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Integrated Management Strategies For Emerging Neem Diseases

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Neem (*Azadirachta indica* A. Juss.) is a highly valued multipurpose tree species widely distributed in tropical and subtropical regions, playing an important role in forestry, agroforestry, and urban green landscapes. Its adaptability to diverse environmental conditions, drought tolerance, and low maintenance requirements have encouraged extensive planting along roadsides, degraded lands, urban areas, and community forestry programs. Neem contributes to ecological stability by improving soil quality, supporting biodiversity, and regulating microclimate through shade provision, making it an essential component of sustainable land management and climate-resilient forestry systems (Elakovich, S. D. 1996; Adusei, 2022). In addition to ecological benefits, neem possesses significant medicinal, economic, and cultural value. Different plant parts such as leaves, bark, seeds, and oil contain bioactive compounds including azadirachtin, nimbin, and salannin, which exhibit antimicrobial, antifungal, insecticidal, and therapeutic properties. These phytochemicals have led to widespread use of neem in traditional medicine, organic agriculture, and natural pest management. Neem-based products are increasingly recognized as eco-friendly alternatives to synthetic pesticides, reinforcing their role in sustainable agriculture and integrated pest management systems (Adusei, 2022).

Despite its reputation as a hardy and disease-resistant species, increasing reports of emerging diseases such as twig blight, dieback, leaf spot, wilt, and general decline have raised concerns about neem health and long-term sustainability. These diseases are often associated with fungal pathogens and environmental stress factors, including climate change, urban stressors, pathogen evolution, and improper management practices, which collectively increase tree susceptibility and disease severity. Early detection and improved understanding of disease dynamics are therefore essential to prevent large-scale decline and maintain ecological and economic benefits (Elakovich, S. D. 1996).

Traditional single-control methods are often insufficient to manage complex disease systems. Integrated disease management (IDM), combining cultural practices, biological control, host resistance, monitoring, and judicious chemical use, provides a sustainable framework to enhance neem resilience and ensure long-term ecosystem health.

Major Emerging Diseases of Neem

Neem (*Azadirachta indica*), despite its well-known resilience and antimicrobial properties, is increasingly affected by several emerging diseases (Fig. 1) that threaten tree health and productivity. These diseases are primarily linked to fungal pathogens, environmental stress, and complex biotic–abiotic interactions (Elakovich, 1996; Adusei, 2022; Kumar *et al*., 2021; Katan, 2017). Twig blight and dieback are commonly observed in plantations and urban landscapes, characterized by drying of twigs, vascular necrosis, leaf yellowing, canopy thinning, and branch mortality, often associated with *Phomopsis*, *Fusarium*, and *Lasiodiplodia*, particularly under drought, injury, or nutrient stress (Girish *et al*., 2009; Sharma & Florence, 1997; Ray *et al*., 2022). Leaf spot and foliar diseases cause necrotic lesions, chlorosis, premature leaf fall, and reduced photosynthetic efficiency, leading to weakened growth (Sharma *et al*., 2020; Kumar *et al*., 2021). Root rot and wilt diseases, caused by soil-borne pathogens, result in wilting, root decay, and plant death, especially in poorly drained or compacted soils (Katan, 2017; Sharma & Florence, 1997). Additionally, climate variability, drought, urban pollution, and pest–pathogen interactions contribute to region-specific disease patterns, emphasizing the need for continuous monitoring and adaptive management (Ray *et al*., 2022; Mekouar, 2020, 2021).

