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EPIDEMIC DYNAMICS OF ARECA NUT LEAF SPOT AND IMPLICATIONS FOR CROP SUSTAINABILITY IN NORTHERN KERALA: A REVIEW

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ABSTRACT

Arecanut (*Areca catechu* L.) is a crucial plantation crop in India, especially in Kerala and Karnataka, where it sustains the livelihoods of millions of small and marginal farmers and plays a significant role in the regional economy. In recent decades, leaf spot disease has become a major challenge to arecanut production, resulting in substantial yield losses and economic repercussions. This disease is mainly caused by a complex of fungal pathogens, including *Colletotrichum gloeosporioides, Phyllosticta arecae, Pestalotiopsis palmarum, Curvularia sp. and* the recently identified *Colletotrichum kahawae subsp. cigarro*. Its severity is greatly affected by climatic factors such as high humidity, extended rainfall, and ideal temperatures (20–30°C), along with host susceptibility and management practices. Symptoms consist of water-soaked lesions that develop into necrotic spots with yellow halos, merging into widespread foliar necrosis and early leaf drop, which leads to decreased photosynthesis and stunted growth. Recent research emphasizes pathogen identification using molecular tools, the importance of climate-adaptive management, the development of resistant varieties, and the incorporation of modern technologies like remote sensing and machine learning for disease monitoring and forecasting. Effective management depends on an integrated approach that combines cultural practices, chemical and biological control methods, and integrated pest management (IPM) strategies. Collaborative research under initiatives by ICAR, CPCRI, and MIDH promotes sustainable disease management and long-term productivity of arecanut. This review consolidates current knowledge on etiology, the epidemiology, impact, and management of areca nut leaf spot disease, highlighting the necessity for comprehensive, science-based strategies to ensure economic viability and sustainable cultivation.
Keywords **:** Arecanut, Leaf spot, Epidemiology, Etiology.

Introduction

Arecanut (*Areca catechu L.*) is a plantation crop of great economic and socio-cultural importance in India, particularly in the states of Karnataka and Kerala. During the 2013–14 period, Karnataka contributed approximately 62.69% of the country's total arecanut production, followed by Kerala and Assam, making these states the primary production area in India (Sharma *et al.,* 2025). The crop is grown in the humid tropical regions of the Western Ghats, often within mixed-cropping systems, where the favourable climate supports its growth. It provides livelihoods for many small and marginal farmers and significantly contributes to rural incomes through both domestic consumption and the export of areca nut products (Mitra and Devi, 2018). Jayarajan *et al.* (2023) noted that arecanut is typically cultivated as a perennial palm in well-drained soils, but its productivity is influenced by various biotic and abiotic stresses, particularly fungal diseases that affect both yield and quality.

In recent decades, leaf spot disease has become one of the major challenges to arecanut cultivation. Once regarded as a minor issue, it has now reached epidemic proportions in several arecanut-growing areas, especially in northern Kerala and coastal Karnataka. Conditions such as high humidity, extended rainfall, and dense canopy cover facilitate its spread. The disease is commonly linked to fungal genera such as *Colletotrichum, Pestalotiopsis, Phyllosticta,* and occasionally *Curvularia.* In survey work conducted in the hill zones of Karnataka, the severity of the disease caused by *Colletotrichum gloeosporioides* varied from 18.50% in less affected areas to 81.50% in severely impacted sites (Adivappar *et al.*, 2023). Reports often indicate yield losses of 50% or more under severe infections, although precise scientific quantification may differ across regions and years.

Given the increasing prevalence and epidemic nature of this leaf spot complex, this review focuses particularly on the Northern Kerala region, where arecanut is a key cash crop and essential to the local agro -economy. The objective is to synthesize recent findings on the etiology, epidemiology, and impacts of leaf spot disease, as well as to evaluate current management strategies, including cultural, chemical, and integrated approaches. Understanding disease dynamics and region-specific risk factors can lead to more effective prevention and sustainable arecanut production systems.

