Emerging Trends In Plant Disease Management: A Review Of Sustainable And Innovative Approaches

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Abstract
The broad application of chemical pesticides, such as fungicides, insecticides, and bactericides that are toxic to plant pathogens or plant disease vectors, is the mainstay of plant disease control. However, the adverse effects of these chemicals and the byproducts of their decomposition could endanger both humans and the environment, which is what motivated researchers and producers to look for alternative, environmentally benign methods of disease control. Biological control agents that promote plant development, such as rhizobacteria (PGPR), are being employed more frequently in the field as alternative strategies have shown to be effective thus far. Through a variety of methods, such as the production of volatile compounds, induced systemic resistance (ISR), and antimicrobial metabolites, PGPR both directly and indirectly promotes plant growth and inhibits the development of disease in plant systems. Significant structural and functional alterations brought about by these defence mechanisms can provide disease resistance in plants. The biocontrol mechanism and proteomic viewpoint of PGPR elicitors in the management of plant diseases are discussed in the current review.

INTRODUCTION

Growing concerns about unsustainable trends in plant disease management have made it necessary for agricultural scientists, researchers, and a number of governmental and non-governmental institutions and research organisations worldwide to encourage, support, and assist in the enforcement of Integrated Plant Disease Management (IPDM). Recent breakthroughs in IPDM have raised the significance of plant disease control for sustainable development in agriculture, including technological advancements and new delivery techniques. Genetic engineering in particular, one biotechnological technology, offers new ways to lessen reliance on dangerous chemical pesticides. New biological control agents are being employed more regularly, and the agrochemical industry is producing more targeted and specialized solutions [17][24]. Organic farming has gained international recognition and is strongly associated with IPDM. Every year, more and more land is being used for agricultural agriculture around the world, but the number of people working in the food production industry is also falling. Many crop protection techniques were crucial in producing a large portion of the agricultural products that have been harvested thus far [11]. Currently, plant diseases are a serious concern to the farm industry. Every year, plant diseases cause 40% of harvest loss, resulting in an economic impact of $220 billion. A growing global population makes these problems worse, as does increase trade and agriculture. The Environmental Protection Agency's was introduced by the European Commission in 2019 to address global warming and advance sustainable agriculture. IPM encourages environmentally friendly farming and lowers the need of pesticides by utilising biological pest management and cultivation approaches [13]. The most significant bacteria, viruses, and fungi/oomycetes that cause plant pathogenic are listed below in table. The expansion of international trade exacerbates the effects of these infections by hastening the entry of invasive pathogens and causing significant crop damage and yield loss. Particularly in developing nations, these elements may have disastrous effects on the economy and society.

Table 1. A summary of the top ten oomycetes, bacteria, fungi, and viruses that cause damage to plants [20]

	Viruses	**Bacteria**	**Fungi**	**Oomycetes**
1	Tobacco mosaic virus (TMV)	Pseudomonas syringae pathovars	Magnaporthe oryzae	Phytophthora infestans
2	Tomato spotted wilt virus (TSWV)	Ralstonia solanacearum	Botrytis cinerea	Hyaloperonospora arabidopsidis
3	Tomato yellow leaf curl virus (TYLCV)	Agrobacterium tumefaciens	Puccinia spp.	Phytophthora ramorum
4	Cucumber mosaic virus (CMV)	Xanthomonas oryzae pv. oryzae	Fusarium graminearum	Phytophthora sojae
5	Potato virus Y (PVY)	Xanthomonas campestris pathovars	Fusarium oxysporum	Phytophthora capsici
6	Cauliflower mosaic virus (CaMV)	Xanthomonas axonopodis pv. manihotis	Blumeria graminis	Plasmopara viticola
7	African cassava mosaic virus (ACMV)	Erwinia amylovora	Mycosphaerella graminicola	Phytophthora cinnamomi
8	Plum pox virus (PPV)	Xylella fastidiosa	Colletotrichum spp.	Phytophthora parasitica
9	Brome mosaic virus (BMV)	Dickeya (dadantii and solani)	Ustilago maydis	Pythium ultimum
10	Potato virus X (PVX)	Pectobacterium carotovorum	Melampsora lini	Albugo candida

