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REVIEW

Detection of citrus diseases using artificial intelligence: A systematic review

Detección de enfermedades de los cítricos utilizando inteligencia artificial: una revisión sistemática

Richard Injante[1], Sergio Sánchez-Isuiza[1]

[1]Universidad Nacional de San Martín, Facultad de Ingeniería de Sistemas e Informática. Tarapoto, Perú.

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Corresponding author: Richard Injante

ABSTRACT

Early detection of citrus diseases is important for the global agricultural industry, facing threats such as Huanglongbing and canker. This study reviews the current status of the use of artificial intelligence to improve detection accuracy and speed. A systematic literature review was conducted from 2019 to 2023, using databases such as Scopus, IEEE Xplore and ACM, focusing on identifying the fruits studied, prevalent diseases, AI algorithms used and their accuracies, as well as technical challenges in implementing AI systems. The results highlight that oranges, lemons and mandarins are the most investigated fruits, with Huanglongbing, black spot and canker as the most studied diseases. AI algorithms such as Deep Neural Networks (DNN) and Adaboost show high accuracies, essential to improve disease detection. However, challenges include lack of labeled data, adaptation to different agricultural conditions, and effective integration in dynamic agricultural environments. This study reveals the need to advance data quality and algorithm adaptability to strengthen sustainability and efficiency in disease detection in citrus crops.

Keywords: Deep Neural Networks; Adaboost; Deep Learning; Citrus.

RESUMEN

La detección temprana de enfermedades en cítricos es importante para la industria agrícola global, enfrentando amenazas como el Huanglongbing y la cancrosis. Este estudio revisa el estado actual del uso de inteligencia artificial para mejorar la precisión y velocidad de detección. Se realizó una revisión sistemática de la literatura desde 2019 hasta 2023, utilizando bases de datos como Scopus, IEEE Xplore y ACM, centrada en identificar los frutos estudiados, enfermedades prevalentes, algoritmos de IA utilizados y sus precisiones, así como desafíos técnicos en la implementación de sistemas de IA. Los resultados destacan que naranjas, limones y mandarinas son los frutos más investigados, con Huanglongbing, la mancha negra y la cancrosis como las enfermedades más estudiadas. Los algoritmos de IA como las Redes Neuronales Profundas (DNN) y Adaboost muestran altas precisiones, esenciales para mejorar la detección de enfermedades. Sin embargo, los desafíos incluyen la falta de datos etiquetados, adaptación a diferentes condiciones agrícolas y la integración efectiva en entornos agrícolas dinámicos. Este estudio revela la necesidad de avanzar en la calidad de los datos y la adaptabilidad de los algoritmos para fortalecer la sostenibilidad y eficiencia en la detección de enfermedades en los cultivos de cítricos.

Palabras clave: Redes Neuronales Profundas; Adaboost; Aprendizaje Profundo; Cítricos.

INTRODUCTION

Citrus diseases represent a threat to the citrus industry worldwide.[1] Their early detection is crucial to implement effective control measures and limit their spread.[2] In this context, using Artificial Intelligence (AI) improves the rapid detection of citrus diseases. AI algorithms can analyze large data sets, such as leaf and fruit images, to identify early signs of disease with superior accuracy and speed compared to traditional methods.[3] This rapid and accurate detection capability can help growers take preventative measures and mitigate the negative impact of citrus diseases.

Early detection of citrus diseases is necessary for agriculture as it ensures crop health and long-term sustainability.[4] However, this work is hindered by the absence of efficient and rapid methods to identify early signs of disease, leaving growers needing more tools to apply preventive measures promptly.[5]

The rapid spread of diseases and their devastating impact on citrus yields highlight the need to develop and implement advanced detection technologies.[6] This situation puts the economic sustainability of the citrus industry at risk, as detection efficacy is vital for crop health and maintaining the financial stability of the sector.[7]

A holistic approach is required that combines technological advances with disease-specific research, seeking solutions that will detect the disease early and mitigate its spread. [8] The situation's urgency also highlights the importance of reducing reliance on pesticides through more targeted interventions, thus contributing to sustainability by reducing environmental impacts and costs associated with extensive treatments.[9]

Different studies have addressed disease detection in citrus, such as that of [10], who examine deep learning-based object detection models to improve plant disease identification. Their research provides a comprehensive overview of detection methods in tomatoes, citrus, corn, and grapes, highlighting innovations, challenges, and future directions in implementing these models in agriculture. Their contribution adds to technological advances, such as Deep Neural Networks (DNNs), which have significantly improved plant disease detection.

