in current approaches, and directions for future work to increase the practical implementation of deep learning-based tools in everyday agricultural systems to promote sustainable and productive food production.

1.2 *Research Question*

1.2.1 Publications Characteristics

- *RQ1.* Which pattern of publication has developed over time for this field of study?
- *RQ2.* What types of sources are the works being published in?
- *RQ3.* Which sources have the greatest number of papers in the topic that have been published?
- *RQ4.* What are the primary research areas according to the publications that publish the works?

1.2.2 Authors’ Characteristics

- *RQ5.* What is the number of authors contributing to this field?
- *RQ6.* How much do recently published authors contribute?
- *RQ7.* How many authors appear in each publication?

1.2.3 Content Characteristics

RQ8. Which deep learning methods for plant disease are most commonly mentioned?
RQ9. Which are the top plant diseases being addressed through deep learning approaches?
RQ10. Which are the main study approaches on the theoretical publications set?
RQ11. Which are the main application objectives of the case study publications set?
RQ12. Which are the newly emerging research lines related to this research area?

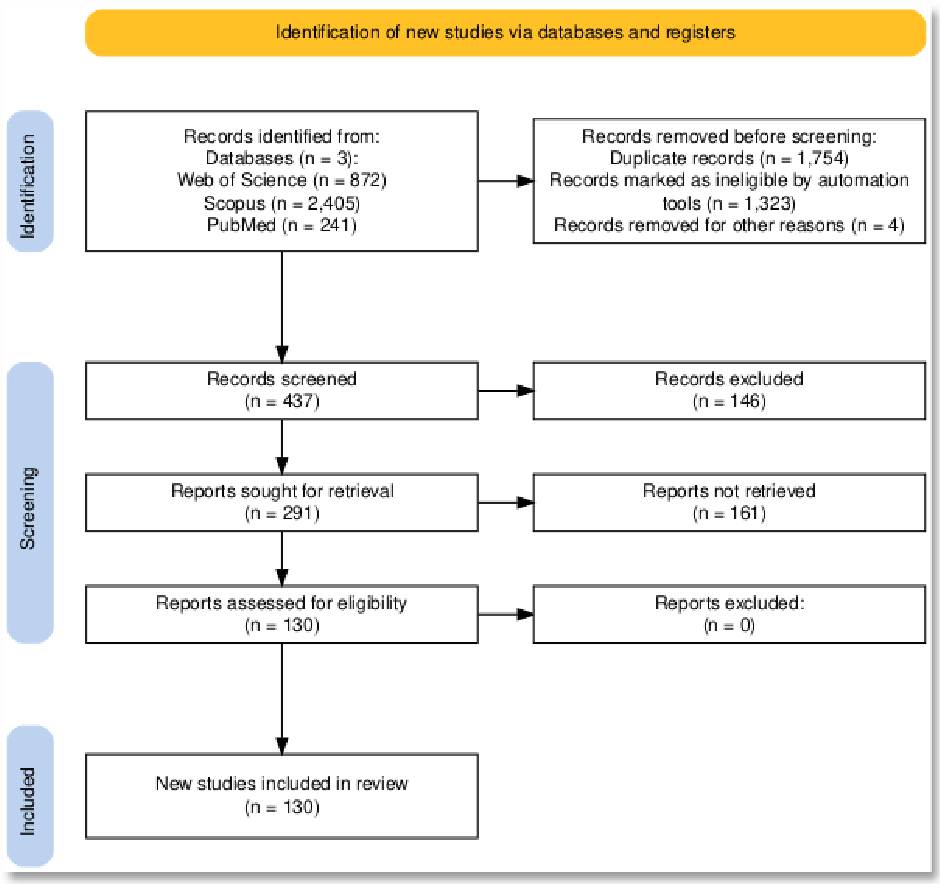
2. Method and Materials

The method chosen in the Systematic Literature Review was to analyze and review the evolution of deep learning techniques in plant diseases. To find related articles, this method reviewed various types of plant diseases using deep learning techniques based on three databases: Scopus, Web of Science, and PubMed. Those three research databases provide insight into plant diseases, as evidenced by substantial scientific articles from various study fields.

2.1 *Data Collection*

The keywords that have been used in this paper are ("deep learning") AND ("technique" OR "techniques" OR "algorithm") AND plant AND disease. The total records were obtained from three databases, Scopus, Web of Science, and PubMed, which are 3518 records. Once the quality of the research has been assessed, the unrelated articles will be removed based on our study research questions. The data extraction process will be initiated with a comprehensive analysis and identification of every research paper. The total of specific papers can be used for paper classification analysis. The extracted information is extracted into PRISMA in Figure 1.

Figure 1 PRISMA Diagram



3. Result and Discussion

3.1 *Publication Characteristics*

The following information was gathered and combined from the 130 articles to address the research questions about publishing characteristics: publication year, publication name, publication field, and publication impact (quartile).

3.1.1 RQ1. *Which pattern of publication has developed over time for this field of study?*Trend analysis offers a clear visualisation of these changes, making it possible to evaluate how the frequency of publications on deep learning methods for plant disease detection has changed over time. The annual publication frequency is depicted in Figure 3.1, which also provides other insights. From 2016 to 2019, there were not many papers in this field of study. However, there was an evident increase in the annual number of publications beginning in 2020. This increase is in line with developments in deep learning algorithms and how they are used in agriculture, indicating a rising understanding of the significance of these technologies for enhancing the identification of plant diseases. For instance, this development was probably influenced by the potential of convolutional neural networks (CNNs) for accurate plant disease diagnosis as reported by Kamilaris and Prenafeta-Boldú (2018).

