Chapter 3

Biosensors on the Field: Early Disease Detection in Crops

Wisdom Leaf Press
Pages number, 12–18

https://journals.icapsr.com/index.php/wlp
DOI: 10.55938/wlp.v1i2.105

Mansi Sahu[1], Shailendra Thapliyal[2] and Mohammed Ismail Iqbal[3]

Abstract

Biosensors are frequently employed in plant disease detection and cellular process understanding. This review examines their usage in agriculture with a particular emphasis on their function in identifying and managing biotic and abiotic hurdles. This article examines the possibilities of biosensor approaches based on nanoparticles for identifying and managing plant diseases in agriculture, contrasting established practices with novel sensing technologies and resolving limitations. Nano-biosensors have developed rapidly in recent years as a result of modifications and customizations known as "nano-tuning" that make advantage of nano-material properties. This leads to the creation of "Next Gen Nano-inspired Biosensors," that integrate well-known biosensors and biosensing technologies with adaptable nanomaterials or nanocomposites. Using probabilistic data to improve analysis rate, the paper unveils Preemptive Classification using Discrete Data (PC-DD). Once the detection phase is finished, data is classified utilizing a random forest technique that combines probability, difference, and series. This research investigates the use of Convolutional Neural Network (CNN)-based Feature Extraction and Feature Classification techniques for the detection of Plant Disease employing Near-infrared and Red, Green, and Blue (RGB) imaging. To extract unique labels, a Wasserstein Distance-based Feature Extraction Model and a specially designed sensor are implemented.

Keywords

Biosensor Technologies, Nano-Biosensors, Nanomaterial-Based Bio-Sensing Devices, Nano Ciagnostic Kits, Transistor-Based Biosensor

1. Introduction

The demand for equipment to identify and treat plant diseases is growing since existing approaches require three to five days of labor-intensive work and early identification is critical for agricultural yield and

[1]Division of Research & Innovation, Uttaranchal University, Dehradun, mansi.smile.1999@gmail.com
[2]Uttaranchal Institute of Management, Uttaranchal University, Dehradun, India, shailendra@uumail.in
[3]College of Engineering and Technology, University of technology and sciences, NIZWA