On the other hand,[11] highlights the use of automatic and deep learning techniques in citrus orchards, allowing early detection of diseases, pests, and water stress, thus improving crop productivity and quality. They also highlight the superiority of deep learning models over traditional machine learning models in classifying plant diseases and water deficits.

About the automated detection and classification of citrus plant leaf diseases,[12] emphasizes the need for advanced tools to automate this process, thus improving efficiency and accuracy in agricultural production. Their research on genetic engineering in citrus[2] highlights the development of transgenic varieties resistant to diseases such as citrus canker and Huanglongbing (HLB). This progress represents a significant step forward in obtaining more resistant crops and mitigating the negative impacts of diseases on citrus production worldwide.

Finally,[13] emphasizes this technology's importance in improving efficiency and accuracy in disease detection, fruit sorting, and automated harvesting. They propose solutions to address existing challenges, such as the lack of diversified data sets and the need for high-quality image processing hardware.

The objective of this study is to analyze the current status of citrus disease detection using AI, focusing on identifying the algorithms used their accuracy in identifying diseases such as citrus canker, black spot, Huanglongbing (HLB), and other relevant pathologies, as well as the most studied citrus fruits, such as oranges, lemons, and mandarins. It seeks to understand the technical challenges faced in implementing AI systems in citrus disease detection, including the need for diversified and representative data sets.

METHODOS

An exploratory systematic review was carried out to analyze and summarize the existing academic literature in a specific field of knowledge. This type of review provides an exhaustive view of the current state of knowledge by identifying, evaluating, and critically synthesizing previous research findings. Thus, it is consolidated as a fundamental tool in scientific research, facilitating the detection of gaps in knowledge and providing a basis for informed decision-making.

The review method followed the phases established by[14]: planning, conducting the review, and writing the report. This approach seeks to define the research questions, establish the key terms and their synonyms for the search, select the relevant databases, and establish inclusion and exclusion criteria. Once the quality material is located, it is thoroughly examined to extract relevant information, and finally, the findings are reported. With this clarification, the phases carried out in the present review are described:

Research questions

To answer the proposed objective, the following research questions were drawn:

RQ1: Which fruits are most studied?

Q2: What are the most common diseases affecting citrus?

Q3: What are the most commonly used artificial intelligence algorithms to detect citrus diseases?

Q4: What are the technical challenges and limitations facing implementing artificial intelligence systems in citrus disease prevention and control?

Search strategy

The key term "citrus diseases," translated into English as "citrus diseases," was used. In addition, the OR operator was used to incorporate the similar term "citrus pests." With the search string defined as "Citrus diseases" OR "citrus pests," three databases were selected: Scopus, IEEE Xplore, and ACM. These databases were chosen because of their broad international and regional coverage, ability to apply advanced search filters, and guarantee of academic quality in the contributions.

The article selection process began by applying the search string using the advanced search tools of each database, covering the fields of title, keywords, and abstract (first classification). Then, filters were implemented considering inclusion and exclusion criteria, such as year range, language, source, and document type, applied manually (second classification). Subsequently, the metadata were imported and organized in Excel, where duplicates were eliminated, taking the Scopus database as a reference (third classification). In addition, based on reading the title and abstract, articles focused on citrus diseases and including Deep Learning and Machine Learning were filtered (fourth classification). Finally, the articles were downloaded from the three above databases (fifth classification). Table 1 shows the number of articles obtained in each classification.

Table 1. Number of items by classification

Database	Ranking				
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Scopus	25491	96	93	53	24
IEEE	421	114	111	74	14
ACM	303	7	7	5	2

Inclusion and exclusion criteria

Defining inclusion and exclusion criteria is crucial to guarantee the objectivity and reproducibility of the review. These criteria ensure that the selected articles are relevant to the research questions and meet the established quality standards. [14] Accordingly, the following inclusion criteria were established:

- Published between 2019 and 2023.
- Spanish and English language.
- Research articles (original or empirical), conferences and book chapters.
- Focused on citrus diseases.

The exclusion criteria were established as follows:

- Review articles or other types of secondary sources.
- Duplicate publications.