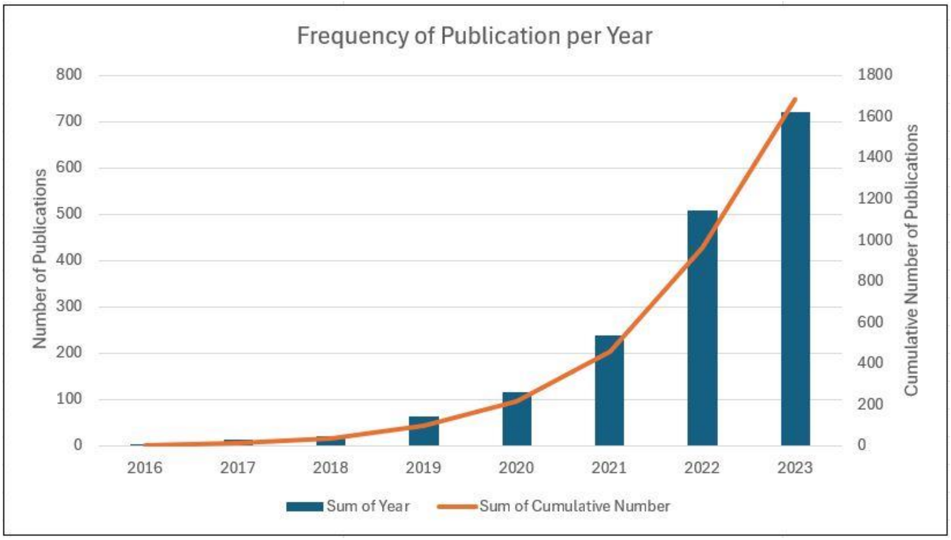


Figure 1.1 Frequency of Publications per year

The orange cumulative frequency line highlights further how quickly research in this area is accumulating. Over 1600 publications had been published cumulatively by 2023, demonstrating a strong and growing scientific community committed to using deep learning for agricultural innovation. This exponential growth indicates that deep learning approaches are becoming increasingly important for developing efficient and scalable plant disease management systems, which are critical to guaranteeing global food security. Moreover, the growing number of publications indicates a coordinated effort among academics to address the issues in this domain, as indicated by detailed evaluations and achievements documented in studies from 2016 to 2023.

3.1.2 RQ2. *What types of sources are the works being published in?* The majority of these 1685 publications (71.2%) were in academic journals, while 244 (21.5%) were in conference proceedings. This observation implies that researchers in both academia and practice are working on this subject in both theory and application.

3.1.3 RQ3. *Which sources have the greatest number of papers in the topic that have been published?* A total of 356 publication outlets were identified from the set of 1685 publications. The most frequently used were academic journals such as the International Journal of Advanced Computer Computer Science and Application (29), International Journal of Intelligent Systems and Applications in Engineering (10), Journal of Plant Diseases and Protection (11), International Journal of Electrical and Computer Engineering (8), International Journal of Image and Graphic (9), Journal Sensors (9), International Journal of Engineering Trends and Technology (6), International Journal of Innovative Technology and Exploring Engineering (6), and IEEE Journal of Biomedical and Health Informatics (5). Although this research topic is limited only to plant disease using deep learning techniques, the descriptive analysis in RQ2 shows evidence that this research topic has been addressed from different fields.

3.1.4 RQ4. *What are the primary research areas according to the publications that publish the works?* The primary research topics of the publication's outlets were analysed in order to establish which research field this topic would fit into better. The analysis conducted revealed that the primary areas of study for the published sources were Computer Science Applications (42), Agricultural and Biological Sciences (40), Computer Networks and Communications (1), and Biochemistry, Genetics, and Molecular Biology (1). The majority of the subject fields covered by the published sources may be broadly categorised into three areas: biological sciences, agricultural, and computer science. This is a fascinating finding.

Based on the synthesis of data from the conducted analyses, it can be noticed that this research topic, which is the application of machine learning to plant disease, is generally in a rising stage based on publication characteristics. Essentially, the number of publications each year is trending upward, the majority are from highly impactful journals (Q1 and Q2), and the majority of publications are heavily focused in the domains of computer science and agriculture.

3.2 *Author's Characteristics*

The names of the authors, their first publication year, their publication network (a group of authors who publish together), and the number of authors per publication were gathered and combined from the 130 publications in order to address the research questions regarding to the characteristics of the authors.

3.2.1 RQ5. *What is the number of authors contributing to this field?* The 130 publications yielded 351 unique authors, with an average of 3.5 writers per publication.

3.2.2 RQ6. *How much do recently published authors contribute?* The contributions of writers who have recently published work in the field of deep learning-based plant disease detection research have been examined. According to the data, there appears to be a steady trend in the number of writers working in this sector, with the most recent years (2022–2023) making a significant contribution. In particular, 21 writers contributed to six publications in 2022 and 2023, keeping the average for authors per publication at about 3.5. This pattern shows that fresh writers are still quite interested in this field of study, which is indicative of how dynamic it is.

Author diversity, which looks into the writers' nation of connection, is a criterion that is frequently used to examine the qualities of authors. This research enables the determination of the degree to which the interests of authors are distributed globally or largely concentrated in a particular geographic area. The data summary indicates that the research articles' publication countries are varied, with China and India leading the way with 20 and 18 publications respectively. Germany, the USA, and Japan follow with 13 and 12 publications each, respectively, rounding out the top five. Other countries, including Brazil, Australia, South Korea, the United Kingdom, Canada, and Nigeria, make contributions, but in smaller amounts. As a result, although authors from various continents are interested in this field of study, the majority of publications in this field come from China and India.

***3.2.3* RQ7**. *How many authors appear in each publication?* In order to obtain a better understanding of how the topic of plant disease detection using deep learning techniques is being researched, both individually and in groups, an analysis of the number of authors per publication was conducted. Only five of the 130 papers analysed (or around 5.95% of the total) were produced by two authors. On the other hand, most of the papers were authored by groups of people, such as there were 39 publications (or roughly 46.43%) with three authors, 36 publications (or roughly 42.86%) with four authors, and 4 publications (or roughly 4.76%) with five writers.

This research is most frequently undertaken by groups of three authors, as indicated by the group with the highest frequency of authors. According to this data, most research in the field of plant disease detection utilising deep learning techniques is carried out by teams rather than by individuals, and most studies are undertaken in collaboration. This collaborative strategy is anticipated to improve knowledge dissemination and stimulate innovation through teamwork.