Evolution and Emerging Trends of Arecanut Leaf Spot Disease

Leaf spot and related foliar diseases of arecanut have a long history in India; however, the current epidemics dominated by *Colletotrichum spp.* and *Phyllosticta spp.* in Kerala and neighboring Karnataka have intensified only in the last decade. Classical foliar disorders of arecanut, such as yellow-leaf were reported from the West Coast as early as the early 20th century. Nevertheless, systematic surveys and molecular diagnostics conducted over the past five to eight years have documented a significant increase in both the incidence and severity of leaf-spot outbreaks across the Malabar and hill zones (CPCRI, 2022; update surveys 2023). Intensive surveys carried out between 2022 and 2023 recorded very high local disease severity in several taluks, and field reports from 2023 to 2024 indicate increasingly frequent and severe epidemics compared to previous years, suggesting both an expanded presence of pathogens and higher inoculum loads in plantation debris (survey studies 2023; CPCRI news 2024). Notably, CPCRI and collaborating researchers have reported the emergence of novel or previously uncommon *Colletotrichum* lineages on arecanut, including the first report *of Colletotrichum kahawae sub* sp. *cigarro* on arecanut in India, indicating a changing composition of pathogens that may be driving recent outbreaks.

Climate trends in the Western Ghats, such as an increased frequency of heavy precipitation events, longer periods of high relative humidity, and changes in the timing and intensity of the monsoon, are likely contributing to the recent increase in foliar epidemics by extending leaf-wetness periods and enhancing spore production and dispersal. Reviews and regional studies linking changing precipitation and humidity patterns to a greater risk of fungal diseases support this explanation and emphasize that extreme precipitation events favor polycyclic foliar pathogens.

Varietal response and garden management significantly influence epidemic outcomes. Recent surveys and CPCRI evaluations show clear variation among arecanut genotypes in their susceptibility to foliar pathogens, with gardens that have dense canopies, poor nutrition, or inadequate sanitation consistently exhibiting higher disease incidence and greater yield losses. While breeding and clonal selection efforts, as documented in ICAR/CPCRI reports, are underway to identify more tolerant genotypes, validated resistant cultivars for leaf spot remain limited. Therefore, integrated agronomic and phytosanitary measures currently serve as the primary means to reduce epidemic risk.

Impact Assessment of Arecanut Leaf Spot Disease

The leaf spot epidemic affecting arecanut, mainly caused by *Colletotrichum gloeosporioides, Phyllosticta arecae, and Pestalotiopsis palmarum*, has become a significant barrier to arecanut production in Kerala and Karnataka, leading to considerable impacts on yield, economy, and plant health. Field surveys conducted in northern Kerala and coastal Karnataka indicate disease severity ranging from 18.5% to 81.5%, with affected plantations experiencing yield reductions of 20–50 per cent especially under severe epidemic conditions (Survey and identification of pathogens, 2024; Times of India, 2025). Economically, the epidemic has caused substantial financial losses for small and marginal farmers, resulting in annual income reductions of 30–40% due to decreased nut yield, poor nut quality, and increased costs for fungicides and labour (Press Information Bureau, 2025; CPCRI, 2022). On a regional level, the Karnataka State Natural Disaster Monitoring Centre estimated that during the monsoon season, horticultural crops across 5.74 lakh hectares, valued at Rs. 3,569 crore, were severely damaged, with arecanut plantations being among the most affected (Press Information Bureau, 2025). In addition to immediate yield losses, repeated defoliation and chronic infection weaken the palms, leading to reduced vigor, stunted growth, and susceptibility to secondary infections and abiotic stresses such as drought and nutrient deficiency. Continuous disease pressure results in a gradual decline in palm health, poor bunch development, and a shortened economic lifespan, ultimately requiring replanting and increasing long-term cultivation costs. Similar chronic effects have been noted in arecanut plantations throughout the Western Ghats, where unmanaged foliar diseases have significantly diminished palm vigor and yield potential (Hegde *et al.,* 2018). Moreover, prolonged disease prevalence in humid coastal areas has been shown to worsen stress-related disorders and diminish productivity amid changing climatic conditions (Patil *et al*., 2022). These findings highlight the urgent necessity for integrated and sustainable disease management strategies to protect both the productivity and economic viability of arecanut plantations in endemic regions.

