



Advances in Automated Citrus Disease Detection and Classification: A Comprehensive Survey of Image Processing, Machine Learning, and Deep Learning Techniques

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Abstract- Citrus fruits, particularly oranges, are among the most widely cultivated and economically important fruits worldwide. They are highly valued for their rich nutritional content, including vitamins, minerals, antioxidants, and dietary fiber, which contribute significantly to human health. However, the production and commercialization of citrus fruits are severely affected by various diseases that reduce both yield and fruit quality. These diseases impact not only the leaves and stems but also the fruits, leading to economic losses for growers and suppliers. To address these challenges, researchers have increasingly adopted machine vision and artificial intelligence (AI)-based approaches for citrus disease detection and fruit grading. Between 2010 and 2024, numerous studies have explored the use of image processing, machine learning, and deep learning techniques to identify disease symptoms in citrus leaves and fruits and to classify fruits based on quality attributes such as size, shape, texture, and skin color. Advanced image acquisition systems combined with feature extraction methods have enabled accurate and rapid assessment of citrus health and quality. Recent developments in machine learning algorithms, including Support Vector Machines (SVM), Random Forests (RF), Artificial Neural Networks (ANN), Convolutional Neural Networks (CNN), and transfer learning models, have demonstrated high accuracy in citrus disease classification. Similarly, machine vision systems have been successfully employed for automated fruit grading, reducing human intervention and improving consistency in quality assessment. These technologies offer significant advantages in terms of speed, precision, scalability, and cost-effectiveness compared with traditional manual inspection methods. Despite these advancements, several challenges remain. Many existing studies focus on a limited range of citrus diseases and are often conducted under controlled laboratory conditions. The performance of disease detection and grading systems can be affected by variations in illumination, background complexity, camera orientation, fruit occlusion, and environmental factors such as dust and moisture. Furthermore, the availability of large, diverse, and well-annotated datasets remains a significant challenge for developing robust and generalizable models.

Keywords- Citrus Disease Detection, Plant Disease Detection, Deep learning, Machine learning, Citrus Disease, CNN, Feature Extraction, Segmentation



I INTRODUCTION

Citrus fruits are among the most important horticultural crops cultivated worldwide and play a significant role in global agricultural production and trade. Common citrus fruits such as oranges, lemons, mandarins, grapefruits, and limes are widely consumed due to their rich nutritional value, including vitamins, minerals, antioxidants, and dietary fiber. Citrus fruits contribute substantially to human health by enhancing immunity, supporting digestion, and reducing the risk of various chronic diseases. Owing to their high economic and nutritional importance, maintaining citrus fruit quality and productivity has become a major concern for growers, researchers, and agricultural industries [1].

Despite their significance, citrus crops are highly susceptible to various diseases, including citrus canker, citrus greening (Huanglongbing), black spot, anthracnose, melanose, and scab. These diseases affect leaves, stems, branches, and fruits, resulting in reduced yield, inferior fruit quality, and substantial economic losses. Traditional disease detection methods primarily rely on visual inspection by agricultural experts, which is time-consuming, labor-intensive, subjective, and often ineffective for large-scale orchards. Similarly, fruit grading and quality assessment are generally performed manually, leading to inconsistencies and increased operational costs [2-3].

Recent advancements in computer vision, machine learning, and artificial intelligence have transformed agricultural monitoring systems by enabling automated disease detection and fruit grading. Image processing techniques can identify disease symptoms from citrus leaves and fruits, while machine learning algorithms classify diseases and assess fruit quality based on visual characteristics such as color, texture, shape, and size. Deep learning models, particularly Convolutional Neural Networks (CNNs), have demonstrated remarkable performance in agricultural image analysis, providing accurate and efficient solutions for disease recognition and quality evaluation. Several studies have reported successful applications of machine learning techniques such as Support Vector Machines (SVM), Random Forest (RF), Artificial Neural Networks (ANN), and deep learning architectures for citrus disease classification. Similarly, automated fruit grading systems have been developed to improve sorting accuracy and reduce dependence on manual inspection. Recent research has further explored the integration of edge computing, Internet of Things (IoT) devices, hyperspectral imaging, and unmanned aerial vehicles (UAVs) to enhance real-time monitoring and decision-making capabilities in citrus farming. According to [4] machine vision technologies have significantly improved citrus disease prediction and fruit grading accuracy, although challenges related to environmental variability and dataset limitations remain. [5] highlighted the effectiveness of deep learning and hyperspectral imaging for citrus disease detection, while [6] demonstrated the practical applicability of automated fruit grading systems using adaptive deep learning frameworks. [7] reported that

attention-based deep learning models achieved disease classification accuracies exceeding 98% under complex orchard conditions. Furthermore, recent reviews by [8] emphasized the growing importance of explainable artificial intelligence, vision-language models, and fully automated agricultural monitoring systems for future citrus disease management.

