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Review Article

Recent Advances in Plant Pathology: A review from Nigerian Perspective

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Abstract

Plant diseases caused by fungi, oomycetes, bacteria, viruses and plant-parasitic nematodes remain important constraints to crop productivity, food security and farmers' livelihoods. Effective management depends on timely detection, reliable identification of the causal organism and interpretation of diagnostic results within the epidemiological context of the crop and production environment. This narrative review examines conventional and emerging approaches to plant disease detection, with emphasis on their relevance to agricultural conditions in Nigeria. Conventional methods—including field symptom assessment, microscopy and pathogen isolation—remain important because they provide useful biological evidence, but may be limited by symptom overlap, slow pathogen growth, latent infection and specialist skill requirements. Molecular methods such as PCR and sequencing improve pathogen detection and characterization, while immunological assays and emerging biosensors can support targeted diagnosis. Imaging, machine learning, deep learning and remote sensing offer opportunities for non-destructive surveillance, but model performance may decline when systems trained on controlled images are applied to diverse field conditions. Nigerian examples, including molecular characterization of papaya bunchy-top-associated phytoplasma and research on plant-parasitic nematodes, demonstrate the value of combining morphological, biological and molecular evidence. The review argues that no single diagnostic method is adequate for every pathosystem. A tiered approach linking field surveillance, laboratory confirmation, digital tools and extension services is more appropriate. Priorities for Nigeria include locally validated diagnostic protocols, stronger plant-health surveillance, accessible laboratory capacity, representative image and pathogen databases, and sustained collaboration among universities, research institutes, regulators and farmers.

Keywords: *Machine Learning; Molecular Diagnostics; Next-Generation Sequencing; Nigeria; Plant Pathology; Plant Disease Diagnosis; Remote Sensing*

Introduction

This article is a narrative review of conventional and emerging approaches to plant disease detection, with a Nigeria-focused discussion of their potential application. It synthesizes selected peer-reviewed literature and documented Nigerian case studies; it is not presented as a systematic review or meta-analysis. Accordingly, no claim of exhaustive database searching or quantitative pooling is made.

Plant diseases threaten food availability, agricultural productivity, and the income of farming communities across the world. A broad range of pathogens—including fungi, bacteria, viruses, and nematodes—can infect plant organs such as leaves, stems, roots, and fruits. Symptoms may include

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discolouration, lesions, and wilting, while severe infections can reduce crop yield and quality. The global burden of plant pathogens and pests is substantial, although its magnitude varies by crop, pathogen, location, and production system (Savary *et al*., 2019; Strange & Scott, 2005). Reliable early diagnosis and appropriate disease control are therefore important for limiting losses and maintaining sustainable crop production (Oliver, 2024; Venbrux *et al*., 2023). Historically, plant pathologists have used visual examination, microscopy, and the isolation and cultivation of suspected pathogens to diagnose diseases. These methods remain useful sources of diagnostic evidence, but they may be slow, labour-intensive, and dependent on specialist skills (Venbrux *et al*., 2023; Patel *et al*., 2023). Diagnosis can also be difficult when different diseases produce similar symptoms or when infections are latent or at an early stage.

Molecular and other advanced diagnostic approaches can help identify certain infections before obvious symptoms develop, allowing earlier management decisions. PCR-based assays, sequencing technologies, and immunological methods provide complementary forms of evidence for pathogen detection and identification (Azizi *et al*., 2022; Venbrux *et al*., 2023; Patel *et al*., 2023). Computational tools are also being used alongside conventional diagnosis to monitor plant health. Machine-learning and deep-learning systems can examine plant images and classify visible symptoms, although their performance depends on the quality and representativeness of the images used for training and validation (Jackulin & Murugavalli, 2022; Pacal *et al*., 2024; Jelali, 2024).