Symptomatology

Arecanut leaf spot disease exhibits distinct foliar symptoms that aid in early diagnosis and management. The initial symptoms manifest as small, water-soaked lesions on the leaf lamina, which gradually develop into circular to irregular brown or dark brown spots surrounded by yellow halos. These lesions may merge, resulting in extensive necrosis and premature leaf drop, thereby diminishing the photosynthetic capacity and overall health of the palm (Pandian *et al*., 2024; Naik *et al.,* 2021). In severe cases, both the upper and lower leaf surfaces may display black, hair-like structures associated with *Colletotrichum* species, aiding in pathogen identification (Athira *et al*., 2017). The progression of the disease often leads to stunted growth, reduced nut production, and increased vulnerability to secondary infections, worsening yield losses (Krishnan *et al.,* 2023). Environmental factors, such as high humidity and temperature, further intensify the severity of the disease, underscoring the necessity for climate-adaptive management strategies (Hebbar *et al*., 2024).

Fig. 1: initial stage of symptom development small, yellowish to light brown spots scattered across the leaf lamina.

Fig 2: Numerous yellowish-brown, circular to oval spots scattered over the leaf and each lesion has a distinct yellow halo surrounding a dark brown to black necrotic center.

Fig. 3: Complete destruction of plant

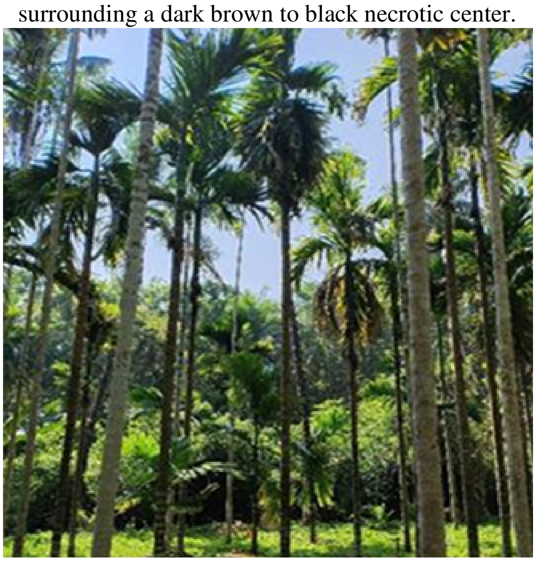

Fig. 4: Completely infected field

Etiology: The Causal Agent

Arecanut leaf spot disease is increasingly recognized as a complex of pathogens rather than being attributed to a single fungus. In the primary arecanut cultivation areas of northern Kerala and coastal Karnataka*, Colletotrichum gloeosporioides* and *Phyllosticta arecae* are commonly identified as the main agents responsible for epidemic outbreaks (Pruthvi Raj *et al*., 2023). Additionally, Pestalotia arecae (or Pestalotiopsis palmarum) *Curvularia* frequently co exists in infected materials, leading to mixed infections that enhance the complexity and severity of lesions (Nagesh and Latha, 2023).

A recent multi-gene phylogenetic study conducted across India has uncovered a broader diversity of Colletotrichum species linked to both leaf spot and inflorescence dieback in arecanut, indicating the potential emergence of cryptic and novel lineages (Anonymous, 2024). This implies that the pathogen complex is dynamic and evolving in response to local selection pressures. Surveys carried out in the hill and coastal regions of Karnataka have shown that *C. gloeosporioides* is often the dominant isolate in leaf spot epidemics, with disease severities exceeding 80% in certain taluks (Pruthvi Raj *et al*., 2023). Morphological and molecular characterization of *C. gloeosporioides* isolates from arecanut in Karnataka confirmed ITS rDNA identity, marking it as one of the first molecularly validated reports of this pathogen in Indian arecanut systems (Naik *et al*., 2022).