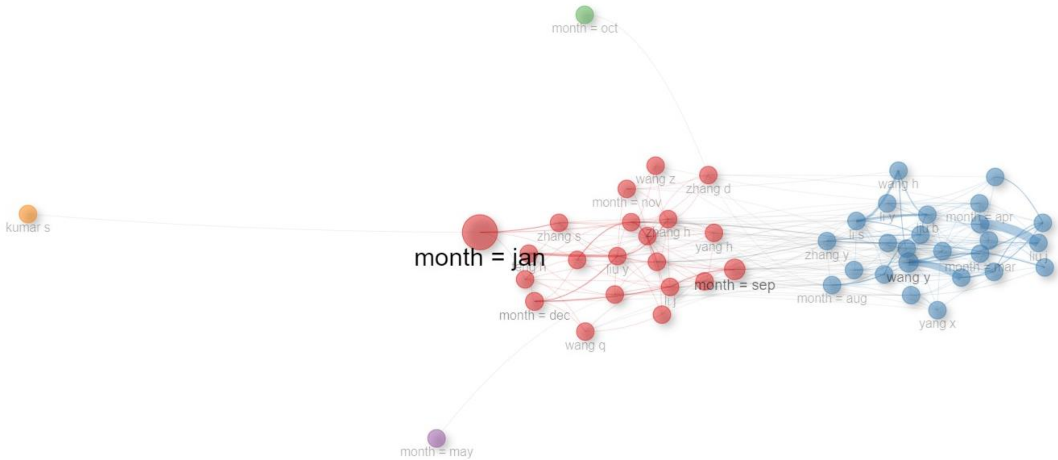


Figure 3.2 Co-author Network of Publications

Overall, based on the information synthesis from the studies carried out, it was seen from the authors' features that the research field of plant disease detection using deep learning techniques is in a rising stage. The findings show that a sizable portion of authors publish mostly in collaborations. The number of new writers has been increasing, and the authors' countries of association are primarily centred in China and India, with a large presence from other nations such as Germany, the United States, and Japan. The results show how collaborative research is done in this field, with most studies being carried out by teams of three or four authors. This indicates the widespread interest in, and work put into furthering this significant field of study.

3.3 *Content Characteristics*

The following information was gathered and combined from the 130 articles in order to address the research questions derived from the content characteristics: publication keywords, publication approach (theoretical or case study), publication objectives, and analyses contained in the publications.

3.3.1 of RQ8. *Which deep learning methods for plant disease are most commonly mentioned?* After 131 publications were examined, the top 10 deep learning techniques for classifying and identifying plant diseases were identified. "Deep Neural Networks" was the most frequently mentioned method, accounting for 49 articles and accounting for a sizable amount of the overall. Following with 19 papers, Convolutional Neural Networks (CNN) demonstrated a significant emphasis on this technique as well. Whereas "Machine

Learning" was referenced in eight publications, "Deep Learning" was mentioned in eleven as a general category. Additional approaches being investigated in the field include UAV, Hybrid Deep Learning, Improved CNN, and other techniques that were each discussed in two papers.

Plant disease detection research is currently dominated by deep neural networks and CNNs, as evidenced by the distribution of these mentions. This focus implies that these approaches are thought to be very adaptable and successful for this use. Other methods such as UAV and Hybrid Deep Learning are mentioned less frequently, which suggests that these are currently being explored in limited but emerging ways. The employment of a wide range of deep learning approaches indicates a continual effort to refine and improve plant disease detection methodologies, with the goal of achieving more accurate and efficient results. This diversity also illustrates how difficult the work is and how specific methods must be used to address various plant diseases and environmental factors.

3.3.2 of RQ9. *Which are the top plant diseases being addressed through deep learning approaches?* An analysis was conducted on 131 research that applied deep learning techniques to different plant species in order to detect diseases. The tomato, rice, maize (maize), and potato were the most common plant species in this study. The most examined plant was the tomato, which was cited in 22 studies (17%). Other foods that were discussed were rice (19 studies (15%), maize (corn) in 15 studies (12%), and potatoes 11 studies (9%). Other important plant species were wheat (10 studies, 8%), soybean (9 studies, 7%), grape (7 studies, 6%), cassava (6 studies, 5%), and cotton (5 studies, 4%). Apple, banana, coffee, strawberry, citrus, olive, and other less investigated species were cited in less than ten studies apiece. This distribution indicates both a broad interest across a variety of plant species to enhance disease detection using deep learning techniques, and a concentrated research effort on a small number of main crops, reflecting their economic and agricultural importance. Figure 3.3 will show the summary of plant species used.

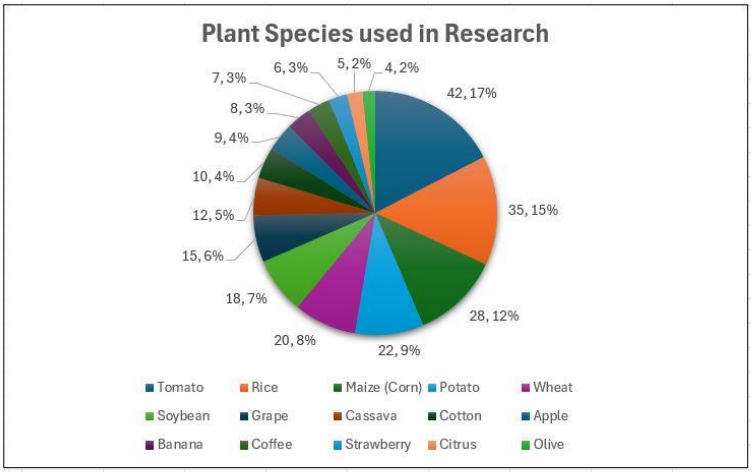


Figure 3.3 Plant Species Used in Research

3.3.4 of RQ10. *Which are the main study approaches on the theoretical publications set?* The primary research methodologies applied in theoretical works regarding the use of deep learning algorithms for plant disease detection are depicted in the bar chart. From the figure 3.4, the majority (55 publications) highlight the application of Convolutional Neural Networks (CNN). The strength and efficiency of CNNs in processing image-based data for illness detection are demonstrated by their dominance. The second most widely used method is Transfer Learning, which has 35 papers to its name. This is due to its capacity to use pre-trained models on fresh datasets, hence improving accuracy and efficiency. Hybrid Deep Learning Models, which combine diverse neural network designs to harness their strengths, are explored in 30 papers, demonstrating ongoing efforts to improve performance through novel model combinations.