Although significant progress has been achieved, several research challenges remain. Most existing studies focus on a limited number of diseases and are conducted under controlled conditions. The performance of machine vision systems can be affected by variations in illumination, background complexity, camera positioning, fruit occlusion, and environmental noise. Moreover, the lack of large-scale, diverse, and standardized datasets limits the generalizability of developed models across different geographic regions and citrus varieties.

Therefore, there is a growing need for robust, intelligent, and fully automated citrus disease detection and fruit grading systems capable of operating effectively under real-world agricultural conditions. Future research should focus on integrating advanced deep learning techniques, multimodal sensing technologies, IoT-based monitoring systems, and explainable AI frameworks to improve accuracy, reliability, and practical deployment. Such advancements can support sustainable citrus production, reduce economic losses, and enhance the overall efficiency of modern precision agriculture[9-10].

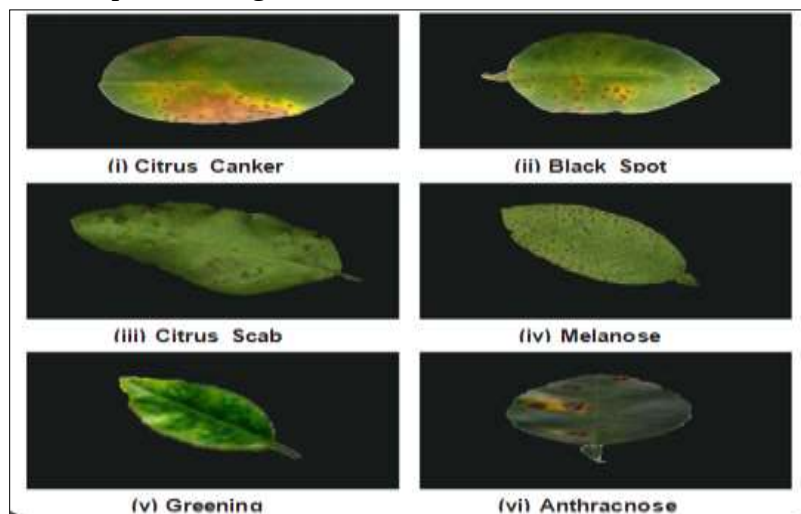


Fig. 1 Samples of citrus diseases

Because of this, this review will only talk about the image processing techniques used to identify illnesses and pests using photos taken in visible light. Most of the time, the signs of plant diseases are easy to see on the plant that has them. It is conceivable to build algorithms for image processing that will allow these diseases to be diagnosed quickly, accurately, and at a low cost from standard digital photos. In recent years, a lot of survey



studies have been written for automatically identifying leaf diseases. In the 2016 work by [11] the authors looked at many ways to segment and extract features, techniques such as principal component analysis (PCA), wavelet transform, Gabor filter, and threshold-based, edge-based, and region-based analysis.[12] explains how to perform segmentation and get rid of the backdrop in the scene.

They employed a color segmentation method that involved masking green pixels to get rid of the background, and then they used an Otsu thresholding method on the image that had the infection. They start by pulling out the diseases' color, shape, and texture. Then, they utilize a support vector machine (SVM) classifier to figure out how well the diseases were put into groups. In another survey, image-based techniques to plant segmentation were briefly looked at [13] survey focuses on three strategies: color-based segmentation, threshold-based segmentation, and learning-based segmentation. In the work of [14], the authors talked about different ways to use image processing to find diseases in leaves. In [15], experts talked about eleven different plant diseases. Plants are susceptible to a variety of conditions, including late scorch, bacterial spot, fungal spot, sunburn, early and late blight caused by sooty mould, and other diseases. Some of these conditions can be fatal. The support vector machine (SVM) is used to determine the properties of the texture, such as homogeneity, contrast, energy, cluster shading, and cluster prominence, so that diseases can be organized into groups. These features allow for the texture to be analyzed. We are offering a comprehensive taxonomy of citrus illnesses because of issues that have been found in prior studies. This taxonomy covers preprocessing, segmentation, feature extraction, feature selection, and classification, as well as the challenges, rewards, and downsides associated with each stage individually. In addition to this, there should be a debate on the manner in which the various approaches to improving the accuracy of detection and classification are distinct from one another[16].

