Pioneering Disease Prediction in Cinnamon Leaves using Machine Learning: A Systematic Literature Review

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Abstract

The integration of Machine Learning (ML) in agricultural disease prediction has become increasingly prominent. This review paper explores the evolution of techniques used for predicting diseases in cinnamon leaves and analyzes common cinnamon leaf diseases, drawing on research conducted up to 2023. The paper highlights the evolution of ML methodologies, particularly in the areas of image processing, feature extraction, and classification algorithms. It provides an in-depth analysis of various approaches, such as Convolutional Neural Networks (CNNs), Support Vector Machines (SVMs), and Random Forests, evaluating their effectiveness in disease prediction. From an initial set of 100 studies, 22 were selected for detailed analysis based on their relevance and contribution to the field. Additionally, the review addresses the challenges associated with developing reliable ML models. Through the synthesis of findings from multiple studies, this paper offers a comprehensive overview of current research in cinnamon leaf disease and prediction, identifying existing gaps and proposing directions for future investigations to improve the precision and applicability of ML-driven solutions in agriculture.

Keywords: Cinnamon Leaf Diseases, Machine Learning, Agricultural Disease Prediction, Classification Algorithms

I. INTRODUCTION

In Cinnamon, known locally as "Kurundu" in Sri Lanka, has been a valuable commodity since antiquity, cherished for its unique aroma, flavor, and medicinal properties. Derived from the inner bark of various species within the Cinnamomum genus, cinnamon has a rich history intertwined with trade, culture, and culinary traditions. Among the many species, Cinnamomum verum, commonly referred to as Ceylon cinnamon or "true" cinnamon, holds a place of particular significance. Native to Sri Lanka, Ceylon cinnamon is distinguished by its superior quality, which has earned it a prominent position in both local and global markets(Wickramasinghe *et al.*, 2018). The cultivation of cinnamon in Sri Lanka dates back several centuries, with the Dutch colonial rulers playing a crucial role in establishing systematic cultivation practices in the 18th century. The Dutch Governor Falk was instrumental in promoting cinnamon cultivation, which soon became one of the island's most lucrative exports. By 1841, the demand for cinnamon had surged, leading to the commercial production of cinnamon leaf oil, by product that further expanded the industry’s economic footprint (Wijesekera and Chichester, 1978).

Today, cinnamon is cultivated across approximately 14,000 to 16,000 hectares in Sri Lanka, with the Ambalangoda region being a key production area. This region alone accounts for nearly 50% of the country's total cinnamon output, underscoring its importance in the national economy. Ceylon cinnamon's economic value extends beyond its use as a spice. The chemical composition of Ceylon cinnamon, particularly its low levels of coumarin, makes it highly sought after in the global market. Coumarin, a naturally occurring compound found in higher concentrations in other cinnamon varieties like Cassia, can be harmful in large doses, which enhances the appeal of Ceylon cinnamon for health-conscious consumers. Additionally, the extracts from cinnamon leaves and bark are used in the food industry as natural preservatives due to their antimicrobial properties, as well as in the pharmaceutical and cosmetic industries for their therapeutic benefits (Suriyagoda *et al.*, 2021).

Despite its global recognition and economic importance, the cinnamon industry in Sri Lanka faces significant challenges, particularly from pests and diseases that threaten both the yield and quality of the crop. Among the most common foliar diseases are leaf blight, caused by Colletotrichum gloeosporioides, and algal leaf spot, caused by Cephaleuros virescens. These diseases, along with infestations by insect pests like jumping plant louse/ leaf galls, thrips attack, can lead to severe reductions in cinnamon yield, causing substantial economic losses for farmers (Rajapakse and Kumara, 2007).Traditional disease management strategies, including the use of fungicides and pest control measures, have proven to be only partially effective. These methods are often labor-intensive, environmentally harmful, and unsustainable in the long term, necessitating the exploration of more advanced and targeted approaches (Jayasinghe *et al.*, 2020).