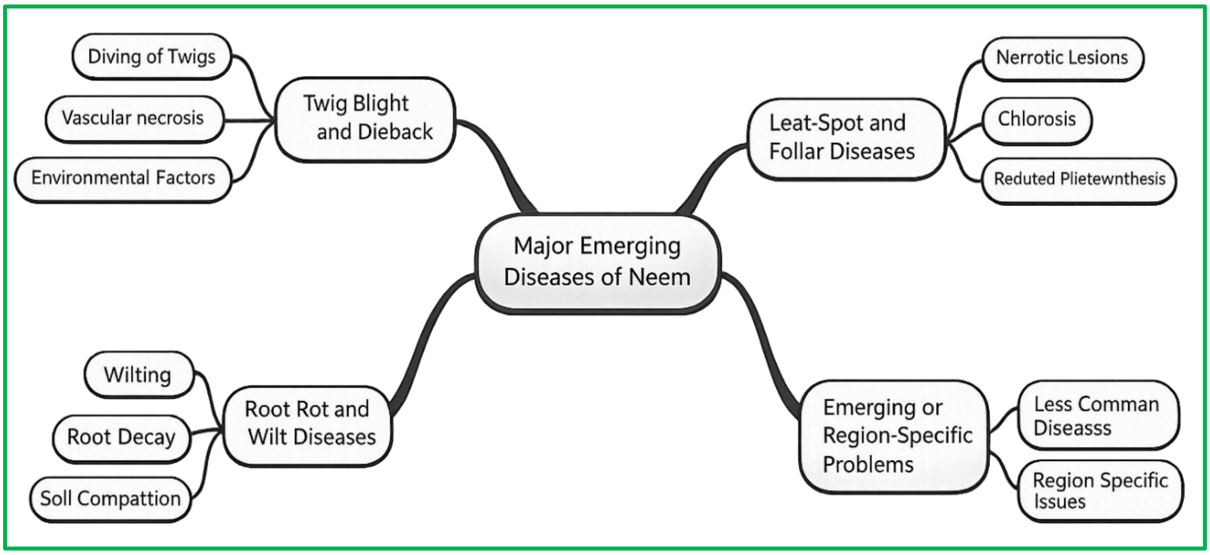

Fig 1. Major emerging diseases of Neem

Factors Contributing to Disease Emergence

The increasing incidence of diseases in neem (*Azadirachta indica*) plantations and urban environments results from combined environmental, biological, and management-related pressures. Despite its reputation as a hardy species, changing ecological conditions and anthropogenic stressors are enhancing disease susceptibility, emphasizing the need for integrated disease management strategies (Elakovich, 1996; Adusei, 2022).

Climate Change (Temperature and Drought Stress): Climate variability, including rising temperatures, irregular rainfall, and prolonged drought, influences pathogen survival and host resistance. Drought stress reduces physiological vigor and nutrient uptake, predisposing neem to opportunistic pathogens and intensifying dieback and decline. Altered climatic conditions may also modify host–pathogen dynamics and expand pathogen distribution ranges (Mekouar, 2020, 2021; Ray *et al*., 2022).

Urban Pollution and Soil Compaction: Urban stressors such as air pollution, heavy metals, and soil compaction impair photosynthesis, root growth, and water infiltration. These factors create chronic stress that weakens natural defense mechanisms and increases vulnerability to fungal infections (Adusei, 2022).

Poor Plantation Management Practices: High planting density, inadequate sanitation, improper pruning, and poor irrigation promote pathogen survival and disease spread, especially in monoculture systems with reduced genetic diversity.

Pathogen Evolution and Spread: Genetic adaptation, global plant movement, and nursery trade facilitate the emergence and dissemination of aggressive pathogen strains, highlighting the importance of molecular monitoring (Girish *et al*., 2009).

Abiotic Stress Increasing Susceptibility: Abiotic factors such as nutrient deficiency, salinity, and waterlogging weaken host defenses and reduce secondary metabolite production, leading to gradual decline and increased disease risk (Elakovich, 1996; Adusei, 2022).

Disease Diagnosis and Monitoring

Effective disease diagnosis and monitoring are essential components of integrated disease management (Fig 2) in neem (*Azadirachta indica*), enabling early detection, accurate pathogen identification, and timely interventions to minimize disease spread in forestry and urban ecosystems (Elakovich, 1996; Adusei, 2022). Field symptom assessment involves systematic observation of twig drying, chlorosis, necrosis, wilting, and branch dieback, supported by visual surveys, disease rating scales, and regular monitoring to assess incidence, severity, and spatial distribution of diseases. Laboratory isolation and identification provide confirmation of causal agents through culture-based techniques and morphological and microscopic analyses, allowing accurate identification of pathogens such as *Phomopsis* and *Fusarium* and differentiation between primary pathogens and secondary colonizers (Sharma & Florence, 1997).

Advances in molecular diagnostics, particularly PCR-based methods targeting ITS regions, enable rapid and sensitive detection of pathogens at early infection stages; PCR detection of *Phomopsis azadirachtae* has proven effective for diagnosing neem dieback (Girish *et al*., 2009). Integrating field observations with laboratory and molecular tools strengthens early warning systems, reduces disease-related losses, and supports sustainable disease management under changing environmental conditions (Mekouar, 2020, 2021; Ray *et al*., 2022).