Literature Review

Classification and Impacts of Plant Diseases

Plant diseases may be grouped according to their causal agents, including fungal, bacterial, viral, and nematode-associated diseases, as well as disorders caused by other biological agents or non-infectious factors. This classification supports diagnosis, epidemiological investigation, research, and the selection of suitable management measures (Oliver, 2024). Powdery mildew, rust, and late blight are examples of important diseases that can cause serious losses in crop yield and quality. The consequences of disease are not uniform: crop susceptibility, pathogen biology, environmental conditions, and the timing of intervention all influence disease development and resulting losses (Savary *et al*., 2019; Strange & Scott, 2005).

Table 1: *Examples of Plant Diseases, their Causal Agents, Affected Crops and Typical Symptoms*

Disease	Causal Agent	Major Crops Affected	Typical Symptoms
Late blight	Phytophthora infestans	Potato, tomato	Leaf spots and stem lesions
Powdery mildew	Erysiphe spp.	Wheat, grapes	White, powder-like growth on leaves
Bacterial wilt	Ralstonia solanacearum	Tomato, potato	Wilting and yellowing
Tobacco mosaic	Tobacco mosaic virus	Tobacco	Mosaic patterns and stunted growth
Root-knot nematode disease	Meloidogyne spp.	Tomato, carrot	Root galls and impaired nutrient uptake

Bacterial diseases, including bacterial wilt and bacterial leaf spot, affect many crops and may spread quickly when conditions favour infection. Plant viruses can cause symptoms such as stunting, leaf colour changes, and mosaic patterns, while plant-parasitic nematodes injure roots and reduce the plant's ability to absorb water and nutrients. Accurate identification is important because symptoms alone may not reliably distinguish between pathogens or separate infectious diseases from abiotic disorders (Oliver, 2024; Venbrux *et al*., 2023; Pun *et al*., 2024). Collectively, plant pathogens and pests place a substantial burden on crop production and global food security through losses in both yield and product quality (Savary *et al*., 2019; Strange & Scott, 2005).

Modern Diagnostic Technologies in Plant Pathology

Molecular and Immunological Techniques

Molecular diagnostic tools detect pathogen-associated nucleic acids or proteins and can improve the sensitivity and specificity of diagnosis when assays are appropriately designed and validated. Conventional PCR amplifies a selected DNA target, whereas reverse-transcription PCR is used when the target is RNA. Real-time quantitative PCR (qPCR) monitors amplification during the reaction and can support sensitive detection and, where properly calibrated, quantification. Loop-mediated isothermal amplification (LAMP) offers an alternative that operates at a constant temperature and may be useful where access to conventional thermal cyclers is limited. However, assay performance depends on primer or probe specificity, extraction quality, inhibitors in plant tissue, appropriate controls and genetic variability of the pathogen (Azizi *et al*., 2022; Venbrux *et al*., 2023; Cubero *et al*., 2024).

Computational, Imaging and Remote-Sensing Approaches

Image analysis, machine learning, deep learning and remote sensing are increasingly used to support plant disease surveillance. Convolutional neural networks can learn image features for classification, detection and segmentation, while conventional machine-learning methods may use manually extracted colour, texture and shape features. These systems can assist rapid screening, but an image classifier identifies visual patterns rather than proving the presence of a particular pathogen. Nutrient deficiency, drought, chemical injury and multiple infections may produce similar symptoms. Image-based predictions should therefore be treated as screening evidence and, where consequential decisions are involved, confirmed through field assessment or laboratory testing (Jackulin & Murugavalli, 2022; Pacal *et al*., 2024; Cubero *et al*., 2024).

Conventional Diagnostic Approaches

Visual inspection: This widely used, low-cost approach involves looking for symptoms such as leaf spots, wilting, and changes in colour. It is useful for preliminary field assessment, but symptoms may be ambiguous and assessments may vary between observers. Infections that are latent or at an early stage may also go unnoticed, so visual inspection is often strengthened by laboratory confirmation where available (Venbrux *et al*., 2023; Patel *et al*., 2023).

