Chapter 3

Biosensors on the Field: Early Disease Detection in Crops

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

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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 population development worldwide [1]. For accurate forecasts, management plans, and crop losses, early diagnosis is crucial. Enhanced early and accurate detection due to technological developments in bio-sensing methods facilitate automated and real-time monitoring, promoting sustainable crop protection [2]. Effective plant pathogen control tactics depend on their ability to identify the disease. However, novel approaches are more economical than old laboratory-based techniques since they do not require specialist knowledge and are not as time-consuming and expensive [3]. By offering practical methods for crop protection and early microbe identification, nanotechnology is revolutionizing the agricultural industry. By managing pesticide-related environmental concerns and improving the quality of the air, water, and soil, nano-biosensor development, in contrast to previous approaches, enables the early identification and prevention of microorganisms in crops [4]. For farmers to avoid crop failure, early identification of plant diseases is essential. Biosensor technologies, such surface plasmon resonance-based biosensors, colorimetric biosensors, and fluorescence-based experiments, improve agricultural techniques and maximize productivity. With the application of these technologies, plant illnesses may be detected, guaranteeing precise analysis and minimal errors when detecting disease-related characteristics [5]. Nano-biosensors, compact analytical tools used for monitoring the environment, quality assurance, agriculture, and healthcare, have been made possible by nanotechnology. These tools provide easy-to-use techniques for diagnosing and detecting plant diseases [6]. In contemporary agriculture, infection detection is important. New, inexpensive, portable, and quick diagnostic techniques are required since conventional procedures are expensive and labor-intensive. Compact devices called bio-sensors appear to be a promising solution to this situation [7]. Biosensors inspired by nanotechnology have had an enormous impact on environmental sciences, health, and quality control. These biosensors identify microRNAs, phytohormones, abiotic stressors, and plant pathogens. Sensitive to heat, acidity, and changes in metabolism, they are chemical sensors that offer important insights into vital functions like as growth, respiration, photosynthesis, and nutrient transmission [8]. Ensuring sustainable output and satisfying the demands for food, fuel, fiber, and fodder requires minimizing agricultural losses. New sensor technologies are being designed to precisely identify crop stresses and enable effective management, leading to advances in our understanding of plant stressors [9]. Crop yields are greatly impacted by plant diseases, that affects world productivity and food security. Although repeated usage can eventually lower pathogen susceptibility, chemical treatment remains the primary technique to prevent illness prevalence [10].

2. Early Disease Detection in Crops

Agricultural ecosystems are negatively impacted by ecological problems such as pesticide residues, heavy metal buildup, 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]. 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 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.

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