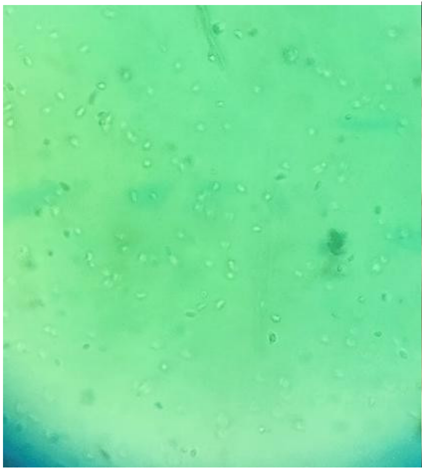

Fig. 5

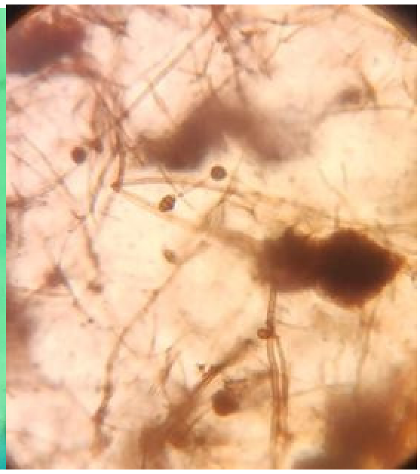

Fig. 6

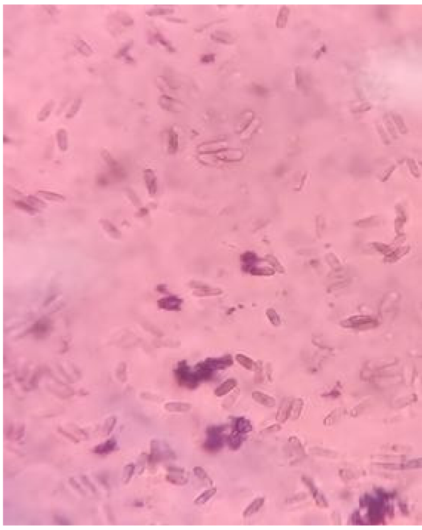

Fig. 7

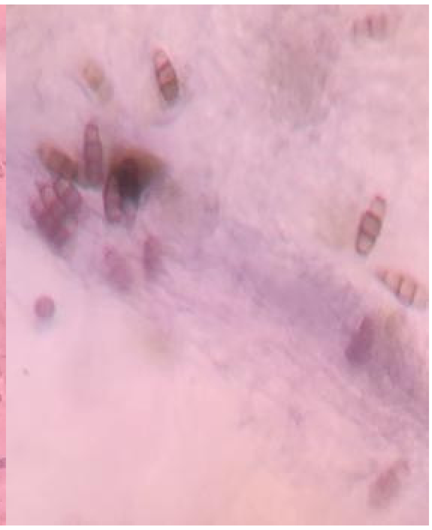

Fig. 8

Different type of spores; Fig 5: *Phyllosticta arecae,* Fig 6*: Curvularia*, Fig 7*: Colletotrichum gloeosporioides,* Fig 8*: Pestalotia arecae*

Morphological traits continue to serve as valuable first-line diagnostic features, though they have limitations. *Colletotrichum* spp typically produce acervuli on infected tissues, featuring dark setae (hair-like structures) and generating hyaline, often single-celled, cylindrical conidia. *Phyllosticta* species are distinguished by pycnidia that release hyaline conidia through an ostiole, often found in gelatinous masses (Prathibha *et al.,* 2024). *Pestalotiopsis or Pestalotia* conidia are fusiform, multiseptate, and may possess apical and basal appendages, facilitating their spread in humid conditions (Nagesh and Latha, 2023).