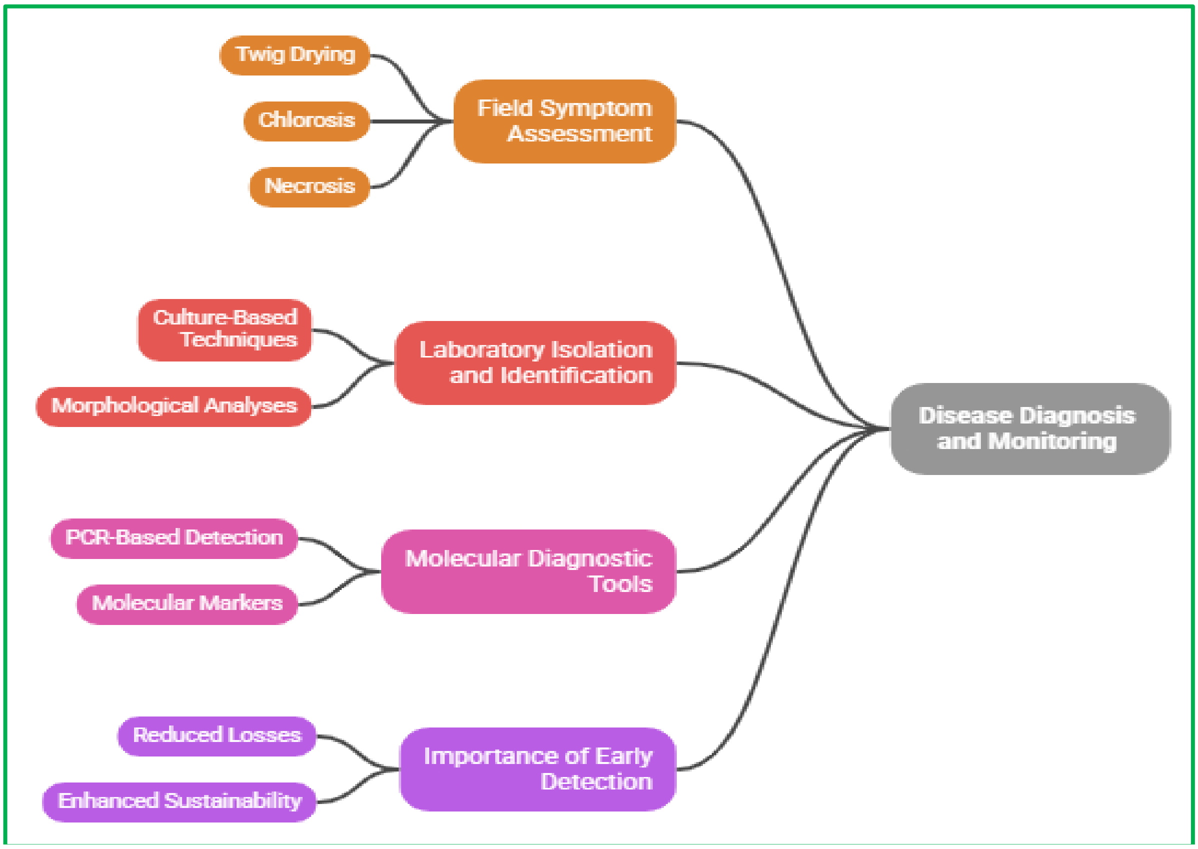

Fig. 2 Disease Diagnosis and Monitoring

Integrated Disease Management Strategies

Integrated disease management is essential for maintaining (Fig 3) the health and productivity of neem (*Azadirachta indica*) in forestry, agroforestry, and urban ecosystems. Because neem diseases result from interactions among pathogens, environmental stress, and host susceptibility, a holistic approach combining cultural, biological, chemical, and genetic strategies is required for sustainable control (Elakovich, 1996; Adusei, 2022).

Cultural Practices: Cultural methods reduce disease pressure by improving tree vigor and minimizing pathogen spread. Proper spacing enhances air circulation while pruning and sanitation remove infected tissues and reduce inoculum sources. Appropriate site selection, well-drained soils, balanced nutrition, and proper irrigation strengthen plant health and reduce susceptibility to root and foliar diseases.

Biological Control: Beneficial microbes such as *Trichoderma* and *Pseudomonas* suppress pathogens through competition, antibiosis, and induced resistance. Endophytic microorganisms also contribute to natural disease suppression and improved plant growth, offering environmentally sustainable alternatives (Adusei, 2022).

Chemical Management: Targeted fungicide applications may be used during severe outbreaks but should be applied judiciously with rotation of active ingredients to prevent resistance and environmental impacts.

Host Resistance and Genetic Selection: Selection of disease-tolerant neem genotypes enhances long-term resilience and reduces reliance on chemicals.

Integrated Pest and Disease Management (IPDM): IPDM integrates cultural, biological, and chemical strategies to promote sustainable disease control and ecosystem health (Mekouar, 2020, 2021; Ray *et al*., 2022).