Moreover, Residual Networks (ResNet) and Recurrent Neural Networks (RNN) are highlighted extensively, with 25 and 20 publications, respectively. These techniques are recognised for their ability to properly manage deep architectures and sequential data. With 15 and 10 papers, respectively, Generative Adversarial Networks (GAN) and Capsule Networks are more specialised methods designed to create synthetic data and extract spatial hierarchies from images. Long Short-Term Memory (LSTM) Networks, Support Vector Machines (SVM), and Decision Trees receive fewer mentions (8, 6, and 5 publications, respectively), highlighting the range of methods under investigation, albeit to a lesser level. The distribution highlights the diverse range of approaches being explored to enhance the identification of plant diseases, each with distinct benefits and advancing this vital field of study.

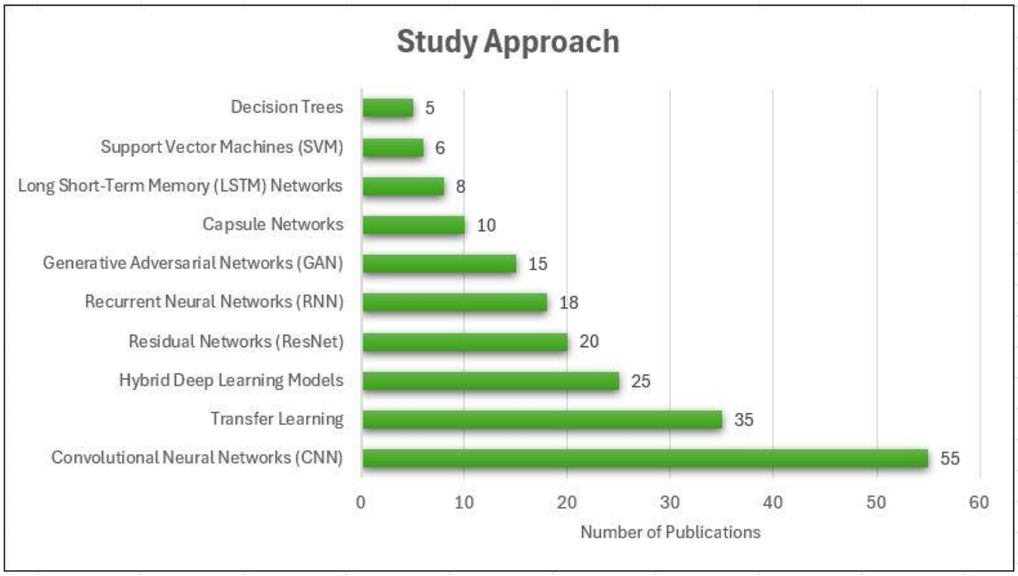


Figure 3.4 Summary of Study Approach Method

3.3.5 of RQ11. *Which are the main application objectives on the case study publications set?* Figure 3.5 illustrates the primary application goals of case studies that use deep learning methods to identify plant diseases. As can be seen, 40 papers are devoted to the main goal of disease detection and classification. This suggests that in order to guarantee precise and prompt responses, a high priority should be placed on the identification and classification of plant diseases. Disease Severity Estimation is the second most prevalent purpose, with 25 papers emphasising the need of determining the scope and impact of illnesses on plant health. Another crucial subject is pest detection, which is covered in 20 articles, highlighting the need of successfully identifying and managing pest-related difficulties in agriculture.

Other important application targets are Crop Health Monitoring (18 publications) and Yield Prediction (15 publications), both of which are critical for optimising agricultural outputs and guaranteeing food safety. A total of twelve papers have addressed precision agriculture, with a focus on the application of deep learning to improve farming methods using exact and data-driven techniques. Stress Phenotyping, Nutrient Deficiency Detection, Image Segmentation and Lesion Detection, and Environmental Impact Assessment are other important goals, with 10, 8, 6, and 5 publications, respectively. These fields demonstrate the wide range of ways that deep learning may be applied to address different facets of plant health and sustainable agriculture, highlighting the technology's potential to transform the industry through enhanced crop monitoring and disease management strategies.