Microscopy: Microscopic examination can reveal structures associated with disease, including bacterial cells and fungal spores. It remains important for observing diagnostic structures and supporting morphological identification, although interpretation requires suitable equipment and trained personnel. For organisms that cannot be reliably distinguished by morphology alone, microscopy may need to be combined with molecular methods (Venbrux *et al*., 2023; Pun *et al*., 2024).

Culture-based techniques: Suspected fungi, bacteria, and other culturable microorganisms can be isolated and grown on appropriate media to assist identification. Isolation can provide material for further morphological, physiological, and molecular characterization. However, culture-based methods are not suitable for every pathogen and may be labour-intensive and slow, limiting their suitability for rapid or large-scale testing (Venbrux *et al*., 2023; Patel *et al*., 2023).

Molecular Diagnostic Methods

Molecular techniques have strengthened pathogen identification by providing evidence that is less dependent on visible symptoms or the ability to culture an organism. PCR-based assays are useful when the suspected pathogen and a suitable target sequence are known. Sequencing provides additional information for taxonomic identification, strain comparison and phylogenetic analysis. Next-generation sequencing can investigate complex microbial communities and mixed infections, including organisms that are difficult to culture. Nevertheless, detection of pathogen DNA or RNA does not always demonstrate that the organism is alive or is the cause of the observed symptoms. Results should be interpreted alongside symptomatology, isolation or other supporting evidence, sequence quality, reference-database coverage and contamination controls (Venbrux *et al*., 2023; Cubero *et al*., 2024).

Table 2: *Examples Of Molecular Techniques Used to Detect Plant Pathogens*

Technique	Description and Application	Sources
Polymerase chain reaction (PCR)	Amplifies selected pathogen-specific DNA or RNA sequences and can support sensitive detection and early diagnosis.	Azizi *et al*. (2022); Venbrux *et al*. (2023)
Enzyme-linked immunosorbent assay (ELISA)	Detects particular pathogen-associated antigens or proteins and is commonly used to test for several plant viruses and bacteria.	Azizi *et al*. (2022); Venbrux *et al*. (2023)
Next-generation sequencing (NGS)	Provides broad genetic information and can help identify known, novel, mixed, or difficult-to-culture pathogens.	Azizi *et al*. (2022); Venbrux *et al*. (2023)

Imaging and Computational Diagnosis

Digital imaging and computational analysis can quantify visible disease symptoms and support repeatable assessment over time. Image-processing methods may measure lesion area, chlorosis and necrosis, while machine-learning models classify or locate symptoms in images. A major limitation is the domain gap between controlled image datasets and actual farms. A 2024 review focused on tomato disease and pest detection found that relatively few studies used images collected in real agricultural settings; models trained on uniform-background images may therefore report performance that does not transfer reliably to field conditions (Jelali, 2024). Systematic reviews also identify dataset imbalance, inconsistent annotation and limited external validation as recurring concerns (Pacal *et al*., 2024; Antwi *et al*., 2024).

Table 3: *Examples of Computational and Imaging Techniques Used in Plant Disease Detection*

Technique	Description and Application	Sources
Image processing	Digital analysis of plant images can help detect and measure visible disease symptoms quickly.	Mahlein (2016); Yang (2020); Jackulin & Murugavalli (2022)
Machine learning and deep learning	Computational models can classify symptoms in plant images and assist automated disease monitoring.	Pardede *et al*. (2020); Jackulin & Murugavalli (2022)
Remote sensing	Drones, satellites, and multispectral or hyperspectral sensors can help monitor crop disease and stress across fields.	Mahlein (2016); Yang (2020)

Remote-sensing tools—including unmanned aerial vehicles, satellites and multispectral or hyperspectral sensors—can survey crop canopies and detect changes associated with disease or other plant stresses. Spectral measurements may reveal changes in pigments, water status and canopy structure before symptoms are easily distinguished by the human eye. However, these signals are not necessarily pathogen-specific: drought, nutrient stress, crop age and canopy density can produce overlapping responses. Remote sensing is therefore most useful when combined with ground-truth observations, weather information and laboratory diagnosis of representative samples (Mahlein, 2016; Oerke, 2020; Terentev *et al*., 2022; Cubero *et al*., 2024).