Due to morphological overlap and the existence of cryptic species, molecular diagnostics are increasingly becoming the standard for accurate identification. Multi-locus sequencing (e.g., ITS, β-tubulin, GAPDH, ACT) has been utilized in studies of arecanut pathogens to delineate species and evaluate genetic variability (Anonymous, 2024). These molecular investigations in India also indicate intraspecific variation and the possible emergence of more virulent genotypes under disease pressure. The evolving etiology of arecanut leaf spot characterized by pathogen diversity, mixed infections, and cryptic lineages highlights the necessity for continuous pathogen monitoring, molecular surveillance, and adaptive disease management strategies.

Epidemiology

The epidemiology of arecanut leaf spot disease is influenced by the intricate interactions among the pathogen, host, and environment, particularly in the humid tropics of northern Kerala and coastal Karnataka. The main pathogens *Colletotrichum gloeosporioides*, *Phyllosticta arecae,* and *Pestalotiopsis palmarum* utilize survival strategies that enable inoculum to persist across seasons. Infected leaf debris, fallen leaves, and crop litter serve as the primary reservoirs of inoculum, containing dormant mycelia, conidia, or sclerotia until favorable conditions return (Sharma *et al*., 2023; Nagesh and Latha, 2023).

These pathogens can survive for several months in plant debris under dry or suboptimal conditions, providing a source for primary infections in the following season (Anonymous, 2024). When conditions become favourable especially during the monsoon dispersal occurs through rain splash, wind currents, irrigation water, and mechanical contact (Pruthvi Raj *et al.,* 2023; Prathibha *et al*., 2024). High humidity (greater than 85–90%) and prolonged leaf wetness promote spore germination and appressoria formation, allowing for penetration into leaf tissue. Lesions develop, expand, and merge, resulting in premature defoliation and a decrease in photosynthetic capacity. Multiple infection cycles within a single season are common, particularly in dense plantings with inadequate ventilation (Anonymous, 2024; Prathibha *et al.,* 2024).

Environmental factors significantly impact disease severity. High rainfall, extended leaf wetness (12 hours or more), and temperatures ranging from 20 to 30 °C coincide with peak outbreaks (Prathibha *et al.,* 2024). Host factors such as varietal susceptibility, high planting density, shaded microclimates, and nutrient deficiencies (especially Nitrogen and Potassium) worsen disease severity (Ramesh *et al.,* 2023). Under these conditions, disease severity in some areas can exceed 80%, with yield losses surpassing 50% in poorly managed gardens (Pruthvi Raj *et al.,* 2024).

Understanding the persistence of inoculum, dispersal mechanisms, and environmental triggers is essential for developing targeted disease management strategies. Integrated approaches—such as field sanitation, canopy management, the use of resistant cultivars, nutrient optimization, and timely fungicide application can effectively lower inoculum levels and break the disease cycle.

Management Strategies for Arecanut Leaf Spot Disease

Effective management of arecanut leaf spot disease requires an integrated approach that combines cultural, chemical, and biological methods within an ecologically sustainable framework. The perennial nature of arecanut and the survival ability of *Colletotrichum* spp., *Phyllosticta arecae*, and *Pestalotiopsis* spp. in infected leaf litter necessitate proactive and site-specific interventions (Athira *et al*., 2023; Deepa *et al*., 2024). Cultural management forms the foundation of leaf spot control and serves as the first line of defence. Regular sanitation, including the removal and destruction of infected and fallen leaves, significantly reduces inoculum levels and limits pathogen spread within plantations (CPCRI, 2022; Nair *et al*., 2023). Maintaining adequate spacing and pruning overcrowded fronds enhances air circulation, lowers canopy humidity, and shortens leaf wetness duration, thereby creating unfavourable conditions for fungal sporulation and infection (Naik *et al.,* 2021). Proper water management is equally vital, as excessive moisture and waterlogging favor *Colletotrichum* proliferation; thus, ensuring efficient drainage, mulching, and controlled irrigation schedules can minimize disease incidence (Ramesh *et al*., 2022). Balanced nutrient application, especially of sufficient nitrogen and potassium, improves plant vigor and resistance, whereas nutrient deficiencies heighten susceptibility (Patil *et al*., 2024). Intercropping with non-host species, removal of alternate hosts, and maintenance of overall field hygiene further reduce the survival and spread of leaf spot pathogens (Sharma *et al*., 2023).