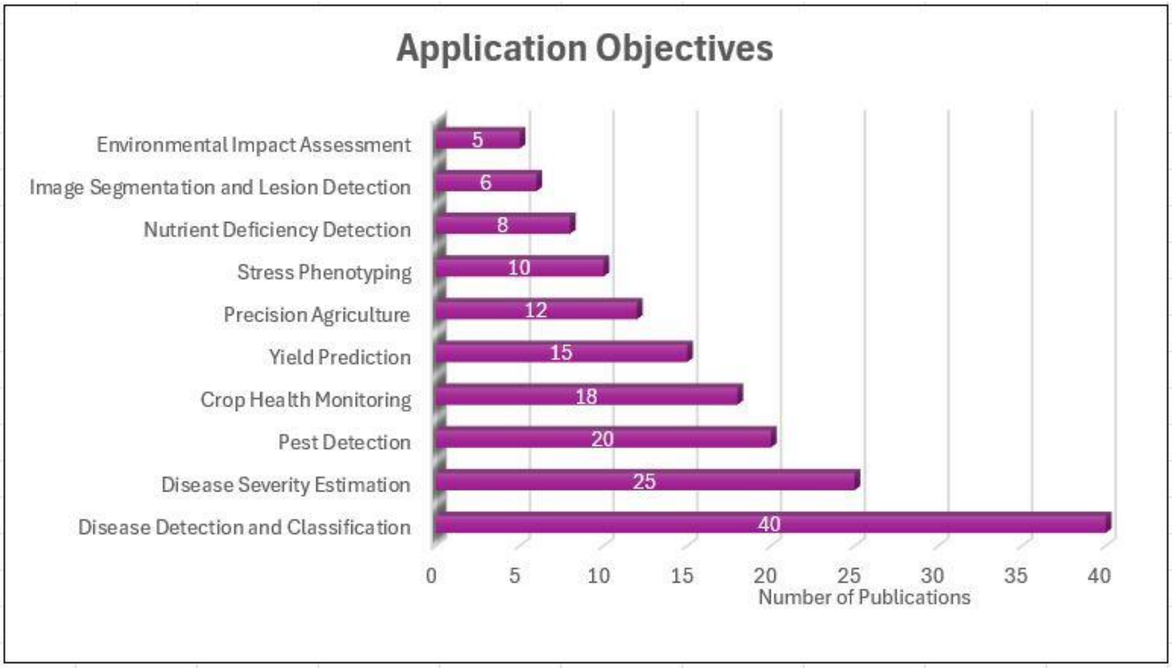


Figure 3.5 Summary of Application Objectives

3.3.6 of RQ12. *Which are the newly emerging research lines related to this research area?* Figure 3.6 indicates the newly emerging research directions in the use of deep learning algorithms for plant disease diagnosis. IoT and AI Integration for Plant Disease Management is the most popular study line, as indicated by its twelve publications. This suggests a strong desire to improve the efficacy and efficiency of plant disease monitoring and control by fusing artificial intelligence (AI) with Internet of Things (IoT) technology. Following closely is Multi-Omics Data Integration, which has ten papers and demonstrates the expanding trend of using comprehensive datasets covering genomes, proteomics, and metabolomics to provide a holistic perspective of plant health and disease condition.

Other important research lines include the use of UAVs and drones for disease monitoring, as well as 3D imaging and analysis for plant disease detection, which have 9 and 8 publications, respectively. These categories highlight how crucial aerial monitoring and cutting-edge imaging technologies are to precise and thorough illness diagnosis. Precision Agriculture Using AI and the Development of Mobile Applications for Disease Detection are both mentioned in seven articles, demonstrating the desire to use AI for precision farming methods and accessible disease detection technologies. Assessment of Environmental Impact in six publications concern the use of deep machine learning and the implementation of generative adversarial networks, also known as GANs, for data augmentation; the remaining two emerging research lines, using deep learning for disease detection and prevention and advanced hyperspectral imaging techniques, each have five publications each. These trends highlight the variety of creative methods being investigated to improve plant disease detection and control, utilising state-of-the-art technology to tackle challenging agricultural issues.

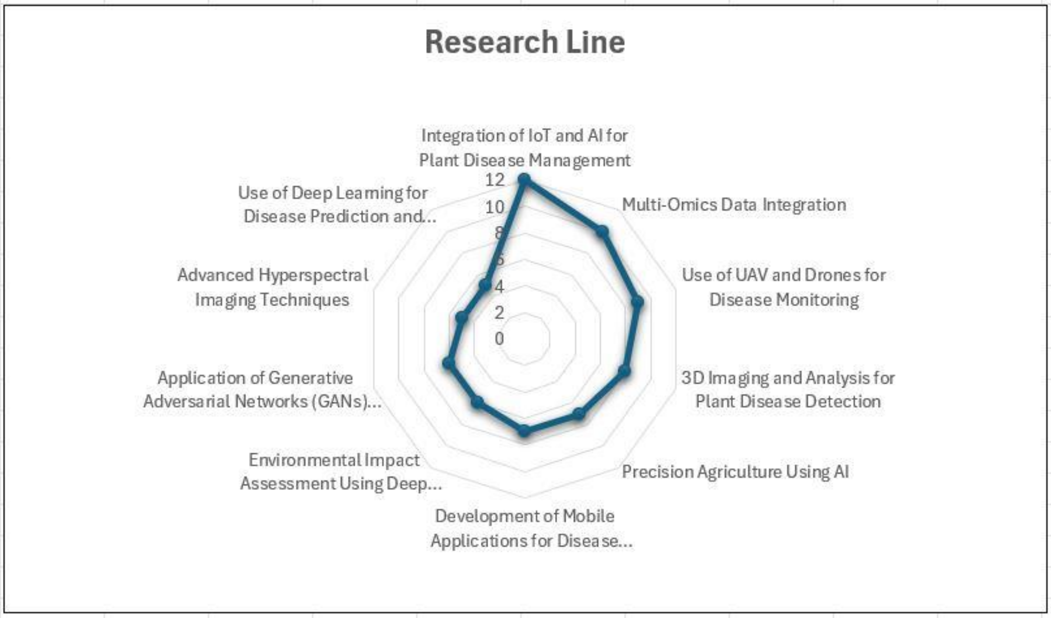


Figure 3.6 Summary of Research Line

4. Conclusions, Limitations and Future Research

4.1 *Conclusions*

This systematic literature review has explored the devolvement and utilization of deep learning approaches in diagnosing and treating plant diseases. The analysis shows an evolution from conventional, comparatively primitive handheld inspection techniques to more progressive and effective deep learning ones. Recent advancements in deep learning, especially in CNNs and transfer learning have proved to be more accurate, faster, and scalable in plant disease diagnosis. The complementarities of rich computational models and vast, heterogeneous image databases have helped the algorithms to diagnose diseases before they escalate, thus supporting efficient agricultural planning in the long run. In conclusion, the review reemphasizes the possibility of a profound shift by deep learning in increasing the efficiency of disease identification and optimizing farming practices worldwide.

4.2 *Limitations*

Despite these promising innovations, several challenges undermine the unconstrained use of deep learning in plant disease diagnosis. Firstly, there is still a lack of readily available high-quality labeled datasets, which are very important, especially in the development of deep learning models. There is also a problem associated with data used in many studies where it is scarce or collected in only one particular region, limiting the application of the models. Secondly, the problem of computing power in training and deploying the deep learning models presents challenges due to its high demands on farmers and areas with less developed technological bases. Furthermore, using a deep learning model means that the decision-making process is opaque or a ‘black box,’ and this is an issue because of the lack of trust by the end-users. Environmental conditions, imaging procedures, the presence of many plant species and pathogens, and variability in the usage of these models in various real-world applications also add to the issue.