Corresponding Author:
E-mail id: mohammed.iqbal@utas.edu.om

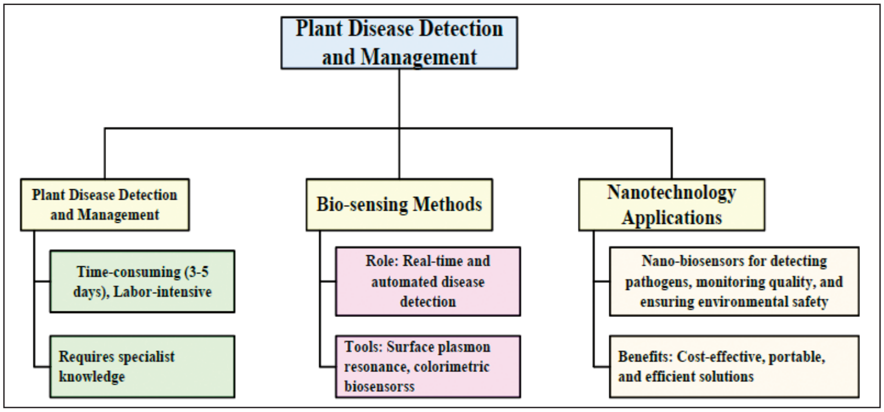

Figure 1. Early Identification and Management of Plant Diseases

population development worldwide [1]. Technological advancements in bio-sensing methods enhance early detection for accurate forecasts, management plans, and crop losses, promoting sustainable crop protection through automated and real-time monitoring [2]. Plant pathogen control strategies rely on disease identification, but novel approaches are more cost-effective and time-efficient than traditional laboratory-based methods due to their lack of specialist knowledge [3]. Nanotechnology is revolutionizing the agricultural industry by providing practical methods for crop protection and early microbe identification. It manages pesticide-related environmental concerns and improves air, water, and soil quality, enabling early identification and prevention of microorganisms in crops [4]. Early identification of plant diseases is crucial for farmers to prevent crop failure. Biosensor technologies like surface plasmon resonance, colorimetric biosensors, and fluorescence-based experiments enhance agricultural techniques, ensuring precise analysis and minimal errors in disease-related characteristics [5]. Nanotechnology enables the development of nano-biosensors, compact analytical tools for monitoring the environment, quality assurance, agriculture, and healthcare, providing easy-to-use methods for diagnosing and detecting plant diseases [6]. In modern agriculture, infection detection is crucial, necessitating new, affordable, portable, and quick diagnostic techniques like bio-sensors, as conventional methods are costly and labour-intensive [7]. Nanotechnology-inspired biosensors significantly impact environmental sciences, health, and quality control by identifying microRNAs, phytohormones, abiotic stressors, and plant pathogens. These chemical sensors, sensitive to heat, acidity, and metabolism changes, provide crucial insights into vital functions like growth, respiration, photosynthesis, and nutrient transmission [8]. New sensor technologies are being developed to accurately identify crop stresses, enabling effective management and enhancing our understanding of plant stressors, to ensure sustainable output and meet food, fuel, fiber, and fodder demands [9]. Plant diseases significantly impact crop yields, affecting global productivity and food security. Chemical treatment remains the primary method to prevent illness prevalence [10]. Figure 1 shows early identification and management of plant diseases

2. Early Disease Detection in Crops

Agricultural ecosystems are adversely affected by ecological issues like pesticide residues, heavy metal accumulation, and toxic element pollution. Such health issues as nerve and bone marrow abnormalities, metabolic disorders, infertility, disruption of cellular function, respiratory and immunological illnesses, might be brought on by these perilous factors [11]. Farmers must quickly, accurately, and sensitively detect pathogens in order to prevent disease outbreaks. There are several methods, however they usually have concerns with inaccuracy, low precision, poor detection times, and unreliability. The development of bio-sensing technologies for accurate and early pathogen detection is becoming more and more important in order to provide effective disease management measures [12]. Early identification and prompt diagnosis in plant pathology are necessary to prevent pathogen-related losses in food production, which have decreased yields and value. Treating new illnesses and complex infections in a globally interconnected market requires innovative tools like portable systems and Internet of Things (IoT) connected devices [13]. Major microbiological problems that impact agricultural output include global bacterial and viral infections. Biosensors track nanoparticles that assist with illness detection by maintaining a close watch on microbial macro-molecules. Data from these sensors is analyzed by machine learning (ML) algorithms, revealing different learning patterns [14]. The environment and human health are negatively impacted by conventional chemical spraying approaches. Plant pathogen diagnosis is made possible by affordable, effective, and precise technologies utilizing biosensors based on nanomaterials. Intelligent plant diagnostic biosensors are emerging by integrating nano-biosensors with artificial intelligence (AI), IoT, cloud computing, drones, and 5G connectivity [15]. The immediate, sensitive, efficient, and economical detection of food pollutants through biosensor research is a global issue for food safety. The potential of biosensors to significantly solve the global concern of food safety is being highlighted by the advancements in downsizing, IoT, and nanoscale science and technology [16]. On-site, real-time, and frequent monitoring of pollutants can be challenging attributed to the labor-intensive, expensive, complex, and time-consuming nature of conventional technologies for measuring environmental samples, such as spectroscopy and chromatography [17]. To minimize spread and monetary losses, early disease diagnosis is crucial for plant health. Since serological and DNA-based approaches have been developed, conventional methods such as ocular scouting are complex. The effectiveness of rapid, non-invasive detection techniques like spectroscopy has increased due to technological advancements [18]. Crop productivity and agricultural monitoring can be enhanced by nanotechnology, which includes instruments like DNA sequencing, quantum dots, and nanoparticles. Nano diagnostic kits may assist to identify possible plant infections promptly, enabling rapid, precise, and affordable plant disease diagnostic approaches. Traditional diagnostic methods are labor-intensive and have limited sensitivity [19]. New technological innovations and their uses in plant pathogen diagnosis and agricultural monitoring are described in table 1 below.