Based on the application of the criteria, 40 scientific articles were obtained for analysis.

RESULTS AND DISCUSSION

After completing the selection of relevant articles and conducting an exhaustive review of each one, we proceeded to answer the research questions raised:

Q1: Which fruits are most studied?

This question focuses on investigating the types of citrus fruits that have been investigated in recent studies. It is crucial to understand which specific fruits are under investigation, as each may have characteristics and susceptibilities to diseases that vary by region and farming practices.

Table 2. Fruits that are most studied

Fruits	Articles
Oranges	(15), (11), (16), (17), (18), (19), (20), (21), (22), (23), (24), (25), (6), (26), (27), (28), (29), (30), (31), (32), (33) (34), (35), (36), (37), (38), (39), (40), (41), (42), (43), (44), (45), (46), (47), (48)
Lemons	(15), (11), (17), (18), (19), (20), (21), (25), (26), (29), (30), (32), (34), (37), (39), (40), (41), (42), (43), (44), (45)
Limes	(16), (24), (25), (26), (30)
Grapefruits	(19), (24), (25), (26), (28), (30)
Tangerines	(17), (18), (21), (49), (22), (23), (24), (25), (6), (29), (30), (31), (36), (39), (40), (41), (42), (43), (44), (48)
Grapefruits	(16)

According to the results in table 2, oranges are the primary research focus, with 34 studies focused on them. The popularity and extensive cultivation of these fruits justify the significant attention they receive in the scientific field.

Lemons also occupy a prominent place, as mentioned in 22 research studies. Their frequent use in both cooking and the beverage industry supports the considerable attention they receive in scientific studies. Mandarins also occupy an important place, as mentioned in 17 investigations. Their sweet taste makes them highly appreciated by consumers, which supports the considerable attention they receive in scientific studies. In contrast, limes and grapefruits are studied in 5 and 6 studies, respectively. Although these numbers are smaller than oranges, lemons, and tangerines, they indicate a solid interest in these fruits. Finally, grapefruits appear in only one study, suggesting a lower prevalence or perceived impact than other citrus fruits.

Q2: What are the most common diseases affecting citrus?

This question identifies which diseases primarily affect citrus and are being investigated. Understanding which diseases are being studied is crucial because their prevalence and severity can vary by region and farming practices. Therefore, knowing which ones are under investigation helps to evaluate better the results of these studies and their relevance to agriculture and plant health.

Table 3. Most common diseases affecting citrus fruit

Diseases	Articles
Huanglongbing (HLB)	(15), (16), (18), (20), (21), (49), (23), (24), (25), (27), (28), (29), (32), (34), (50), (35), (36), (37), (38), (39), (42), (43), (45), (46), (47), (48)
Scab	(11), (16), (19), (22), (23), (24), (25), (31), (35), (38)
Canker	(15), (11), (17), (20), (21), (49), (22), (23), (24), (25), (6), (28), (29), (30), (31), (32), (33), (34), (50), (35), (36), (37), (38), (39)
Black spot	(15), (11), (16), (17), (19), (20), (49), (22), (23), (24), (25), (6), (15), (29), (30), (31), (33), (34), (35), (36), (37), (38), (39), (40), (41), (51), (43), (44), (52)
Scurvy	(25)
Citrus greening	(11)
Iron chlorosis	(17), (18)
Melanosis	(17), (19), (22), (24), (28), (30), (31), (50), (36), (37)
Phytophthora	(25), (6), (27)
Gummosis	(49)
Anthracnose	(11), (16), (19),(28), (30)

According to the results in table 3, the most researched disease in citrus is black spot, with 30 studies dedicated to better understanding it. This disease is notorious for causing spots on fruit, which reduces their commercial value and affects production considerably. Canker is another disease that receives much attention, with 26 studies focused on it. This disease causes lesions on fruit and leaves, hurting citrus production and quality. Huanglongbing (HLB), mentioned in 25 studies, is one of the most critical diseases for citrus. The high frequency of studies on HLB reflects its importance and the urgency of finding practical solutions to combat it. Other problems studied include Melanosis, with ten studies, and scab, with seven studies. Melanosis causes spots on the peel of fruits, while scab mainly affects leaves and fruits.