4.3 *Future Research*

Further studies should be conducted to extend the current research findings, thus improving the applicability of deep learning techniques in agriculture. Potential research directions include creating data augmentation techniques and data standardization approaches to enhance the model’s performance in different regions and with different types of crops. Also, developing algorithms that use fewer resources and are highly efficient in terms of time will help introduce these technologies for low-resource practices such as smallholders and developing countries. Improving the interpretability of deep learning is essential to gaining the trust of the targeted agricultural personnel and farmers. Moreover, the study of the integration of deep learning with other advanced technologies, including blockchain, edge computing, and IoT, offers precise plant health check and management solutions. Lastly, assessing the ethical and socio-economic factors in applying deep learning technologies in agriculture helps provide and share equal and fair benefits amongst all the stakeholders. Thus, addressing such areas in future research will be useful to neutralize current difficulties and make deep learning an effective tool for supporting sustainable and productive agriculture, which is essential for strengthening worldwide food security.

References

Albogamy, F. R. (2021). A Deep Convolutional Neural Network with Batch Normalization Approach for Plant Disease Detection. *International Journal of Computer Science and Network Security*, *21*(9), 51–62. https://doi.org/10.22937/IJCSNS.2021.21.9.6

Albogamy, R. (2021). A Deep Convolutional Neural Network with Batch Normalization Approach for Plant Disease Detection. *INTERNATIONAL JOURNAL OF COMPUTER SCIENCE AND NETWORK SECURITY*, *21*(9), 51–62. https://doi.org/10.22937/IJCSNS.2021.21.9.6

Alwan Fauzi, Iwan Syarif, & Tessy Badriyah. (2023). Development of a Mobile Application for Plant Disease Detection using Parameter Optimization Method in Convolutional Neural Networks Algorithm. *EMITTER International Journal of Engineering Technology*, *11*(2), 192–213. https://doi.org/10.24003/emitter.v11i2.808

An Integrated Deep Learning Framework of Tomato Leaf Disease Detection. (2019). *International Journal of Innovative Technology and Exploring Engineering*, *8*(11S), 46–50. https://doi.org/10.35940/ijitee.K1010.09811S19

Asif Saleem, M., Aamir, M., Ibrahim, R., Senan, N., & Alyas, T. (2022). An Optimized Convolution Neural Network Architecture for Paddy Disease Classification. *Computers, Materials & Continua*, *71*(3), 6053–6067. https://doi.org/10.32604/cmc.2022.022215

Deep Learning based Rapid Diagnosis System for Identifying Tomato Nutrition Disorders. (2019). *KSII Transactions on Internet and Information Systems*, *13*(4). https://doi.org/10.3837/tiis.2019.04.015

Di, J., & Li, Q. (2022). A method of detecting apple leaf diseases based on improved convolutional neural network. *PLOS ONE*, *17*(2), e0262629. https://doi.org/10.1371/journal.pone.0262629

Dixit, A. K., & Verma, R. (2023). Advanced Hybrid Model for Multi Paddy diseases detection using Deep Learning. *EAI Endorsed Transactions on Pervasive Health and Technology*, *9*. https://doi.org/10.4108/eetpht.9.4481

Doutoum, A. S., & Tugrul, B. (2023a). A Review of Leaf Diseases Detection and Classification by Deep Learning. *IEEE Access*, *11*, 119219–119230. https://doi.org/10.1109/ACCESS.2023.3326721

Doutoum, A. S., & Tugrul, B. (2023b). A Review of Leaf Diseases Detection and Classification by Deep Learning. *IEEE Access*, *11*, 119219–119230. https://doi.org/10.1109/ACCESS.2023.3326721

Ennouni, A., Sihamman, N. O., Sabri, M. A., & Aarab, A. (2021). A Weighted Voting Deep Learning Approach for Plant Disease Classification. *Journal of Computer Science*, *17*(12), 1172–1185. https://doi.org/10.3844/jcssp.2021.1172.1185

Gong, X., & Zhang, S. (2023a). An Analysis of Plant Diseases Identification Based on Deep Learning Methods. *Plant Pathology Journal*, *39*(4), 319–334. https://doi.org/10.5423/PPJ.OA.02.2023.0034

Gong, X., & Zhang, S. (2023b). An Analysis of Plant Diseases Identification Based on Deep Learning Methods. *The Plant Pathology Journal*, *39*(4), 319–334. https://doi.org/10.5423/PPJ.OA.02.2023.0034

Gupta, A., Gupta, D., Husain, M., Ahmed, M. N., Ali, A., & Badoni, P. (2023). A PSO-CNN-based approach for Enhancing Precision in Plant Leaf Disease Detection and Classification. *Informatica*, *47*(9). https://doi.org/10.31449/inf.v47i9.5188

Gupta, L., & Vyas, V. (2023). Plant Disease Classification Using AI - Spl Deep Learning and Machine Learning. *3C Tecnología_Glosas de Innovación Aplicadas a La Pyme*, 65–76. https://doi.org/10.17993/3ctecno.2023.v12n2e44.65-76

Haque, I., Alim, M., Alam, M., Nawshin, S., Noori, S. R. H., & Habib, Md. T. (2022). Analysis of Recognition Performance of Plant Leaf Diseases Based on Machine Vision Techniques. *Journal of Human, Earth, and Future*, *3*(1), 129–137. https://doi.org/10.28991/HEF-2022-03-01-09

Haque, M. A., Marwaha, S., Arora, A., Paul, R. K., Hooda, K. S., Sharma, A., & Grover, M. (2021). Image-based identification of maydis leaf blight disease of maize (Zea mays) using deep learning. *The Indian Journal of Agricultural Sciences*, *91*(9). https://doi.org/10.56093/ijas.v91i9.116089