However, the food security of today is in peril due to the continuous reliance on these outdated and customary methods. Because of pesticide resistance, different market factors, and the expected negative impacts of pesticide use, modern plant protection has experienced a revolution. Therefore, it has been determined that the constant reliance on synthetic pesticides is undesirable. In the current environment, one of the most appropriate and relevant strategies for combating plant diseases and boosting crop yields is integrated pest management (IPDM). The implementation of modern technology in IPDM with diverse cropping methods is necessary for this tactic [11]. New mechanisms of action, concerns about pesticide residues, new tools to prevent pathogen resistance and the emergence of new pathogen races, evaluation of novel biocontrol agents, state-of-the-art molecular tools, etc. are all taken into account in this scientific assessment of plant protection trends. The employment of modern technical techniques is becoming more and more significant, particularly the development of innovative, high-yielding disease-resistant cultivars, smart sprayers, and remote sensing devices that enable accurate and systematic pathogen surveillance [10]. Additionally, this integrated management system may be compatible with genetic methods and strategies such as RNA interference, plant-incorporated protectants, marker technology, and stacked characteristics. These are a huge difficulty and are badly and urgently needed. The concept of integrated plant disease management (IPDM) will give scientists worldwide the chance to collaborate on the creation of integrated management plans for plant diseases and pathogens.

A plant pathogen detection method should ideally be sensitive, rapid, accurate, dependable, easy to use, and affordable. It should also be able to identify pathogens in complicated matrices like soil samples or plant extracts. This study's primary goal is to provide an overview of the most recent and developing trends in plant pathogen detection techniques (Fig 1). This comprises both more sophisticated approaches like biosensors and high-throughput sequencing techniques, as well as more traditional approaches like immunological, nucleic acid-based, and cultivation-based detection procedures [13]. Researchers and stakeholders should be able to readily assess the various possibilities that are currently accessible and choose the method that is most appropriate for their particular usage by going over the methodology as well as the primary benefits and drawbacks of the techniques that are currently available. Furthermore, we provided pertinent instances of each technique's effective application in the identification of plant diseases [14].

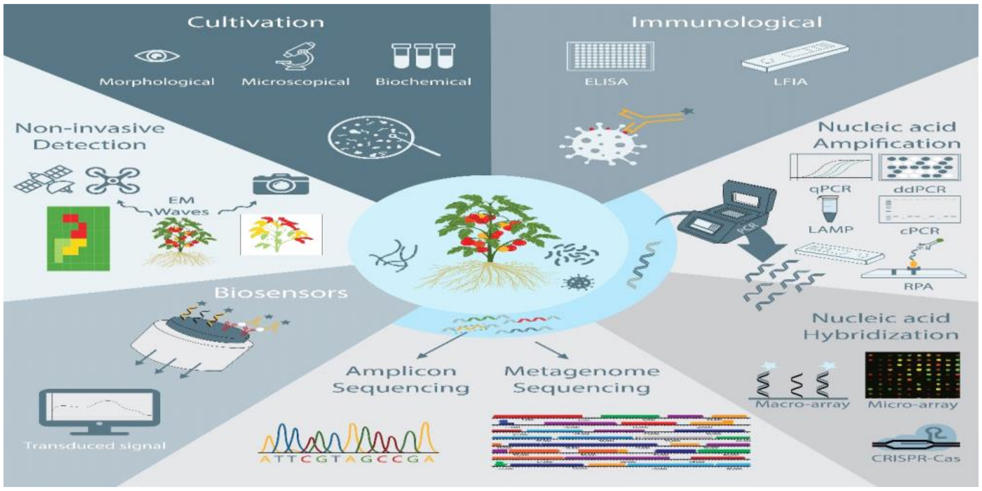

Fig 1: An outline of the methods for detecting plant pathogens that were covered in this review, including biological sensors, non-invasive monitoring, serological and cultivation-based techniques nucleic acid synthesis and integration methods, and DNA sequencing methods [17].