Q3: What are the most commonly used artificial intelligence algorithms for detecting citrus diseases, and the accuracy of artificial intelligence algorithms?

Understanding which algorithms are employed allows us to more accurately assess research results and their practical feasibility in improving citrus health. This approach seeks to optimize early disease detection and strengthen crop management and care strategies, thus promoting significant advances in agriculture and the sustainability of agricultural production systems.

Figure 1 shows the accuracy (%) of several algorithms used in research studies. Deep Neural Networks (DNN) stand out, with variability in accuracy from 89,1 % to 99,7 %, as observed in multiple studies. [10, 27, 11, 24] Artificial Neural Networks (ANN) are also remarkable, reaching up to 94,8 % in specific studies. [6, 22, 25] Among the classical algorithms, Adaboost shows an accuracy ranging from 87,65 % to 94,4 %, with frequent mentions in the reviewed studies. [12, 16, 23, 26] Linear Discriminant Analysis (LDA) stands out with a maximum accuracy of 97,98 % [3, 25], while Support Vector Machines (SVM) reach up to 97,0 % in certain studies. [18, 29]

Deep learning algorithms such as Convolutional Neural Networks (CNN) show remarkable accuracies, such as 92,0 % and 93,7 % in specific studies [14, 40], while models such as VGG19 and ResNet50 reach up to 94,0 % and 99,7 %, respectively, according to the analyzed articles. [17, 4, 20, 30] In addition, Improved Genetic Algorithms (ImGA) present consistent accuracies of 96,5 %, 97,7 %, and 97,5 % in the reviewed studies [2, 12, 21, 28, 33], standing out for their efficacy in specific applications.

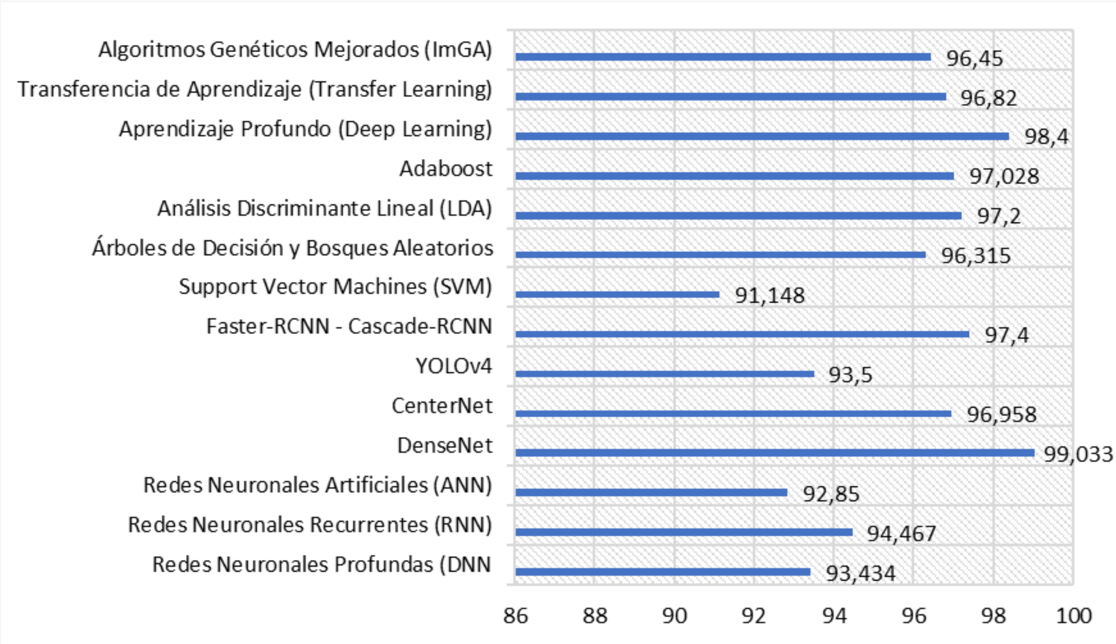

Figure 1. Artificial intelligence algorithms most commonly used to detect citrus diseases and accuracy of the algorithms

Q4: What technical challenges and limitations are faced in implementing artificial intelligence systems in citrus disease prevention and control?

This question focuses on qualifying the implementation of AI systems for citrus disease prevention and control. Overcoming these challenges will strengthen the capacity of AI in crop protection, thereby improving food security and global agricultural sustainability.