Beyond its challenges in cultivation, cinnamon's importance extends far beyond its role as a spice. Owing to its special properties, cinnamon is a multipurpose ingredient widely used not only in kitchens as a tasty addition to various dishes but also in medicine (Pathirana and Senaratne, 2020). The essential oil derived from cinnamon leaf, which contains a high concentration of trans-cinnamaldehyde, possesses strong antibacterial properties. These properties are effective against infections in plants and animals, as well as bacteria and fungi associated with food spoilage and food poisoning. In addition to its culinary applications, cinnamon offers numerous health advantages, including anti-inflammatory properties, antimicrobial activity, a reduced risk of cardiovascular disease, improved cognitive function, and a decreased chance of colon cancer. The various parts of the cinnamon plant, including the outer bark, inner bark, and leaves, are used for medicinal purposes.

In this context, the advent of Machine Learning (ML) presents a transformative opportunity for the cinnamon industry. ML, a subset of artificial intelligence (AI), involves the use of algorithms and statistical models to analyze large datasets, identify patterns, and predict outcomes with a high degree of accuracy. The application of machine learning (ML) in cinnamon disease management is still in its early stages. Some studies have made strides in related areas, such as using image processing techniques and algorithms like Speeded up Robust Features (SURF) for data extraction from cinnamon (Chandima and Kartheeswaran, 2016; Sunitha *et al.*, 2022). These techniques have been employed to predict the maturity levels of cinnamon trees using classifiers such as Support Vector Machines (SVMs). While these initial findings are promising, there remains a significant gap in research specifically targeting the detection and management of diseases in cinnamon leaves using ML techniques.

In recent years, the application of Machine Learning (ML) has emerged as a transformative opportunity for addressing these challenges. ML, a subset of Artificial Intelligence (AI), allows for the analysis of large datasets, enabling accurate predictions and early detection of diseases through pattern recognition (Gunasekara *et al.*, 2021; Shandilya *et al.*, 2024).Techniques like deep learning and Convolutional Neural Networks (CNNs) have shown significant promise in detecting diseases in cinnamon crops by leveraging image processing technologies. For instance, the potential of CNNs for characterizing cinnamon diseases such as rough bark and stripe canker, providing a model for future applications in this field (Jayasena *et al.*, 2023).Recent reviews have emphasized the growing interest in the application of ML in the cinnamon industry. These studies highlight the potential of deep learning models, particularly Convolutional Neural Networks (CNNs), in improving disease detection and management for cinnamon crops (Giraddi, Desai and Deshpande, 2020; Feltes *et al.*, 2023). Other research has discussed the integration of remote sensing technologies with ML, which offers greater precision in monitoring crop health and managing diseases (T* *et al.*, 2020; Tusher *et al.*, 2022). Additionally, advanced ML techniques such as Transfer Learning have shown potential in addressing key challenges, particularly in disease detection and quality control within the cinnamon industry (Fatima *et al.*, 2021).

This systematic literature review aims to explore the current state of research on cinnamon leaf diseases, their management strategies, and the use of ML in disease detection and prediction. By examining studies conducted up to 2023, the review seeks to evaluate the effectiveness of ML techniques in this domain, assess the impact of these technological advances on the cinnamon industry, and identify areas that require further research. The findings of this review are expected to provide valuable insights for researchers, practitioners, and policymakers interested in improving the sustainability and efficiency of cinnamon production through the integration of

ML technologies. By bridging the gap between traditional practices and technological advancements, this review aims to contribute to the ongoing efforts to enhance the resilience and productivity of the cinnamon industry in Sri Lanka and beyond.

II. METHODOLOGY

A. *Systematic Literature Review*

The This study adopts a systematic literature review (SLR) methodology to explore the application of machine learning (ML) in the prediction and management of diseases in cinnamon leaves. The review process was structured into three key phases: planning, conducting, and reporting.

In the planning phase, we identified relevant electronic databases, including IEEE Xplore, Springer, and ACM Digital Library, Google Scholar to source research papers related to our study. Key research questions were defined to guide the review, and specific search strings were developed based on keywords pertinent to the intersection of cinnamon leaf diseases and machine learning. During the conducting phase, we systematically searched the selected databases using the predefined search strings. The search results were carefully reviewed to select studies that addressed our research focus. Additionally, references from these studies were used to perform snowballing, ensuring a comprehensive inclusion of relevant literature. The studies were analyzed to extract essential information such as abstracts, keywords, methodologies, and findings, which were then categorized for further evaluation. In the reporting phase, the selected studies were synthesized and organized into a detailed analysis. The studies were documented with a focus on their contributions to the understanding of ML applications in cinnamon leaf disease prediction. The summarized research was then compiled into structured documents that provide a comprehensive overview of the literature, highlighting key trends, methodologies and future directions in the field. This systematic review process, guided by established SLR protocols, ensures a thorough and objective evaluation of the existing literature, offering valuable insights into the potential of machine learning in enhancing disease management strategies for the cinnamon industry.