II CITRUS DISEASES AND THEIR SYMPTOMS

Citrus plants can get sick from a number of different things. Most of the time, the diseases show up on the leaves and the flowers. In table 1, the citrus leaf diseases and their symptoms are explained in detail, and figure 1 shows what the diseases look like.

Table 1. Citrus Leaf Diseases

Diseases	Symptoms	Pathogens
Greasy Spot	"Yellow, dark brown, and even black spots can be seen on the underside of the leaf. As these yellow spots get darker, more of them will start to show up on the top of the leaf. There's a chance that the leaves will fall off too fast.[6]	Mycosphaere lla citri

Citrus Leaf miner	The females lay their eggs on the back of the leaf. When the eggs hatch, they turn into larvae. When the larvae hatch, they start to eat by making shallow holes in the leaves that look like snakes. The disease is shown by leaves that are wrinkly and curled. Pieces of food or trash are stuck in the ducts.[6]	Phyllocnistis citrella
Melrose	"There are tiny brown dots with a golden ring around them on the leaf's surface. As the disease gets worse, a thick liquid comes out of the spot, dries out, gets stiffer, and makes the leaf look like it is made of sandpaper. There's a chance that the leaves will fall off too fast.[7]	Diaporthe citri
Physiological Disorders	"The leaves can turn yellow if they don't have enough magnesium, iron, or zinc, or if chemicals hurt them"[8].	Wind, intense sunlight, nutrient deficiencies, herbicide toxicity
Sooty Mold	"Mites eat the cells that make up the rind of the fruit, which hurts the fruit. When the fruit is young, the damaged cells turn dark (this is called "bronzing"). When the fruit is fully grown, the damaged cells turn rusty and feel rough (this is called "sharkskin").[8]	Capnodium spp
Black Spot Canker	"The impacts of this fungus are likely to be felt by citrus plants growing in subtropical regions everywhere.[9] "Symptoms of citrus canker include brown patches on the leaves, which are frequently accompanied by an oily [10]	Phyllosticta citricarpa Xanthomonas axonopodis.



Fig. 2. Different types of Citrus Fruit diseases (a) anthracnose (b) Blackspot (c) canker (d) greening (e) healthy (f) scab

III CITRUS FRUIT GRADING

For the purposes of quality control, each and every citrus fruit is subjected to an inspection, during which they are judged on the basis of their size, development, and the presence or absence of any abnormalities. According to the conventional method of quantifying, the size of citrus fruit is determined by its total mass. Before the bundles are put together, the estimation is carried out physically by weighing each individual citrus fruit to get a standard size[17].