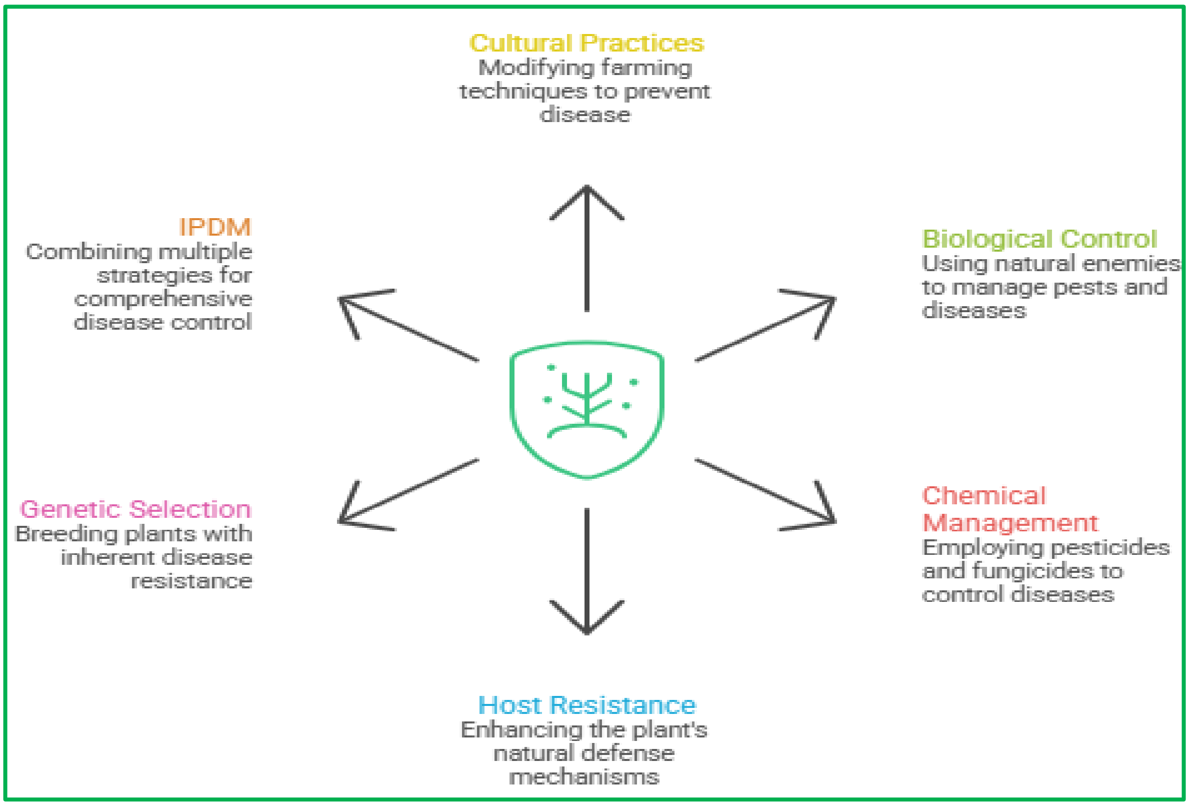

Fig. 3 Integrated Disease Management Strategies

Future Research Needs

Emerging disease challenges in neem (*Azadirachta indica*) highlight the need for advanced research integrating molecular biology, climate adaptation, microbiome-based solutions, and improved monitoring systems to support sustainable management and long-term forest health (Elakovich, 1996; Adusei, 2022).

Molecular Studies on Pathogens: Molecular tools such as PCR, DNA sequencing, and phylogenetic analysis enable early pathogen detection and improved understanding of pathogen diversity and host–pathogen interactions. PCR-based identification of *Phomopsis azadirachtae* demonstrates the value of molecular diagnostics in disease surveillance (Girish *et al*., 2009).

Climate-Resilient Neem Varieties: Research should focus on developing drought- and heat-tolerant neem genotypes through genetic studies and breeding programs to address climate-driven disease risks (Mekouar, 2020; Ray *et al*., 2022).

Microbiome-Based Disease Suppression: Exploring rhizosphere and endophytic microbes such as *Trichoderma* may enhance natural disease resistance and soil health (Adusei, 2022).

Early Warning Systems: Integration of remote sensing, climate modeling, and field monitoring can improve early detection and proactive disease management (Mekouar, 2020, 2021).

Conclusion

Neem is facing increasing disease problems due to the combined effects of environmental stress, changing climate, evolving pathogens, and improper management practices. Although neem is known for its hardiness and natural medicinal properties, rising temperatures, drought, pollution, and new pathogen strains are weakening its overall health. Therefore, managing neem diseases requires a complete and practical approach rather than depending on a single method. Early diagnosis through regular field observation and simple laboratory tools is very important. Improving cultural practices such as proper spacing, pruning, sanitation, and soil management can strengthen tree health. Using beneficial microbes and selecting disease-tolerant neem varieties can further reduce disease risk. Combining pest and disease management with climate-resilient forestry practices will help neem trees adapt to environmental changes. Continued research, better monitoring systems, and early warning approaches are also necessary. A well-planned, science-based strategy will help protect neem trees and maintain their ecological, economic, and social importance for future generations.

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