Agriculture and forest ecosystems experience crop losses caused by plant diseases, which comprise bacteria, fungus, and viruses. Conventional techniques, including microscopy and DNA, are laborious and complicated. More specificity and sensitivity are available for early illness diagnosis employing new nanomaterial-based bio-sensing devices [20]. Affordable, adaptable, and user-friendly alternatives are required since traditional detection technologies are expensive, labor-intensive, and demand specialized training. Although gas-sensing devices have limitations such as sensor drift and varying complexity, they are capable of detecting volatile organic molecules from stressed plants. These specific types of substitutes provide portable, approachable alternatives [21]. For crop preservation and early diagnosis, early infection authentication is crucial. A very sensitive dual-mode operated sensor is required for agricultural pathogen detection, however microcantilever-based biosensors are an excellent alternative [22]. Due to their cell-free nature, viral diseases are challenging to detect in crops during the early stages of infection. Research teams are utilizing immune-assay or Q-PCR-based technologies, that are essential to agronomy, to create rapid and easy-to-use on-field diagnostic kits [23]. Innovative sensing and bio-sensing technologies, including the field-effect transistor-based biosensor (bio-FET), are being made

Table 1. Emerging Technologies in Agricultural Monitoring and Plant Pathogen Diagnosis.

	Aspects	Details and uses
1	Importance of Early Diagnosis	Essential to prevent pathogen-related losses in food production, which reduce yields and value [13].
2	Tools of Innovative Diagnostic	Portable systems and IoT-connected devices address new and complex plant infections in a global market [13].
3	Major Microbiological Challenges	Global bacterial and viral infections significantly impact agricultural output. Biosensors and ML analyze microbial macro-molecules [14].
4	Drawbacks of Traditional Methods	Conventional chemical spraying harms the environment and human health [15].
5	Advancements in Biosensors	Integration of nano-biosensors with AI, IoT, drones, cloud computing, and 5G for intelligent plant diagnostics [15].
6	Food Safety through Biosensors	Biosensor research addresses global food safety concerns, enhancing pollutant detection with IoT and nanoscale advancements [16].
7	Limitations of Conventional Monitoring	Traditional techniques (e.g., spectroscopy, chromatography) are labor-intensive, expensive, and time-consuming [17].
8	Rapid Disease Diagnosis	Non-invasive methods like spectroscopy improve effectiveness; traditional methods (serological/DNA-based) are complex but effective [18].
9	Nanotechnology in Agriculture	Includes DNA sequencing, quantum dots, and nanoparticles for enhanced diagnostics. Nano diagnostic kits enable precise, rapid, and affordable detection [19].

possible by breakthroughs in biotechnology and material science. These devices may be designed with sustainable materials, customized for specific applications and offer low-cost, accurate, and real-time parameter monitoring [24]. Harmful microbes, such as rot, wilting, and tumor growth, have a major effect on agricultural crop productivity. Effective disease management necessitates a determination of the specific pathogen triggering plant infections, and many techniques are employed in this context [25].

3. Recommendation

After thorough literature review we propose following recommendations for future.

- Future research should focus on developing advantageous, user-friendly sensing systems that enable reliable diagnosis after symptoms appear and predictive monitoring before symptoms begin in order to minimize losses and reduce dependency on pharmaceuticals.