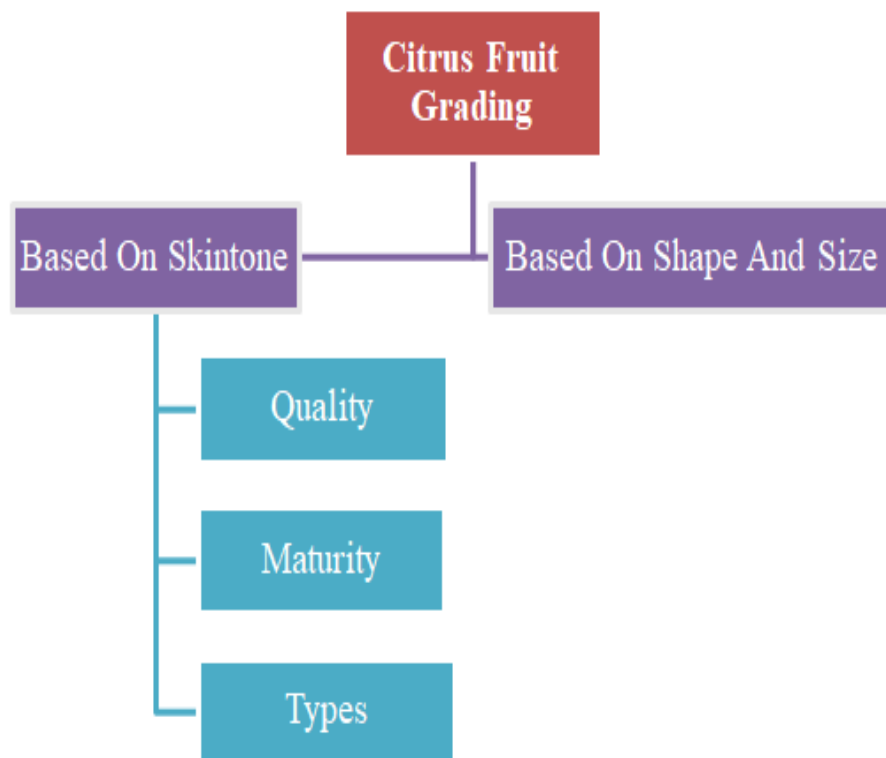


Fig.3. Grading of Fruits

This manual measuring method is not only inefficient but also time-consuming and cumbersome [18]. As a result, the development of a prototype for citrus fruit classification is essential [19]. The importance of size and fault grading when it comes to citrus products cannot be overstated. The grading of citrus fruits also takes into consideration the shape of the fruit itself. The state of the citrus fruits was determined by applying the heuristic shape separator approach, and shape numbers were discovered for the myriad of various organic products that were manufactured. The majority of the approaches taken to arrive at the findings were conceptually comparable to the ways in which people arrive at decisions [20]. The system performed disassembles the pictures of the citrus fruits in order to identify their characteristics and arrange them in a specific hierarchy.

Some of the methods that it used to do this were shading distance, linear discriminant analysis (LDA), and probability distribution function (PDF). Using the Probability Distribution Function (PDF), this was done. [21]

Recently, some researchers have been making use of computer vision to carry out a variety of computations for the purpose of organizing and reviewing [22]. The grading of fruits is accomplished through the application of decision tree techniques, artificial neural networks, key-value networks, back propagation algorithms, Bayes algorithms, and support vector machines [23]. Numerous academic articles have been written and published on the topic of citrus fruit grading. The first criteria for classifying citrus fruits are their size and form, and the second is their coloration. Also, samples of citrus fruits are shown based on how good they are and samples of citrus fruits are shown based on what kind they are.

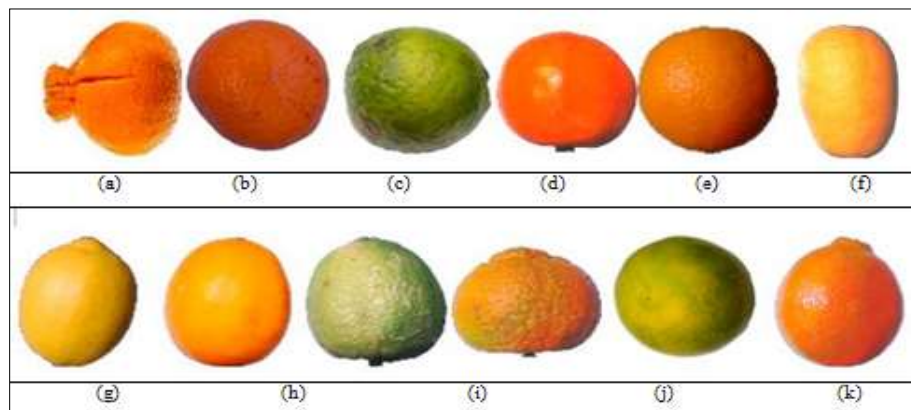


Fig. 4. Different types of Citrus Fruits (a) Bergamout1, (b) Bergamout2, (c) Bitter, (d) Clementine, (e) Kinnow, (f) Kumquat, (g) Lemon, (h) Lemon Meyer, (i) Limes, (j) Mandarin, (k) Sweet, (l) Tangelo

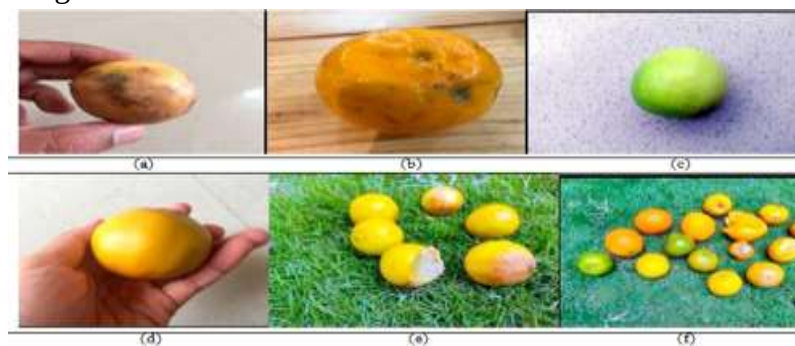


Fig. 5. Different citrus fruits based on their quality (a) Lime bad quality, (b) Orange bad quality, (c) Lime good quality, (d) Orange good quality, (e) Lime mixed quality, (f) Orange mixed quality