Chemical control remains an essential component of disease management, particularly during periods of high infection pressure. Field evaluations have demonstrated that systemic fungicides such as hexaconazole, propiconazole, and difenoconazole (0.1%) significantly reduce disease severity, often by 13–20% compared to untreated controls (Hegde, 2018; Kumar *et al.*, 2023). These fungicides inhibit ergosterol biosynthesis, suppressing pathogen growth and sporulation. Protectant fungicides, including Bordeaux mixture (1%), mancozeb (.3 %), and copper oxychloride (0.25%), are commonly applied as preventive sprays before the onset of monsoon or during early disease appearance (CPCRI, 2022; Thomas *et al.,* 2023). The initial spray is usually recommended at the appearance of the first symptoms, followed by two to three subsequent sprays at 20–30-day intervals (Rao *et al*., 2023). However, repeated and indiscriminate use of fungicides may lead to resistance and environmental pollution. To prevent these issues, the rotation of fungicides with different modes of action and integration with cultural and biological practices are critical for sustainable control (Patil, 2022; Bhat *et al*., 2025).

Biological control has gained increasing attention as an eco-friendly complement or alternative to chemical fungicides. Beneficial microorganisms such as *Trichoderma harzianum*, *T. viride*, and *Bacillus subtilis* have shown strong antagonistic activity against *Colletotrichum* spp. through mechanisms including mycoparasitism, antibiosis, and induction of systemic resistance (Prakash *et al*., 2023; Singh *et al.,* 2024). Application of these biocontrol agents as soil inoculants, seedling dips, or foliar sprays has resulted in significant reductions in disease severity while improving plant vigor and soil microbiome health. The efficacy of Trichoderma-based formulations increases when combined with organic amendments such as neem cake or farmyard manure (Joseph *et al.,* 2023). Furthermore, endophytic microbes and plant growth-promoting rhizobacteria have demonstrated potential in priming host defence mechanisms, thereby providing long-term protection against foliar pathogens (Ghosh *et al.,* 2024). Integration of these biological agents with low-dose chemical sprays or alternate applications can effectively manage disease while reducing chemical residues and resistance risks (Thomas *et al*., 2023).

An Integrated Disease Management (IDM) approach that strategically combines cultural, chemical, biological, and resistant variety deployment remains the most effective and sustainable strategy for managing arecanut leaf spot disease. IDM emphasizes regular monitoring, early diagnosis, and management decisions based on economic threshold levels to ensure targeted interventions (NIPHM, 2015; CPCRI, 2022). Disease forecasting models that use climatic parameters such as humidity and rainfall can predict potential outbreaks and optimize spray schedules (Kumar *et al*., 2023). The use of tolerant or resistant cultivars, along with proper canopy management, balanced fertilization, and water regulation, enhances plant resilience and reduces infection risk (Nair *et al*., 2023). The integration of biological control agents within IDM programs also contributes to long-term suppression of disease with minimal ecological impact (Prakash *et al.,* 2023). Collectively, these integrated strategies have been shown to significantly lower disease intensity, improve yield and nut quality, and enhance the economic and environmental sustainability of arecanut cultivation systems in India (CPCRI, 2022; Thomas *et al.,* 2023; Bhat *et al*., 2025).

Future Directions in Arecanut Leaf Spot Management

Arecanut (*Areca catechu* L.) is a plantation crop of significant economic importance, particularly in the tropical regions of India. Leaf spot disease, primarily caused by *Colletotrichum* species, continues to be a major threat to its productivity. Recent research has provided valuable insights into the epidemiology, pathogen identification, and management of this disease, revealing promising directions for future control strategies.