B. *Research Questions*

Research questions are central to guiding a systematic literature review. Table 01 presents the research questions that this study aims to address. By examining these questions, we can identify gaps in the current literature and better understand the state of research in the application of machine learning for disease prediction in cinnamon leaves.

Table 01: Research questions

No	Research Question
RQ1	What are the common cinnamon leaf diseases identified in existing studies?
RQ2	How can various machine learning techniques be effectively utilized to create a predictive model for accurately identify cinnamon diseases?
RQ3	What challenges and limitations have been identified in past studies on machine learning applications for leaf disease prediction?

C. *Study Selection*

The study selection process involved several key steps:

1) *Terms and Search Strings:*

The search terms were applied across two main segments: cinnamon leaf disease and machine learning. The search string was applied to three metadata fields: title, abstract, and keywords. Table 02 represents the search strings applied in the databases.

Table 02: Search terms of the mapping study on pioneering disease prediction in cinnamon leaves using machine learning

Area	Search Terms
Cinnamon Disease	"Cinnamon leaf disease", "cinnamon diseases "
Disease Identification	"Leaf disease identification using machine learning", "plant disease detection", "plant disease classification"
Machine Learning	"Machine learning", "ML approaches", "artificial intelligence in agriculture"
Cinnamon disease management	"Cinnamon leaf disease management", "cinnamon leaf disease treatment"
Search String	(“cinnamon leaf disease” OR “cinnamon disease”) AND (“leaf disease identification using machine learning” OR “plant disease detection” OR “plant disease classification”) AND (“machine learning” OR “ML approaches” OR “artificial intelligence in agriculture”) AND ("cinnamon leaf disease management", "cinnamon leaf disease treatment")

3) *Sources:*

This Systematic Literature Review was performed using the following electronic databases and considered the most relevant studies.

i. IEEE Xplore <http://ieeexplore.ieee.org>
ii. Springer Link <https://link.springer.com>
iii. Science Direct<https://www.sciencedirect.com>
iv. Google Scholar<https://www.sciencedirect.com>
v. ACM Digital Library<https://dl.acm.org>

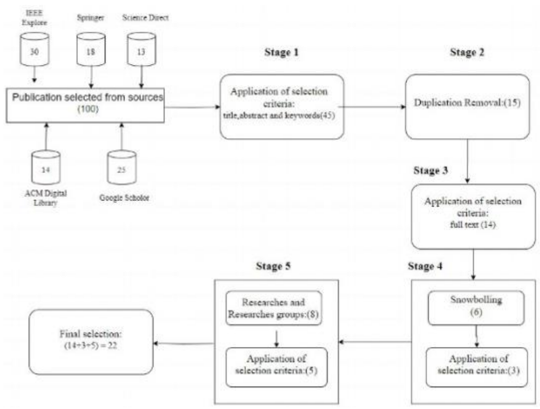

Figure 01: Selection Process Flow

4) *Inclusion and exclusion criteria:*

The selection process for this study was organized based on two inclusion criterion and five exclusion criteria. Table 03 and Table 04 depict the inclusion and exclusion criteria used in the filtering process respectively.

Table 03: Inclusion criteria of the selection process

No	Inclusion criteria (IC)
IC1	Focuses on common cinnamon leaf diseases.
IC2	Describes the application of machine learning techniques for the prediction of cinnamon plant diseases.

Table 04: Exclusion criteria of the selection process

No	Exclusion criteria (EC)
EC1	The paper does not contain an abstract
EC2	The paper is published only as an abstract
EC3	The paper is not written in English
EC4	The paper is an earlier version of a study that has already been selected
EC5	The paper is not a primary study. It is either editorial or summaries of keynotes and tutorials

5) *Data extraction and synthesis:*

In this study, a thorough examination of publications to 2023 was conducted to evaluate the application of machine learning techniques in predicting diseases in cinnamon leaves. The initial retrieval process gathered 100 publications from several reputable digital libraries, including IEEE Xplore, Springer, ScienceDirect, ACM Digital Library, and Google Scholar.