Table 4. Technical challenges and constraints in AI implementation for citrus diseases

Challenges and limitations	Articles
Redundant feature selection and limitation in feature extraction.	(17), (21), (22), (25), (6), (26), (30), (40), (41)
Limited availability and scarcity of large annotated datasets	(19), (49), (22), (24), (25), (6), (27), (28), (30), (32), (33), (37), (38), (42), (52), (48)
Need for high quality data and lack of quality data for training	(11), (16), (17), (18), (20), (49), (6), (27), (29), (37), (38), (39), (40), (41)
Improving accuracy and speed of detection, and performance issues with imagery	(15), (19), (21), (49), (22), (23), (24), (25), (6), (26), (28), (29), (31), (34), (50), (35), (36), (51), (43), (44) , (46), (48)
Integrating machine vision systems in dynamic agricultural environments and lack of interoperability	(15), (17), (18), (20), (49), (23), (26), (28), (29), (45)
Variations in fruit characteristics and limitation in identifying pest types	(21), (24), (27), (30), (46)
Scalability, high computational time, costs and resources.	(25), (28), (29), (30), (52), (47)
Illumination and presence of noise in citrus leaf images	(11), (16), (18)

According to table 4, the studies identify several technical challenges and limitations in implementing AI for disease detection and control in citrus crops. Among them is the need to improve feature selection and extraction, avoiding redundancies and ensuring the features' relevance. This task is crucial to optimize the accuracy of AI models. The scarcity of large annotated datasets represents another significant challenge. The need for adequately labeled data limits the practical training of AI models, which is essential to achieve accurate and generalizable results. In addition, the quality of the data used for training algorithms is crucial. More high-quality data can positively affect the effectiveness and accuracy of AI models in citrus disease detection.

Improving detection accuracy and speed and managing performance issues with citrus leaf images are also critical challenges. These aspects are fundamental to enable early and accurate disease detection, thus improving responsiveness in agriculture. Integrating machine vision systems in dynamic agricultural environments poses additional challenges due to the need for interoperability between different systems and devices. This is crucial for the effective implementation of AI solutions in agriculture. Natural variability in fruit characteristics and accurate identification of different types of pests are also critical challenges that need to be addressed to improve the effectiveness of AI systems in detecting citrus diseases.

Finally, challenges related to scalability, high computational time, costs, and resources required to implement and maintain AI systems in agricultural environments are crucial points that require attention to ensure the viability and sustainability of these technologies. These challenges highlight the complexity and variety of obstacles that must be overcome to effectively implement AI for disease prevention and control in citrus crops, highlighting the importance of innovative and adaptive solutions.

CONCLUSIONS

Early detection of diseases such as Huanglongbing (HLB) and citrus canker is crucial in containing their spread and protecting the citrus industry globally. AI, especially algorithms such as DNN and SVM, has proven highly effective in accurately and rapidly identifying these diseases in fruits such as oranges, lemons, and mandarins.

Research highlights that the most studied diseases include black spot, canker, and HLB, reflecting their significant impact on citrus production and marketing worldwide. These diseases are the subject of numerous studies due to their negative effect on yields and crop quality.

AI algorithms, such as DNN and SVM, have achieved accuracy levels above 90 % in many cases, underscoring their potential to improve phytosanitary management practices and optimize agricultural production. The variability in the accuracy of these algorithms highlights the importance of selecting the appropriate method according to specific crop conditions and disease characteristics.

However, implementing AI systems faces challenges, such as the limited availability of high-quality labeled data and the adaptation of algorithms to climatic and geographical variations. These obstacles must be overcome in future studies to maximize the potential of AI in crop protection and ensure its practical applicability in dynamic agricultural environments.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORSHIP CONTRIBUTION

Conceptualization: Sergio Sánchez-Isuiza and Richard Injante.
Formal analysis: Richard Injante.
Research: Sergio Sánchez-Isuiza and Richard Injante.
Methodology: Sergio Sánchez-Isuiza and Richard Injante.
Supervision: Richard Injante.
Validation: Richard Injante.
Visualization: Sergio Sánchez-Isuiza.
Writing - original draft: Sergio Sánchez-Isuiza and Richard Injante.
Writing - revision and editing: Sergio Sánchez-Isuiza and Richard Injante.