Accurate identification of the causal pathogens remains fundamental for effective management. Studies employing symptomatological, morphological, and molecular techniques have confirmed *Colletotrichum kahawae* subsp. *cigarro* and *Colletotrichum gloeosporioides* as predominant agents responsible for leaf spot in arecanut (Pandian *et al*., 2024; Nair *et al*., 2024). The adoption of advanced molecular tools such as ITS sequencing, multilocus phylogenetic analysis, and PCR-based detection methods has enhanced diagnostic precision and facilitated the differentiation of closely related species, enabling the development of more targeted disease control approaches.

Environmental factors such as temperature, humidity, and rainfall play a critical role in disease development and severity. Predictive modeling based on weather parameters has emerged as a key strategy for anticipating disease outbreaks. Machine learning algorithms trained on historical climate and disease datasets have demonstrated high accuracy in forecasting disease incidence, thereby allowing pre-emptive management interventions (Krishna *et al*., 2022; Rajashree *et al*., 2022). The integration of these predictive models into farm-level management systems allows for optimized timing of fungicide applications and other cultural practices, minimizing both disease impact and excessive chemical use.

Technological innovations in surveillance and management are shaping the next generation of arecanut disease control systems. IoT-based monitoring networks equipped with sensors for temperature, relative humidity, and soil moisture can collect real-time microclimatic data. When coupled with machine learning frameworks, these data streams facilitate accurate forecasting of disease risk and yield loss potential, empowering growers to apply timely preventive actions (Kanan *et al*., 2022). Remote sensing technologies, including unmanned aerial vehicles (UAVs) equipped with multispectral and hyperspectral sensors, offer high-resolution and non-destructive monitoring capabilities over extensive plantation areas. UAV-based systems can rapidly detect early signs of leaf spot infection, assess canopy health, and quantify disease severity across large-scale arecanut plantations (Lei *et al*., 2021; Prakash *et al*., 2023). These drone-based approaches significantly reduce labor intensity and enhance the spatial precision of disease surveillance, especially in regions where conventional field scouting is time-consuming or impractical.

Furthermore, advancements in artificial intelligence (AI) have revolutionized image-based disease detection. Convolutional neural networks (CNNs), support vector machines (SVMs), and other deep learning architectures have been successfully employed for the automated recognition and categorization of arecanut foliar diseases (Shedthi *et al*., 2023). These tools enable rapid and reliable disease diagnosis in real-time field conditions, reducing dependence on expert evaluations and supporting timely intervention.

Collectively, these emerging tools point toward a future of integrated, data-driven disease management in arecanut plantations. The convergence of molecular diagnostics, climate- based predictive analytics, IoT-enabled field monitoring, UAV-based remote sensing, and AI-assisted disease recognition represents a transformative shift toward precision phytopathology. Such interdisciplinary integration promotes sustainable disease control, resource optimization, and the long-term resilience of arecanut cultivation systems.

Conclusion

Arecanut leaf spot epidemics in Northern Kerala have become a significant obstacle to sustainable arecanut production, leading to considerable yield losses, economic difficulties, and long-term effects on plantation health. The frequent occurrence of this disease is closely associated with the region's humid tropical climate, which promotes the rapid growth and spread of key pathogens such as *Colletotrichum gloeosporioides, Phyllosticta arecae*, and *Pestalotiopsis palmarum*. The variability in disease incidence, ranging from mild leaf spotting to severe defoliation, highlights the complex interactions between pathogen virulence, host susceptibility, and environmental conditions. Traditional management practices, while somewhat effective, often fall short in controlling large-scale epidemics, especially in the face of changing climatic conditions. Recent advancements in disease monitoring, including molecular diagnostics, weather-based predictive modelling, and UAV-based remote sensing, present promising opportunities for early detection and timely interventions. However, sustainable management necessitates an integrated approach that combines cultural practices, resistant or tolerant cultivars, targeted fungicide applications, and continuous field monitoring. Additionally, enhancing farmer awareness, extension services, and capacity-building initiatives is essential for the adoption of integrated disease management strategies. Addressing these challenges comprehensively will not only reduce the impact of leaf spot epidemics but also enhance the long-term resilience and productivity of arecanut plantations in Northern Kerala.

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