- The Sustainable Development Goals could be achieved with the support of plant engineering, rhizosphere engineering, agricultural sciences, and nanotechnology—all without endangering the environment, economy, natural resources, and public health.
- Monitoring agricultural attributes, nano-sensors identify pesticide residues, heavy metals, plant diseases, fertilizer levels, and toxins. They support sustainable agriculture and are able to forecast crop failures. Their usefulness as plant diagnostic instruments depends on improved precision and sensitivity, indicating their potential in agro-ecosystems.
- The development of multi-functional, broad-spectrum nano-sensors, along with the possibility of breakthroughs in super-new nanomaterials, might expedite the adoption of technology in the future.
- Intelligent delivery systems that can identify, map, and treat particular locations in fields can be created by integrating nano-enabled biosensors with robotics and GPS technology. Small sample sizes and automated measurements additionally become possible by this technique.
- Recent advancements in nano-inspired biosensors have made it imperative that effective programs be developed to motivate researchers to concentrate on tracking the growth and health of vegetation.
- In contrast to conventional approaches which involve for expensive devices and prolonged testing times, nanotechnology instruments provide quick and sensitive pathogen probes for plant pathogen detection, providing a faster diagnostic approach.
- Nanoscale devices exhibiting special capabilities, such as anticipating challenges, responding to specific environments, determining problems, and initiating disease management measures, could be utilized in creating advanced agricultural systems. These devices would serve as early warning systems and protective measures simultaneously.

Conclusion

The domains of food and beverage inspection, the security and defence industry, disease diagnostics, pharmacy, and medicine have all benefited from the recent advances in optical biosensors. Cost-effective, reliable, accurate, and sensitive biosensors are becoming more and more popular. With an emphasis on the past five years in particular, this research examines the present advances in nano-inspired biosensors for plant-based applications. These innovations can detect bacterial, viral, and fungal infections employing materials including gold, magnetic nanoparticles, graphene, and quantum dots. Powerful, long-lasting sensors are required for nano-based devices to withstand persistent environmental changes. To create novel components made of materials and nanoparticles resistant to environmental shifts, additional research is required. It is anticipated that these sensitive, affordable, and specialized nanotechnologies will be utilized extensively in the future. With the objective of eliminating unidentifiable data and cutting down on analysis time and complexity, the classification process involves splitting identical and non-identical data into discrete intervals. By using series, probabilities, and differences in series, this method improves detection accuracy.

ORCID iDs

Mansi Sahu https://orcid.org/0009-0003-2859-0620
Shailendra Thapliyal https://orcid.org/0009-0002-6212-2057
Mohammed Ismail Iqbal https://orcid.org/0000-0001-6636-7014