Emerging Approaches: Biosensors and High-Throughput Diagnostics

Plant disease diagnostics are also moving towards portable and high-throughput platforms. Biosensors combine a biological recognition element with a signal-transduction system to detect target molecules or pathogen-associated components. Their potential advantages include rapid analysis, small sample requirements and possible use outside centralized laboratories. Practical deployment nevertheless requires evaluation of analytical sensitivity, specificity, reproducibility, shelf life, sample preparation, cost and performance in complex plant extracts. A positive sensor response should not be interpreted as definitive pathogen identification unless the device has been validated against an accepted reference method (Venbrux *et al*., 2023; Cubero *et al*., 2024; Bukhamsin *et al*., 2025).

Integrated Diagnosis and the Importance of Pathogen Confirmation

An effective diagnostic workflow commonly proceeds from field observation to sample collection, preliminary examination and confirmatory testing. Symptom assessment helps identify the affected plant organ and guide sampling, while microscopy and culture can provide morphological or biological evidence. Molecular assays can confirm the identity of a suspected pathogen, and sequencing can resolve uncertain identifications or investigate genetic relationships. This integration is important because a molecular test may detect nucleic acid from non-viable organisms or incidental members of

the plant microbiome. Where causal attribution is required, diagnosis should consider symptom consistency, pathogen detection, isolation or other supporting evidence, and pathogenicity testing when appropriate (Venbrux *et al*., 2023; Cubero *et al*., 2024).

Relevance and Current Evidence from Nigeria

Nigeria's varied agroecological zones support the production of cereals, roots and tubers, legumes, vegetables and fruit crops, but they also create diverse environments in which plant pathogens and pests occur. The national plant-health context should not be treated as uniform: pathogen prevalence, seasonal risk, host susceptibility and access to diagnostic services can differ among humid southern areas, derived savannas and northern savanna zones. A national perspective therefore requires surveillance records and crop-specific evidence rather than extrapolation from a small number of locations.Published Nigerian research illustrates why integrated identification is important. Abdulsalam *et al*. (2021) reviewed plant-parasitic nematodes affecting major cereals in Nigeria and emphasized the need to combine morphological, biochemical and molecular approaches because morphology alone can be difficult to interpret and diagnostic expertise is limited. Their review also noted that reliable crop-loss information and distribution records remain incomplete for several crops and regions. This is an important evidence gap: the absence of a published record should not automatically be interpreted as the absence of a pathogen. A further example is the molecular investigation of papaya bunchy-top disease in Ibadan, Oyo State. Kazeem *et al*. (2021) used PCR, sequence analysis and phylogenetic methods to identify phytoplasma associated with the disease and characterized the detected strains as a distinct subgroup. This study demonstrates the contribution of molecular tools to recognizing and characterizing plant pathogens in Nigeria. It also shows how local diagnostic investigations can contribute to knowledge of pathogen diversity and inform plant-health surveillance.

Research on African yam bean in south-west Nigeria has also combined fungal isolation, morphological examination, reinoculation and ITS sequence confirmation to investigate fungal diseases (Oyedele *et al*., 2024). Such work illustrates the value of combining classical plant pathology with molecular identification. However, findings from one crop or region should not be generalized to all Nigerian production systems without additional surveys.For Nigeria, the practical question is not simply whether advanced technologies exist, but whether they can be maintained, validated and made accessible to the institutions and farmers who need them. Investment priorities include trained plant diagnosticians, functional laboratories, reliable reagent supply, sample referral networks, standardized protocols, digital data management and stronger links between research institutes, universities, extension services and plant-health regulators. Molecular and imaging technologies should complement—not replace—field scouting, crop knowledge and integrated disease management.