IV DETECTION OF CITRUS DISEASES BASED ON MACHINE VISION

Researchers are very interested in making a way for fruit diseases to be diagnosed automatically. This is due to the fact that the conventional method is labor-intensive and calls for an in-depth knowledge of the disease's biology. Machine vision methods can be used to figure out what's wrong with sick citrus. H. Ali et al. were the ones who found the greening infection in kinnow and mandarin fruit for the first time in 2017 [24]. To tell the sick area apart, a formula was used that was based on the difference in the colour E. In addition to a colour histogram, texture traits were used to put diseases into groups. To achieve a 99.9% accuracy level, they employed a variety of methods, such as fine KNN, cubic SVM, boosted tree, and bag of trees, among others. As a direct result of the study done by [25], there is now a way to accurately diagnose problems like Black Spot and Citrus Scab. In their study, they look at the processes of preparation, segmentation, feature extraction, and classification. K-means grouping is the algorithm that is utilised for the segmentation process, and for classification, the SVM and KNN algorithms are used [26].

In the past few years, Muhammad Sharif and his coworkers [27] have come up with a way to identify and classify diseases that is a mix of two different approaches. Melanose, black patches, canker, and greening are only a few of the problems that can occur. In order to categorize citrus diseases, the relevant features are fed into Multiclass SVM, also known as M-SVM. A classification accuracy of 95.8% was achieved using the strategy that was proposed. This includes the following networks: AlexNet, GoogLeNet, Inception v3, ResNet-50, ResNet-101, and SqueezeNet. (GY) were the CNN architectures that were put through their paces in an effort to correctly detect Grapevine yellow. They found that ResNet-50 was the most successful model when they compared it in terms of accuracy as well as the expenses associated with training. [28] Provided an approach that can be used to detect Huanglongbing illness. In addition to that, architectures such as GoogLeNet and VGG were utilized. With a success percentage of 99.53%, VGG had the highest degree of precision. "Recognition and forecasting of the gummosis disease in citrus trees throughout time is possible, as stated in the 2018 study by [29]. In order to conduct an analysis of their data, they utilised techniques such as support vector regression (SVR) and multilinear regression (MLR) [31]. [32] were able to identify the spectral signatures of Huanglongbing (HLB), melanose, oleocellosis (oil spot), and wind scar, Leaf miner, and dust mites." In this study, we present a method known as ant colony optimization (ACO), as well as some notions about variable selection. First of its kind, researchers have developed a reliable method for diagnosing citrus huanglongbing (HLB) disease. A number of different artificial intelligence methods, including as decision trees, support vector machines (SVMs), k-nearest neighbors', and direct discriminant examinations, can be used to locate groupings of sick individuals. According to the findings, essential hyper spectral reflectance has the potential to be utilized in the precise classification of items. When testing for three-way classification accuracy, the SVM scored 90.8%, while when testing for two-way classification (healthy versus asymptotic HLB leaves), it scored 96.0%. According to research published in 2019 by [31] diseases can be utilized to



distinguish between citrus fruits and leaves. All of these conditions are regarded to be illnesses: black spot, canker, scab, greening, and melanose. Donations of Toys for Children in Need Citrus variegated chlorosis, sooty form, leprosy, and citrus variegated leprosy[33].

[34] Conducted a systematic review of machine vision techniques for citrus disease detection and fruit grading. The study analyzed methods developed between 2010 and 2021 and reported that machine learning and deep learning algorithms have significantly improved disease classification and fruit quality assessment. The authors highlighted challenges related to environmental variability and limited datasets while recommending the development of more robust and automated systems.

[35] Presented a comprehensive review of image acquisition, preprocessing, feature extraction, and classification methods for citrus disease detection. The study found that hyperspectral imaging, CNN-based models, and Support Vector Machines (SVM) are among the most effective approaches for disease identification and classification.

[36] Developed a real-time citrus fruit grading and sorting machine using a computer vision-based adaptive deep learning model called SortNet. The proposed system successfully automated fruit inspection and classification, demonstrating high accuracy and reduced dependence on manual labor in post-harvest operations.

[37] Proposed a smart citrus disease detection framework integrating deep learning with edge computing technologies. The model combined CNN and LSTM architectures to enable efficient disease diagnosis in real-time agricultural environments while addressing computational limitations of field devices.

[38] Introduced a Hybrid Attention Network (HaNet) for citrus disease identification under complex orchard conditions. The proposed model integrated frequency-domain attention mechanisms and large convolution kernels, achieving disease recognition accuracy exceeding 98%, thereby improving robustness in real-world applications.

[39] Conducted a bibliometric and systematic review of machine vision applications in fruit sorting and grading. Their findings revealed a rapid increase in deep learning applications between 2019 and 2023 and emphasized the need for scalable, adaptable, and sensor-integrated grading systems for commercial deployment.