Approaches for Managing Plant Diseases

Controlling plant diseases is crucial to keeping different crops' yield losses at bay. Physical, chemical, and biological approaches can be used to categorize the majority of management techniques [14]. While physicochemical approaches are effective in mitigating plant pathogen-induced losses in crop productivity, their high cost, potential health and environmental risks, agrochemical build-up in food and feed, heightened consumer awareness of chemical hazards in food, secondary pest infestation and most notably, the development of pest resistance, discourage their use in agroecosystems. Moreover, agrochemicals negatively affect beneficial soil bacteria that are naturally prevalent, making hosts more vulnerable to plant infections [17]. On the other hand, from the perspective of the environment, solutions based on the target-specific action of microbial agents (biocontrol agents, BCA) and their metabolic products as well as plant products against possible pathogens are far more appealing and promising. Aspergillus, Pichia, Albifimbria, Penicillium, Bacillus, Cupriavidus, Streptomyces, Burkholderia, and Paenibacillus are a few of the often employed biocontrol agents. Microbial volatiles, which are secondary metabolic products of microorganisms with low molecular weight, have been identified as significant compounds that protect plants against a variety of illnesses [10]. It is also well documented that the use of plant products, such as essential oils and crude extracts, can effectively combat a variety of phytopathogens. There are benefits and drawbacks to each biocontrol agent and its metabolic products' ability to control plant diseases, and these factors are largely influenced by the type of BCA being used, the properties of the soil, plant extracts, and the surrounding environmental factors. However, a significant obstacle to controlling crop output losses brought on by different plant pests remains to be addressed: the field-scale administration of BCA and phytochemicals [13].

DISCUSSION

Opto-spectral non-invasive detecting techniques

Visual detection of plant pathogens has given way to more objective methods including imaging and optical or spectral approaches. The use of sophisticated spectral techniques to assess variations in electromagnetic radiation emitted or reflected by plants has increased as a result of digitalization. These techniques can be used on a variety of sizes, from drones performing spectral studies of whole fields to high-resolution photos of a single leaf. As these sensors get smaller, lighter, and less expensive, the agricultural sector may employ them more frequently to monitor and identify "hot spots" where plants are under biotic stress [14]. When compared to other techniques, the employment of optical or spectral imaging offers the following benefits: (i) immediate detection through continuous crop monitoring; (ii) the ability to detect pathogenic stress; and (iii) a gentle detection that doesn't involve sample processing.

Techniques dependent on Cultivation

Plant infections are commonly detected and identified using cultivation-based approaches. By culturing and isolating microorganisms on a particular or semi-selective growth medium, these techniques enable the desired pathogen to spread while preventing the growth of background bacteria. By using structural, microscopical, physiological, molecular, or antigenic tests, the identities of these isolates are verified. Morphological and microscopically findings, however, might be difficult and call for interpretive abilities [12]. A battery of biochemical and phenotypic testing is used in more objective approaches to verify the identification of the clones. Professional assays are frequently more sensitive and dependable. Examples of these are Biolog™ small plates and analytical profile index (API) devices. Fatty acid profiling and matrix-assisted laser desorption/ionization combined with time-of-flight analysis (MALDI-TOF) are examples of alternative techniques. Fiscal identification is another application for gene barcoding. Techniques based on cultivation are easy to use, dependable, and don't require sophisticated machinery. They have the ability to identify living things from non-living ones and measure the pathogen of interest. They are not perfect, nevertheless, because of the host-dependent nature of viral infections, the great plate count anomaly, and the lengthy findings. Because of their ease of use, cultivation-based approaches continue to be widely used despite these drawbacks [21].

Using Immunological Techniques

Plant pathogens can be identified by antibodies that use certain antibodies coupled with enzymes, fluorescence detectors, or nanomaterials. These antibodies come in two varieties: communal and monoclonal, and they both target distinct antigens of pathogenic microbes. Cross-reactivity is a greater danger with polyclonal antibodies, which might produce false-positive results. Although they are typically costlier and less sensitive, monoclonal antibodies, which are made utilizing hybridoma tissue and phage display technologies, improve specificity and repeatability [4]. Although they have limited sensitivity, immunological assays can be used on any plant pathogen that expresses antigenic molecules. Sensitivity can be raised by methods such as immunomagnetic separation, enrichment, and sample preparation. Numerous immunological assays are available and are mostly employed in clinical settings. These assays include western blot examination mechanical cell sorting, fluorescence imaging, luminescence, and latex-induced agglutination [6].