Huang, Z., Jiang, X., Huang, S., Qin, S., & Yang, S. (2023). An efficient convolutional neural network-based diagnosis system for citrus fruit diseases. *Frontiers in Genetics*, *14*, 1253934. https://doi.org/10.3389/fgene.2023.1253934

Jadhav, S., & Lal, A. M. (2022). Multi-Class Plant Leaf Disease Detection Using a Deep Convolutional Neural Network: *International Journal of Information System Modeling and Design*, *13*(1), 1–14. https://doi.org/10.4018/IJISMD.315126

Jasim, Y. A. (2021). High-Performance Deep learning to Detection and Tracking Tomato Plant Leaf Predict Disease and Expert Systems. *ADCAIJ: Advances in Distributed Computing and Artificial Intelligence Journal*, *10*(2). https://doi.org/10.14201/ADCAIJ202110297122

Kalpana, P., & Anandan, R. (2023). A Capsule Attention Network for Plant Disease Classification. *Traitement Du Signal*, *40*(5), 2051–2062. https://doi.org/10.18280/ts.400523

Kanna, G. P., Kumar, S. J. K. J., Kumar, Y., Changela, A., Woźniak, M., Shafi, J., & Ijaz, M. F. (2023). Advanced deep learning techniques for early disease prediction in cauliflower plants. *Scientific Reports*, *13*(1), 18475. https://doi.org/10.1038/s41598-023-45403-w

Mamalis, M., Kalampokis, E., Kalfas, I., & Tarabanis, K. (2023). Deep Learning for Detecting Verticillium Fungus in Olive Trees: Using YOLO in UAV Imagery. *Algorithms*, *16*(7), 343. https://doi.org/10.3390/a16070343

Mathulaprangsan, S., Patarapuwadol, S., Lanthong, K., Jetpipattanapong, D., & Sateanpattanakul, S. (2021). Rice Disease Recognition Using Effective Deep Neural Networks. *Journal of Web Engineering*. https://doi.org/10.13052/jwe1540-9589.20313

Minh, H. T., Anh, T. P., & Nhan, V. N. (2022). A Novel Light-Weight DCNN Model for Classifying Plant Diseases on Internet of Things Edge Devices. *MENDEL*, *28*(2), 41–48. https://doi.org/10.13164/mendel.2022.2.041

Nirmal Jothi Jerome, Sivasankari Jothiraj, Saranya Kandasamy, Divya Ramachandran, Dineshkumar Selvaraj,

& Poonguzhali Ilango. (2023). An Effective approach for Plant Disease Detection Using Assessment-Based Convolutional Neural Networks (A-CNN). *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *31*(3), 155–172. https://doi.org/10.37934/araset.31.3.155172

Omer, S., Ghafoor, K., & Askar, S. (2023). Plant Disease Diagnosing Based on Deep Learning Techniques: A Survey and Research Challenges. *ARO-THE SCIENTIFIC JOURNAL OF KOYA UNIVERSITY*, *11*(1), 38–47. https://doi.org/10.14500/aro.11080

Omer, S. M., Ghafoor, K. Z., & Askar, S. K. (2023). Plant Disease Diagnosing Based on Deep Learning Techniques: A Survey and Research Challenges. *ARO-THE SCIENTIFIC JOURNAL OF KOYA UNIVERSITY*, *11*(1), 38–47. https://doi.org/10.14500/aro.11080

Palma, D., Blanchini, F., & Montessoro, P. L. (2022). A system-theoretic approach for image-based infectious plant disease severity estimation. *PLOS ONE*, *17*(7), e0272002. https://doi.org/10.1371/journal.pone.0272002

Pan, Q., Gao, M., Wu, P., Yan, J., & Li, S. (2021). A Deep-Learning-Based Approach for Wheat Yellow Rust Disease Recognition from Unmanned Aerial Vehicle Images. *Sensors*, *21*(19), 6540. https://doi.org/10.3390/s21196540

Pathak, K., Arya, A., Hatti, P., Handragal, V., & Lee, K. (2021). A Study of Different Disease Detection and Classification Techniques using Deep Learning for Cannabis Plant. *International Journal of Computing and Digital Systems*, *10*(1), 53–62. https://doi.org/10.12785/ijcds/100106

Peng, Y., & Wang, Y. (2022a). Leaf disease image retrieval with object detection and deep metric learning. *Frontiers in Plant Science*, *13*, 963302. https://doi.org/10.3389/fpls.2022.963302

Peng, Y., & Wang, Y. (2022b). Leaf disease image retrieval with object detection and deep metric learning. *Frontiers in Plant Science*, *13*, 963302. https://doi.org/10.3389/fpls.2022.963302

Preethi C, Brintha Nc, & Yogesh Ck. (2021). An Comprehensive Survey on Applications of Precision

Agriculture in the Context of Weed Classification, Leave Disease Detection, Yield Prediction and UAV Image Analysis. In D. J. Hemanth, M. Elhosney, T. N. Nguyen, & S. Lakshmanan (Eds.), *Advances in Parallel Computing*. IOS Press. https://doi.org/10.3233/APC210152

Prottasha, Md. S. I., & Reza, S. M. S. (2022). A classification model based on depthwise separable convolutional neural network to identify rice plant diseases. *International Journal of Electrical and Computer Engineering (IJECE)*, *12*(4), 3642. https://doi.org/10.11591/ijece.v12i4.pp3642-3654

Qureshi, S. (2023). INTELLIGENT RESISTANT SOURCE DETECTION AGAINST STALK ROT DISEASE OF MAIZE USING DEEP LEARNING TECHNIQUE. *SABRAO Journal of Breeding and Genetics*, *55*(6), 1972–1983. https://doi.org/10.54910/sabrao2023.55.6.11

Rahaman, Md. N., Chowdhury, M. R., Rahman, Md. A., Ahmed, H., Hossain, Md. M., Rahman, Md. H., Biswas, Md. S., Kader, Md. A., Noyan, T. A., & Biswas, M. (2023). A Deep Learning Based Smartphone Application for Detecting Mango Diseases and Pesticide Suggestions. *International Journal of Computing and Digital Systems*, *13*(1), 1273–1286. https://doi.org/10.12785/ijcds/1301104