The selection process for these studies was organized into five stages. The first stage involved applying predefined selection criteria to the title, abstract, and keywords of each study. In the first stage, 45 of these publications were selected based on their titles, abstracts, and keywords. This filtration aimed to distill the most relevant studies pertinent to research topics. In second stage, Identified and removed 15 duplicate studies from the remaining 45, leaving 30 publications for further scrutiny.

In the third stage, an in-depth review of the full texts of these 30 publications was conducted. Employing stringent inclusion and exclusion criteria ensured the relevance and completeness of the studies, which led to 14 publications proceeding to the next stage of the selection process. The fourth stage expanded search to include studies referenced in the initial set, a method known as snowballing. This yielded 6 additional publications, out of which 3 met rigorous selection criteria and added to study pool.

The final stage focused on significant contributions from key researchers and research groups. Identified 8 additional relevant publications through this method. After applying final selection criteria, 5 of these were deemed highly pertinent to research aims. This comprehensive process resulted in a final selection of 22 publications, which were considered for systematic review, ensuring a broad and thorough coverage of the final synthesis.

III. RESULT AND DISCUSSION

This Cinnamon, particularly Ceylon cinnamon, is a vital economic asset for Sri Lanka, valued not only for its culinary and medicinal applications but also for its significant contribution to the agricultural sector (Suriyagoda *et al.*, 2021).However, the industry faces persistent challenges from diseases and pests that impact both yield and quality.

Among the most common cinnamon leaf diseases, leaf blight and leaf spot diseases, primarily caused by the fungus Colletotrichum gloeosporioides. This disease manifests as brown or black lesions on leaves, which can spread rapidly, leading to significant foliage loss and a reduction in the plant's photosynthetic ability. Another common issue is algal leaf spot, caused by Cephaleuros virescens, which results in orange or reddish spots on the leaves, eventually causing leaf deterioration (Wickramasinghe *et al.*, 2018; Jayasinghe *et al.*, 2020).In addition to fungal infections, cinnamon plants are also affected by various pests. Jumping plant louse and thrips are frequent insect pests that cause leaf galls and deformation, further impacting the plant's health. These diseases and pests represent major challenges to cinnamon cultivation, addressing these challenges effectively is crucial for maintaining the industry's economic viability (Pathirana and Senaratne, 2020).

Recent advancements in machine learning (ML) have demonstrated great potential for revolutionizing agricultural practices, particularly in disease detection and management. However, research specifically applying these methods to predict diseases in cinnamon leaves remains largely unexplored. Most of the existing literature focuses on general applications of ML in agriculture or on detecting diseases in other parts of the cinnamon plant. One of the key challenges in cinnamon leaf disease prediction using ML techniques is the lack of annotated datasets for training robust models. Image processing techniques have been utilized in related applications, such as recognizing mature cinnamon trees, suggesting the possibility of adapting similar methods for identifying diseases in cinnamon leaves (Chandima and Kartheeswaran, 2016). However, without sufficient data, building an accurate ML model remains a challenge.

Transfer learning has been identified as a promising method to address this data scarcity issue. It has been applied to trace adulteration in spices like cinnamon, which suggests the possibility of applying this technique to cinnamon leaf disease detection (Fatima *et al.*, 2021). By leveraging pre-trained models on other plant datasets, researchers can reduce the need for large, specialized datasets specific to cinnamon.

Convolutional Neural Networks (CNNs) have been a popular choice for image-based disease detection. (Sardogan, Tuncer and Ozen, 2018; Singla, Kalavakonda and Senthil, 2024)Techniques such as CNNs with Learning Vector Quantization (LVQ) have been used in plant disease classification, and similar methodologies that could be adapted for cinnamon disease prediction. The potential of CNNs in identifying specific cinnamon plant diseases has been explored, particularly in deep learning models used to identify conditions like rough bark and stripe canker (Pratondo *et al.*, 2024; Shandilya *et al.*, 2024).