References

1. Patel R., Mitra B., Vinchurkar M., Adami A., Patkar R., Giacomozzi F. ... Baghini M. S. (2023). Plant pathogenicity and associated/related detection systems. A review. *Talanta*, *251*, 123808.
2. He J., Chen K., Pan X., Zhai J., Lin X. (2023). Advanced biosensing technologies for monitoring of agriculture pests and diseases: A review. *Journal of Semiconductors*, *44*(2), 023104.
3. Ali Q., Ahmar S., Sohail M. A., Kamran M., Ali M., Saleem M. H. ... Ali S. (2021). Research advances and applications of biosensing technology for the diagnosis of pathogens in sustainable agriculture. *Environmental Science and Pollution Research*, *28*, 9002–9019.
4. Sellappan L., Manoharan S., Sanmugam A., Anh N. T. (2022). Role of nanobiosensors and biosensors for plant virus detection. In *Nanosensors for smart agriculture* (pp. 493–506). Elsevier.
5. S Subramani S., P Shakeel M., Bin Mohd Aboobaider B., Salahuddin L. B. (2022). Classification learning assisted biosensor data analysis for preemptive plant disease detection. *ACM Transactions on Sensor Networks*.
6. Sheikh Z. N., Raina S., Bhat U. H., Sharma N., Saffeullah P., Mohammad F. ... Islam S. (2024). Deciphering the potential role of nano-based biosensors in growth, development and stress management of crop plants. *South African Journal of Botany*, *167*, 542–553.
7. Plekhanova Y., Tarasov S., Reshetilov A. (2023). Nanobiosensors for Detection of Plant Pathogens. In *Nanophytopathology* (pp. 41–58). CRC Press.
8. Sharma S., Dhadly D. K. (2023). Nano-inspired biosensors and plant diseases: recent advances and challenges. *Nanoparticles and Plant-Microbe Interactions*, 135–162.
9. Kashyap B., Kumar R. (2021). Sensing methodologies in agriculture for monitoring biotic stress in plants due to pathogens and pests. *Inventions*, *6*(2), 29.
10. Shivashakarappa K., Reddy V., Tupakula V. K., Farnian A., Vuppula A., Gunnaiah R. (2022). Nanotechnology for the detection of plant pathogens. *Plant Nano Biology*, *2*, 100018.
11. Sharma P., Pandey V., Sharma M. M. M., Patra A., Singh B., Mehta S., Husen A. (2021). A review on biosensors and nanosensors application in agroecosystems. *Nanoscale Research Letters*, *16*, 1–24.
12. Dyussembayev K., Sambasivam P., Bar I., Brownlie J. C., Shiddiky M. J., Ford R. (2021). Biosensor technologies for early detection and quantification of plant pathogens. *Frontiers in Chemistry*, *9*, 636245.
13. Buja I., Sabella E., Monteduro A. G., Chiriacò M. S., De Bellis L., Luvisi A., Maruccio G. (2021). Advances in plant disease detection and monitoring: From traditional assays to in-field diagnostics. *Sensors*, *21*(6), 2129.
14. Rahmani M. K. I., Ghanimi H. M., Jilani S. F., Aslam M., Alharbi M., Alroobaea R., Sengan S. (2023). Early pathogen prediction in crops using nano biosensors and neural network-based feature extraction and classification. *Big Data Research*, *34*, 100412.
15. Sonu Chaudhary V. (2022). A paradigm of internet-of-nano-things inspired intelligent plant pathogen-diagnostic biosensors. *ECS Sensors Plus*, *1*(3), 031401.
16. Griesche C., Baeumner A. J. (2020). Biosensors to support sustainable agriculture and food safety. *TrAC Trends in Analytical Chemistry*, *128*, 115906.
17. Salouti M., Khadivi Derakhshan F. (2020). Biosensors and nanobiosensors in environmental applications. *Biogenic nano-particles and their use in agro-ecosystems*, 515–591.
18. Attaluri S., Dharavath R. (2023). Novel plant disease detection techniques-a brief review. *Molecular Biology Reports*, *50*(11), 9690–9690.
19. Tomer A., Singh R., Dwivedi S. A. (2021). Nanotechnology for detection and diagnosis of plant diseases. *Biobased Nanotechnology for Green Applications*, 221–237.
20. Kulabhusan P. K., Tripathi A., Kant K. (2022). Gold nanoparticles and plant pathogens: an overview and prospective for biosensing in forestry. *Sensors*, *22*(3), 1259.
21. MacDougall S., Bayansal F., Ahmadi A. (2022). Emerging methods of monitoring volatile organic compounds for detection of plant pests and disease. *Biosensors*, *12*(4), 239.
22. Patkar R. S., Vinchurkar M., Ashwin M., Adami A., Giacomozzi F., Lorenzelli L. ... Rao V. R. (2019). Microcantilever based dual mode biosensor for agricultural applications. *IEEE Sensors Journal*, *20*(13), 6832–6832.

23. Bhanjadeo M. M., Nayak A. K., Singh N. R. (2023). Biomolecule Integrated Nanostructures for Advanced Diagnosis Systems in Viral Disease Management of Crops. In *Agricultural and Environmental Nanotechnology: Novel Technologies and their Ecological Impact* (pp. 251–286). Singapore: Springer Nature Singapore.
24. Elli G., Hamed S., Petrelli M., Ibba P., Ciocca M., Lugli P., Petti L. (2022). Field-effect transistor-based biosensors for environmental and agricultural monitoring. *Sensors*, *22*(11), 4178.
25. Khakimov A., Salakhutdinov I., Omolikov A., Utaganov S. (2022). Traditional and current-prospective methods of agricultural plant diseases detection: A review. In *IOP Conference series: earth and environmental science* (*Vol. 951*, No. 1, p. 012002). IOP Publishing.