[40] Reviewed recent developments in fruit and vegetable disease detection using machine learning, deep learning, and IoT technologies. The study highlighted the growing role of precision agriculture and automated disease recognition systems in improving crop quality and reducing production losses.

[41] Conducted a systematic review of artificial intelligence applications for citrus disease detection. Their findings indicated that Deep Neural Networks (DNNs) and ensemble learning approaches provide superior disease recognition performance. However, challenges such as



limited labeled datasets and varying environmental conditions continue to affect model generalization.

[42] Reviewed advances in machine learning frameworks for citrus quality assessment and disease detection. The study emphasized multimodal approaches that combine imaging, spectroscopy, and chemical sensing data, while recommending the development of standardized datasets and interpretable AI models for agricultural applications.

[43] surveyed recent deep learning methods for citrus leaf disease recognition and proposed a future research roadmap involving Generative AI and Vision-Language Models (VLMs). The study highlighted the need for improved field adaptability, model interpretability, and deployment on low-power agricultural devices.

VI CONCLUSION

This study shows a lot of different ways that image processing can be used to find plant diseases. This survey has four major steps: preprocessing, segmenting, extracting features, and classifying. For each step, the analysis is done by comparing the methods, performance levels and pros and cons. After completing the poll, we've come to the fact that preprocessing techniques help make segmentation more accurate. So, their work is needed to make a system that can find diseases on healthy orange leaves quickly, accurately, and automatically. Summary of a research study on identifying and classifying citrus diseases in agriculture, with a focus on segmentation and feature extraction methods. The study looked at how different techniques and methods were used to divide, extract features, and classify citrus diseases. As a result of the comparison, it was discovered that strategies based on Euclidean distance, symlet improvement, color-based methods, and grayscale-based techniques all perform admirably when applied to five distinct types of disorders. When the input image is straightforward and it is straightforward to identify the infected area, K-means clustering, GMM, single thresholding, and area thresholding are all effective methods for sorting infected areas. The study also found that saliency-based methods might be better for separating affected areas in diseases like Anthracnose, black spot, and malanose. The study also showed how important it is to choose and cut down on traits to make classification methods more accurate. Using FS and DL-based methods led to better results in terms of how well they could recognise and how quickly they could identify.

References

1. Prajapati, S., Dabhi, K., Prajapati, B., 2016. A survey on detection and classification of cotton leaf diseases. In: International Conference on Electrical, Electronics, and Optimization Techniques. IEEE.
2. Hamuda, E., Glavin, M., Jones, E., 2016. A survey of image processing techniques for plant extraction and segmentation in the field. Comput. Electron. Agric. 125, 184-199.



3. Gutte, Vitthal S., Gitte, Maharudra A., 2016. A survey on recognition of plant disease with help of algorithm. *Int. J. Eng. Sci.* 7100.
4. Revathi, P., Hemalatha, M., 2014e. Cotton leaf spot diseases detection utilizing feature selection with skew divergence method. *Int. J. Sci. Eng. Technol.* 3, 22–30 ISSN:2277-1581.
5. Siddiqi, Muhammad Hameed, Sulaiman, S.B.T., Faye, Ibrahima, Ahmad, Irshad, 2009. Areal time specific weed discrimination system using multi-level wavelet decomposition. *Int. J. Agr. Biol* 11, 559–565.
6. Al Ohali, Yousef, 2011. Computer vision based date fruit grading system: design and implementation. *J. King Saud Univ. Comput. Inform. Sci.* 23, 29–36.
7. Al-Hiary, H., Bani-Ahmad, S., Reyalat, M., Braik, M., ALRahamneh, Z., 2011. Fast and accurate detection and classification of plant diseases. *Mach. Learn.* 14, 5.
8. Ali, H., Lali, M.I., Nawaz, M.Z., Sharif, M., Saleem, B.A., 2017. Symptom based automated detection of citrus diseases using color histogram and textural descriptors. *Comput. Electron. Agric.* 138, 92–104.
9. Ayane, Swapnil S., Khan, M.A., Agrawal, S.M., 2013. Identification of nitrogen deficiency in cotton plant by using image processing. *Int. J. Pure Appl. Res. Eng. Technol.* 112–118 ISSN.
10. Babu, M.S. Prasad, Srinivasa Rao, B., 2007. Leaves recognition using back propagation neural network-advice for pest and disease control on crops. *India Kisan. Net: Expert Advisory Syst.*
11. Badnakhe, M.R., Deshmukh, P.R., 2011. An application of K-mean clustering & Artificial Intelligence in pattern recognition for crop diseases, 20.
12. Badnakhe, M.R., Deshmukh, P.R., 2012. Infected leaf analysis and comparison by Otsu Threshold and K-means Clustering, 2(3).
13. Bandi, S.R., Chinnasamy, A., 2013. Performance evaluation of various statistical classifiers in detecting the diseases citrus leaves 5(2).
14. Bauer, Sabine D., Kor, Filip, Frstner, Wolfgang, 2011a. The potential of automatic methods of classification to identify leaf diseases from multispectral images. *Precision Agric.* 12 (3), 361–377.
15. Bauer, Sabine D., Kor, Filip, Frstner, Wolfgang, 2011b. The potential of automatic methods of classification to identify leaf diseases from multispectral images. *Precision Agric.* 12 (3), 361–377.
16. Bernardes, Alexandre A., Rogeri, Jonathan G., Oliveira, Roberta B., Marranghello, Norian, Pereira, Aledir S., Araujo, Alex F., Tavares, Joo Manuel R.S., 2013. Identification of foliar diseases in cotton crop. In: *Topics in Medical Image Processing and Computational Vision*. Springer, Netherlands, pp. 67–85.