Key Research Gaps and Priorities

Several gaps limit the translation of recent diagnostic advances into routine plant-health practice. First, pathogen distribution and disease-loss data are incomplete for some crops and agroecological zones in Nigeria (Abdulsalam *et al*., 2021). Second, diagnostic capacity is uneven, and advanced molecular or sequencing methods may not be available for routine use in every location. Third, many image-based models are developed using datasets that do not adequately represent field variability, limiting their transfer to farms (Jelali, 2024; Antwi *et al*., 2024). Fourth, studies may report pathogen detection without sufficiently distinguishing detection from proof of causation or pathogen viability (Cubero *et al*., 2024).

Future research should establish crop- and region-specific surveillance programmes; generate well-curated reference collections of pathogens and sequence data; validate molecular assays against diverse local isolates; and build image datasets that include different cultivars, growth stages, lighting conditions, disease severities and non-infectious look-alike symptoms. Research should compare the full costs of diagnostic workflows, including equipment, consumables, transport, staff training and maintenance. Studies should also report diagnostic sensitivity, specificity, reproducibility and external validation transparently so that farmers, extension personnel and policy makers can judge the practical value of new tools.

Comparative Assessment of Diagnostic Approaches

Reliable plant disease diagnosis often benefits from using complementary methods rather than depending on a single technique. Visual inspection, microscopy, and culture-based procedures are established approaches that can provide useful preliminary or confirmatory evidence, but they may be slow or may miss infections that have not yet produced clear symptoms. Molecular tools such as PCR, ELISA, and sequencing can offer sensitive and specific detection, although they may require specialized equipment, trained staff, and careful quality control (Azizi *et al*., 2022; Venbrux *et al*., 2023; Patel *et al*.,

2023). Imaging and computational methods can support rapid monitoring over large areas, but their performance depends on representative data, proper validation, and the conditions under which they are deployed (Oerke, 2020; Pacal *et al*., 2024; Jelali, 2024).

Practical Performance and Implementation Considerations

The suitability of a disease-detection approach should be judged using several criteria, including accuracy, sensitivity, speed, cost, scalability, and the purpose for which it will be used. Traditional approaches remain useful for initial assessment and diagnostic confirmation, while molecular assays can provide high analytical sensitivity and specificity when properly designed and validated. Imaging and computational systems offer the possibility of rapid, non-destructive monitoring at scale, but they depend on representative data, technical capacity, and validation in the conditions where they will be applied (Cubero *et al*., 2024; Mahlein, 2016; Venbrux *et al*., 2023; Pacal *et al*., 2024). For Nigeria, the practical value of these technologies should also be considered in relation to laboratory access, equipment maintenance, reagent supply, staff training, internet connectivity, and affordability. Local validation is necessary before methods developed elsewhere are assumed to perform equally well under Nigerian production conditions.

Conclusion

This review demonstrates that recent advances in plant pathology have expanded the range of tools available for detecting and characterizing plant pathogens. Conventional field assessment, microscopy and culture remain important because they provide biological and morphological evidence and can be used in settings where advanced equipment is unavailable. Molecular methods, including PCR and sequencing, improve the precision of pathogen identification and can reveal genetic relationships, while imaging, machine learning and remote sensing offer new opportunities for rapid and non-destructive crop surveillance. However, each approach has limitations. Symptoms may be non-specific, molecular detection does not always establish pathogen viability or causation, and image-based models may not generalize from controlled datasets to real farms.

Future Directions

No single method is ideal for every crop, pathogen or diagnostic setting. A tiered system that combines field observation, suitable laboratory tests, sequencing where necessary, and carefully validated digital tools is more defensible than reliance on any one technology. For Nigeria, the evidence points to the need for stronger crop- and region-specific surveillance, improved diagnostic infrastructure, locally validated assays, representative field-image datasets, trained personnel and sustained collaboration among researchers, extension services and plant-health authorities. Future studies should report methods and diagnostic performance transparently and distinguish pathogen detection from proof of disease causation. Such priorities can help ensure that technological advances are translated into practical, affordable and sustainable plant-health services.

Conflict of Interest

The authors declare they have no conflict of interest.

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