The integration of remote sensing with ML models has also been proposed as a solution for large-scale monitoring of plant diseases. By combining remote sensing data with deep learning, precision agriculture in cinnamon farming could be enhanced, enabling more efficient disease monitoring and management (Lakshan S *et al.*, 2023).This integration could address the environmental variability that impacts disease development in cinnamon plants, ensuring that models generalize well across different regions and climates.

Another emerging technology in cinnamon disease prediction is the use of mobile applications for real-time disease detection (Ekanayaka and Kumara, 2022; Jayasena *et al.*, 2023). Mobile-based tools that utilize image processing have been developed to enhance cinnamon quality and health. This tool demonstrates the feasibility of creating mobile-based solutions for disease detection, providing farmers with immediate insights into the health of their crops.

A significant barrier to the widespread adoption of ML in cinnamon disease prediction is the need for interdisciplinary collaboration. Integrating agricultural knowledge with technological innovations is essential, especially considering the unique characteristics of the cinnamon industry in regions like Sri Lanka (Prof. Koliya Pulasinghe, Dr. Dharshana Kasthurirathna and S.A.A. Ravishan, 2023).Highlight that the unique characteristics of the cinnamon industry in Sri Lanka, including its environmental and climatic factors, must be considered when developing ML-based disease prediction systems. Also, there is significant potential for using ML to predict diseases in cinnamon leaves, the field is still in its early stages.

Future research should focus on developing datasets specific to cinnamon leaf diseases, exploring the use of transfer learning, and integrating ML with remote sensing technologies. Additionally, Interdisciplinary collaboration between agricultural experts and technologists is crucial for ensuring that these models are accurate and applicable in real-world farming scenarios.

Table 05: Feature extraction and system results across studies

Paper ID	Title	System Type	Key Features	Results	Limitations
1	Historical overview of the cinnamon industry.	Historical overview Economic impact	Not applicable	Provides historical context	Does not address current disease management practices or specific disease issues.
2	Ceylon cinnamon': Much more than just a spice	Economic value culinary and medicinal uses	Not applicable	Highlights the multifaceted value of Ceylon cinnamon beyond its culinary uses.	Does not specify common Sri Lankan cinnamon leaf diseases or management techniques.
3	An Introduction to Sri Lanka and Its Cinnamon Industry	Economic impact, industry overview	Not applicable	Provides historical context, cinnamon leaf and economic significance of cinnamon in Sri Lanka	Does not focus on disease management or prediction using ML.
4	Chemical and biological studies of value-added cinnamon products	Cinnamon leaf disease Disease management strategies	Not applicable	Focuses on disease management strategies for cinnamon diseases.	Limited to traditional methods. Lacks advanced machine learning techniques for disease prediction.
5	A Review of Identification and Management Pests and Diseases of Cinnamon (Cinnamomum zeylanicum Blume)	Pests and diseases of cinnamon Environmental factors	Not applicable	Detailed description of pests and diseases in cinnamon	Lacks the application of machine learning for disease prediction.
6	Identification and management of pests and diseases of cinnamon.	Pests and disease identification Cinnamon leaf diseases	Not applicable	Focuses on disease management	Doesn't suggest comprehensive management strategies
7	AgroX: Uplift Ceylon Cinnamon Industry	Technological interventions, Economic development,	Not applicable	Highlights technology's role in advancing the cinnamon industry	No specific mention of disease prediction technologies.
8	Exploring Deep Learning Models for Cinnamon Plant Disease Characterization	Disease types, Image features	Convolutional Neural Networks (CNN)	Achieves high accuracy in identifying specific cinnamon diseases through image analysis	Focuses on specific diseases. Not generalize to all cinnamon diseases and cinnamon leaf diseases.
9	Classification of Cassia Cinnamon and	Visual and chemical	Deep Learning	High accuracy in distinguishing	Focuses on classification, not disease prediction.