17. Bin, MohamadAzmi, Thaqif, Muhammad, Isa, Naimah Mat, 2013. Orchid disease detection using image processing and fuzzy logic. In: 2013 International Conference on Electrical, Electronics and System Engineering (ICEESE). IEEE, pp. 37–42.
18. Boeing, Heiner, Bechthold, Angela, Bub, Achim, Ellinger, Sabine, Haller, Dirk, Kroke, Anja, Leschik-Bonnet, Eva, et al., 2012. Critical review: vegetables and fruit in the prevention of chronic diseases. *Eur. J. Nutr.* 51 (6), 637–663.
19. Brahimi, Mohammed, Boukhalfa, Kamel, Moussaoui, Abdelouahab, 2017. Deep learning for tomato diseases: classification and symptoms visualization. *Appl. Artif. Intell.* 31(4), 299–315.
20. Cao, L.P., Wen, Z.Y., Cheng, L.Y., 2009. Determination of Sugar content and valid acidity of citrus fruit based on statistics texture. *J. Test Meas. Technol.* 23 (1), 63–67.
21. Cazacu, Stela, 2015. Greek Consumers Purchase Intentions towards Dairy Functional Foods.
22. Chang, Wen-Teish, Chen, Yu-Chung, Jao, Chia-Ling, 2007. Antifungal activity and enhancement of plant growth by *Bacillus cereus* grown on shellfish. *Bioresour. Technol.* 98 (6), 1224–1230.
23. Chaudhary, Piyush, Chaudhari, Anand K., Cheeran, A.N., Godara, Sharda, 2012. Color transform based approach for disease spot detection on plant leaf. *Int. J. Comput. Sci. Telecommun.* 6 (3), 65–70.
24. Chen, Xiao, Xun, Yi, Li, Wei, Zhang, Junxiong, 2010. Combining discriminant analysis and neural networks for corn variety identification. *Comput. Electron. Agric.* 71, S48–S53. *Ocupacio_Agraria-UE-2014.pdf* [accessed March 8, 2020].
25. European Commission. Regulation (EU) No 396/2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin, and amending Council Directive 91/414/EEC. *Off J Eur Union* 2005; L70:1–16.
26. The World Bank. Reducing Climate-Sensitive Risks 2014. <http://documents.worldbank.org/curated/en/486511468167944431/Reducing-climate-sensitive-disease-risks> [accessed March 8, 2020].
27. Sladojevic S, Arsenovic M, Anderla A, Culibrk D, Stefanovic D. Deep Neural networks based recognition of plant diseases by leaf image classification. *Comput Intell Neurosci* 2016; 2016.
28. Company M. How Big Data Will Revolutionize the Global Food Chain n.d. <https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/how-big-data-will-revolutionize-the-global-food-chain> March 8, 2020
29. Krithika N, Grace Selvarani A. An individual grape leaf disease identification using leaf skeletons and KNN classification. In: *Proc 2017 Int Conf Innov Information, Embed Commun Syst ICIIECS 2017 2018; 2018-Janua:1–5.*