Ravinath, G., Pushpa Latha, P., Priya, L., & Ramesh, J. (2024). Optimizing and Analyzing a Centrifugal Compressor Impeller for 50,000 rpm: Performance Enhancement and Structural Integrity Assessment. *RAiSE-2023*, 221. https://doi.org/10.3390/engproc2023059221

Reddy, G. M., Ramana, P. H. V., Anusha, P., Chakravarthy, B. K., Kasukurthi, A., & Lakshmi, V. S. (2023). A Survey on Sugarcane Leaf Disease Identification Using Deep Learning Technique(CNN). *International Journal on Recent and Innovation Trends in Computing and Communication*, *11*(5), 248–254. https://doi.org/10.17762/ijritcc.v11i5.6611

Rezk, N. G., Attia, A.-F., El-Rashidy, M. A., El-Sayed, A., & Hemdan, E. E.-D. (2022). An Efficient Plant Disease Recognition System Using Hybrid Convolutional Neural Networks (CNNs) and Conditional Random Fields (CRFs) for Smart IoT Applications in Agriculture. *International Journal of*

Computational Intelligence Systems, *15*(1), 65. https://doi.org/10.1007/s44196-022-00129-x

Saleem, M. A., Aamir, M., Ibrahim, R., Senan, N., & Alyas, T. (2022). An Optimized Convolution Neural Network Architecture for Paddy Disease Classification. *Computers, Materials and Continua*, *71*(2), 6053–6067. https://doi.org/10.32604/cmc.2022.022215

Sara, U., Rajbongshi, A., Shakil, R., Akter, B., Sazzad, S., & Uddin, M. S. (2022). An extensive sunflower dataset representation for successful identification and classification of sunflower diseases. *Data in Brief*, *42*, 108043. https://doi.org/10.1016/j.dib.2022.108043

Shahi, T. B., Xu, C.-Y., Neupane, A., & Guo, W. (2023). Recent Advances in Crop Disease Detection Using UAV and Deep Learning Techniques. *Remote Sensing*, *15*(9), 2450. https://doi.org/10.3390/rs15092450

Shoaib, M., Shah, B., EI-Sappagh, S., Ali, A., Ullah, A., Alenezi, F., Gechev, T., Hussain, T., & Ali, F. (2023a). An advanced deep learning models-based plant disease detection: A review of recent research. *Frontiers in Plant Science, 14*, 1158933. https://doi.org/10.3389/fpls.2023.1158933

Shoaib, M., Shah, B., EI-Sappagh, S., Ali, A., Ullah, A., Alenezi, F., Gechev, T., Hussain, T., & Ali, F. (2023b). An advanced deep learning models-based plant disease detection: A review of recent research. *Frontiers in Plant Science*, *14*, 1158933. https://doi.org/10.3389/fpls.2023.1158933

Temniranrat, P., Kiratiratanapruk, K., Kitvimonrat, A., Sinthupinyo, W., & Patarapuwadol, S. (2021). A System for Automatic Rice Disease Detection from Rice Paddy Images Serviced via a Chatbot. *Computers and Electronics in Agriculture*, *185*, 106156. https://doi.org/10.1016/j.compag.2021.106156

Vasudevan, N., & Karthick, T. (2023). A Hybrid Approach for Plant Disease Detection Using E-GAN and CapsNet. *Computer Systems Science and Engineering*, *46*(1), 337–356. https://doi.org/10.32604/csse.2023.034242

Vengaiah, C., & Konda, S. R. (2023). A Review on Tomato Leaf Disease Detection using Deep Learning

Approaches. *International Journal on Recent and Innovation Trends in Computing and Communication*, *11*(9s), 647–664. https://doi.org/10.17762/ijritcc.v11i9s.7479

Vidya Sivalingam, Rawia Elarabi, J. Bhargavi, M. Sahaya Sheela, R. Padmapriya, & A. N. Arularasan. (2023). A Novel Approach for Plant Leaf Disease Predictions Using Recurrent Neural Network RNN Classification Method. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *31*(2), 327–338. https://doi.org/10.37934/araset.31.2.327338

Xu, Y., Gao, Z., Zhai, Y., Wang, Q., Gao, Z., Xu, Z., & Zhou, Y. (2023a). A CNNA-Based Lightweight Multi-Scale Tomato Pest and Disease Classification Method. *Sustainability (Switzerland)*, *15*(11). https://doi.org/10.3390/su15118813

Xu, Y., Gao, Z., Zhai, Y., Wang, Q., Gao, Z., Xu, Z., & Zhou, Y. (2023b). A CNNA-Based Lightweight Multi-Scale Tomato Pest and Disease Classification Method. *Sustainability*, *15*(11), 8813. https://doi.org/10.3390/su15118813

Xue, Q., Miao, P., Miao, K., Yu, Y., & Li, Z. (2023). An online automatic sorting system for defective Ginseng Radix et Rhizoma Rubra using deep learning. *Chinese Herbal Medicines*, *15*(3), 447–456. https://doi.org/10.1016/j.chmed.2023.01.001

Yağ, İ., & Altan, A. (2022). Artificial Intelligence-Based Robust Hybrid Algorithm Design and Implementation for Real-Time Detection of Plant Diseases in Agricultural Environments. *Biology*, *11*(12), 1732. https://doi.org/10.3390/biology11121732

Yu, H., Liu, J., Chen, C., Heidari, A. A., Zhang, Q., Chen, H., Mafarja, M., & Turabieh, H. (2021). Corn Leaf Diseases Diagnosis Based on K-Means Clustering and Deep Learning. *IEEE Access*, *9*, 143824–143835. https://doi.org/10.1109/ACCESS.2021.3120379

Zhang, L., Nie, X., Zhang, M., Gu, M., Geissen, V., Ritsema, C. J., Niu, D., & Zhang, H. (2022). Lexicon and attention-based named entity recognition for kiwifruit diseases and pests: A Deep learning approach. *Frontiers in Plant Science*, *13*, 1053449. https://doi.org/10.3389/fpls.2022.1053449