	Ceylon Cinnamon using Deep Learning	features of cinnamon	CNN	Cassia and Ceylon cinnamon	
10	Modeling CNN for Detection of Plant Leaf Spot Diseases.	Leaf spot diseases, Image classification	Convolutional Neural Network (CNN)	Classification accuracy of 90.6% for plant leaf diseases.	The model focuses only on leaf spot disease.
11	Recognizing matured cinnamon tree using image processing techniques	Maturity level of cinnamon trees Image processing	Support Vector Machine (SVM)	Identification of maturity level.	Accuracy might decrease in varying environmental conditions or with different cinnamon tree varieties
12	Plant Leaf Disease Detection and Classification Based on CNN with LVQ.	Plant leaf diseases.	CNN with Learning Vector Quantization (LVQ)	Accurate identification of leaf diseases.	LVQ algorithm may not perform well with large and diverse datasets of plant leaf diseases.
13	CinnaSense: Enhancing Cinnamon Quality and Health with Image Processing	Image-based features for cinnamon quality	Image processing	Focuses on improving cinnamon quality through advanced image processing techniques	Limited application to disease prediction and broader health assessments
14	Automatic Recognition of Plant Leaf Diseases Using Deep Learning (Multilayer CNN) and Image Processing	Leaf images Disease features	Multilayer CNN	Accurate leaf disease identification	Limited testing in real-world agricultural settings Results may not fully generalize to outdoor conditions.
15	Differentiating True and False Cinnamon: Exploring Multiple Approaches for Discrimination	Chemical and structural properties of cinnamon	Machine Learning (varied approaches)	Effectively differentiates true vs. false cinnamon	Does not address cinnamon leaf disease detection or prediction.
16	Machine Learning-Based Nutrient Deficiency Detection in Crops	Nutrient deficiencies, Leaf images	Convolutional Neural Network (CNN)	High accuracy in detecting nutrient deficiencies and recommending fertilizers.	System might not account for variations in nutrient deficiency symptoms across different crop types
17	Machine Learning Approach for New Crop Disease Predict and Alert System	Various crop features for disease prediction	Machine Learning, CNN, Random Forest	Efficient in predicting multiple crop diseases	May be too complex for practical deployment in regions with limited technological infrastructure, such as smallholder cinnamon farms.
18	Deep Learning for Agricultural Plant Disease Detection	Leaf images, Disease symptoms	Deep Learning, CNN	High accuracy in disease detection in agriculture	Model's performance may vary across different crop types.
19	Tracing Adulteration in Cumin, Cinnamon, and Coffee using	Chemical composition and adulteration detection	Transfer Learning	High accuracy in detecting adulteration in cinnamon,	Focuses on quality control rather than disease detection

	Transfer Learning			cumin, and coffee	
20	Detection of plant leaf diseases using deep convolutional neural network models	Leaf texture, color, shape	Deep Convolutional Neural Network	High accuracy in disease detection	Limited dataset size
21	Integrating Remote Sensing and Deep Learning for Precision Agriculture in Cinnamon Farming	Remote sensing data and cinnamon farming characteristics	Deep learning	Effective integration of remote sensing data for precision agriculture in cinnamon farming	Lack of real-world validation for disease-specific applications
22	Expert Prediction System for Spice Plants Grown in Sri Lanka	Environmental parameters Historical data	Various ML algorithms	Improves early detection of disease outbreaks in cinnamon crops, allowing for timely intervention	Relies on comprehensive data input

IV.CONCLUSION

This systematic review has explored the application of machine learning (ML) techniques in the prediction and management of cinnamon leaf diseases, with a focus on advancements in image processing and classification algorithms like Convolutional Neural Networks (CNNs), Support Vector Machines (SVMs), and Random Forests. While significant progress has been made in applying ML for disease detection across various crops, research specifically targeting the most common cinnamon leaf diseases in Sri Lanka remains limited. To date, no research has successfully identified a machine-learning model capable of detecting cinnamon leaf prevalent diseases comprehensively.

This review, therefore, aimed to assess and recommend the most suitable ML techniques that could be adapted for cinnamon disease detection. CNNs, with their ability to analyze image data and detect intricate patterns, have emerged as the most promising approach for this purpose. However, there are challenges to overcome, such as the availability of comprehensive datasets that accurately reflect real-world conditions and the development of models that are scalable and robust across different disease types and environmental variations. The integration of ML offers a transformative approach to disease detection and management, providing a more efficient and precise alternative to traditional methods. Future research should focus on bridging the current gaps by developing more adaptable and scalable ML models, leveraging real-world field data, and addressing environmental variability. These advancements are crucial to enhancing disease management strategies and ensuring the sustainability and productivity of the cinnamon industry in Sri Lanka and beyond.

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