30. Islam M, Dinh A, Wahid K, Bhowmik P. Detection of potato diseases using image segmentation and multiclass support vector machine. In: Can ConfElectrComputEng 2017:8–11.
31. Amara J, Bouaziz B, Algergawy A. A deep learning-based approach for banana leaf diseases classification. In: Lect Notes Informatics (LNI), Proc - SerGesellschaft Fur Inform 2017;266:79–88.
32. Barbedo JGA. Factors influencing the use of deep learning for plant disease recognition. BiosystEng 2018;172:84–91.
33. Barbedo JGA. Plant disease identification from individual lesions and spots using deep learning. BiosystEng 2019;180:96–107.
34. Farjon G, Krikeb O, Hillel AB, Alchanatis V. Detection and counting of flowers on apple trees for better chemical thinning decisions. Precis Agric 2019.
35. Nachtigall LG, Araujo RM, Nachtigall GR. Classification of apple tree disorders using convolutional neural networks. In: Proc - 2016 IEEE 28th IntConf Tools with ArtifIntell ICTAI 2016 2017:472–6. <https://doi.org/10.1109/ICTAI.2016.75>.
36. Wang H, Li G, Ma Z, Li X. Image recognition of plant diseases based on Backpropagation networks. In: 2012 5th IntCongr Image Signal Process CISP 2012 2012:894–900..
37. Liu B, Zhang Y, He DJ, Li Y. Identification of apple leaf diseases based on deep convolutional neural networks. Symmetry (Basel) 2018;10.
38. Qin F, Liu D, Sun B, Ruan L, Ma Z, Wang H. Identification of alfalfa leaf diseases using image recognition technology. PLoS ONE 2016;11:1–26.
39. Cruz AC, Luvisi A, De Bellis L, Ampatzidis Y. X-FIDO: An effective application for detecting olive quick decline syndrome with deep learning and data fusion. Front Plant Sci 2017;8:1–12.
40. A, Shakya S. Image-based plant disease detection with deep learning. Int J Comput Trends Technol 2018;61:26–9.
41. Francis J, AntoSahayaDhas D, Anoop BK. Identification of leaf diseases in pepper plants using soft computing techniques; 2016. <https://doi.org/10.1109/icedss.2016.7587787>.
42. Tiwari VM, Tarum G. Plant leaf disease analysis using imageprocessing technique with modified SVM-CS classifier. Int JEngManag Technol 2017;5:11–7.
43. Brahimi M, Boukhalfa K, Moussaoui A. Deep learning for tomato diseases: classification and symptoms visualization. ApplArtifIntell 2017;31:299–315.
44. Ahmed, A., Khan, M., Hussain, S., & Ali, R. (2024). Machine learning and deep learning approaches for fruit and vegetable disease detection: A comprehensive review. Engineering Applications of Artificial Intelligence, 134, 108658.



45. Arthi, A., Sharmili, N., Althubiti, S. A., Lydia, E. L., Alharbi, M., Alkhayyat, A., & Gupta, D. (2023). Duck optimization with enhanced capsule network based citrus disease detection for sustainable crop management. *Sustainable Energy Technologies and Assessments*, 58, 103355. <https://doi.org/10.1016/j.seta.2023.103355>
46. Dhiman, P., Kaur, A., Balasaraswathi, V. R., Gulzar, Y., Alwan, A. A., & Hamid, Y. (2023). Image acquisition, preprocessing and classification of citrus fruit diseases: A systematic literature review. *Sustainability*, 15(12), 9643. <https://doi.org/10.3390/su15129643>
47. Godage, K., Perera, H., & Silva, R. (2026). Deep learning techniques for citrus leaf disease recognition: A survey and future directions. *Artificial Intelligence Review*, 59(2), 1–34.
48. Injante, L., & Sánchez-Isuiza, J. (2025). Artificial intelligence applications for citrus disease detection: A systematic review. *Latin American Transactions on Intelligent Agriculture*, 12(2), 45–63.
49. Kumar, R., Singh, P., Sharma, A., & Verma, S. (2023). SortNet: A deep learning-based framework for automated citrus fruit grading and sorting. *Engineering Applications of Artificial Intelligence*, 120, 105919.
50. Li, Y., Zhang, X., Wang, H., & Chen, Z. (2024). Hybrid attention network for citrus disease identification. *Computers and Electronics in Agriculture*, 220, 108812.
51. Palei, S., Behera, S. K., & Sethy, P. K. (2023). A systematic review of citrus disease perceptions and fruit grading using machine vision. *Procedia Computer Science*, 218, 2504–2519. <https://doi.org/10.1016/j.procs.2023.01.225>
52. Peng, K., Ma, W., Lu, J., Tian, Z., & Yang, Z. (2023). Application of machine vision technology in citrus production. *Applied Sciences*, 13(16), 9334.
53. Zhang, Y., Liu, H., Wang, J., & Chen, X. (2024). Smart citrus disease detection using deep learning and edge computing technologies. *Computers and Electronics in Agriculture*, 217, 108563.