Methods for Sequencing Amino acids

Nucleic acid sequences, which can be utilized as targets for viruses, fungi, or bacteria, are effective molecular tools for the detection and identification of (pathogenic) microorganisms. Techniques based on crossover, duplex amplification, and polymerase chain reaction (PCR) can identify the presence of a genetic sequence specific to the target pathogen [7]. For successful detection, nucleic acid-based methods—especially PCR-based ones—need highly pure DNA or RNA. This is especially crucial for identifying plant pathogens because samples may contain polymers, phenolic chemicals, acidic substances, or heavy metals. There are numerous extraction processes available to acquire pure DNA, varying from basic kits to intricate procedures. Fewer tools are employed since some techniques are not appropriate for point-of-care usage. The tests based on nucleic acids also have trouble distinguishing between bacteria that are viable and non-viable. It's not always easy to extract RNA from complex sample matrices, but "live/dead probes" can help distinguish between functional and non-viable cells. These sensors, however, struggle to distinguish between living and dead cells [16].

Biosensors

A biorecognition element and a hydrodynamic transducer that produces a quantifiable signal when the target analyte binds to the biorecognition feature are coupled to form biosensors [8]. Because they are often inexpensive, simple to use, and capable of producing quick findings, biosensors are a promising tool for point-of-care operations. Typical sensor types are as follows: (i) electrical sensors, which detect the binding event based on changes in electricity, resistance, or conductivity; and (ii) visual detectors, which detect differences in the reflection of incoming light upon binding of a target analyte to the power source biorecognition components. Although there are many different kinds of biorecognition aspects, the majority use molecules, proteins, nucleotide sensors, or antigens to identify a target sample [10].

Vital Oils

Essential oils (EOs) have been used as an environmentally friendly control method for managing plant diseases. They effectively decrease crop diseases and show varying antibacterial efficacy against various plant pathogens. However, their effectiveness as biopesticides may require frequent reapplication and higher application rates. EOs can only be extracted physically and can be classified into multiple classes [15]. The mechanism of antimicrobial action could be a cascade of events, starting with cellular coatings disruption and based on mixture/compound lipophilicity.

Metabolic Maintenance

The employment of suitable antagonists is essential for the biological management of plant diseases. It is possible to isolate the majority of antagonists that significantly suppress pathogenic fungus from bacteria, fungi, and yeast found in plants and soil. It is thought that the antagonists' technique of biological control involves either inducing host resistance or competing with the infections for nutrients and space [1]. Xue et al. (2008) identified strain B501 from the surface of jujube fruit, and the fruit was shown to be resistant to Alternaria alternata-caused black spot disease. Based on the physiological and biochemical characteristics of the bacterium as well as a phylogenetic analysis of its 16S rDNA sequence, Pantoea agglomerans was identified. When given to damaged fruits at the relatively modest dosage of 1 × 107 cfu/ml, strain B501 could successfully and considerably reduce the occurrence of black spot, with a success rate of 80% [22].

Biocontrol is a new, environmentally friendly method of mitigating plant disease:

"Combination" is the most effective method for plant disease biocontrol.

Plant diseases can be effectively controlled by chemical and biological means, but their combined and integrated use with other ways would yield greater results. Combinations can be made sequentially or concurrently. To reduce the incidence of F. oxysporum on chrysanthemum, Minuto et al. (2007), for instance, tested the effects of biological control and physical methods by adjusting the pH and the disinfection protocol of the nutrient solution (using UV radiation, slow sand filtration, or slow rockwool filtration), and applying MBCA (Fusaria mix, Streptomyces griseoviridis, or Trichoderma mix). Combining a neutral pH of the nutrient solution, gradual sand or rockwool filtration, and the application of S. griseoviridis or Trichoderma mix produced the best results. Using each technique separately showed that it was less effective. When applied in combination, treatments that impede the growth and multiplication of the fungus (using hot water, UV-C, and essential oil) were more successful in lowering the fungal population on gladiolus corms during storage period 14 than when applied separately [19].

Biological control products can be used in conjunction with chemicals or cultural practices (disinfection of the soil or nutrient solution, substrate pH regulation) at various stages of a production cycle [18]. The application of these various techniques frequently enables more effective and prolonged illness management. Most of the microbes that have been studied thus far have shown promise in lowering the illness. But very few of them are made available for purchase. These microbes are therefore worthy candidates that ought to be used. Microorganisms and botanicals can be assessed for their biological control abilities using a variety of methods and metrics. AM fungus and other soil organisms have complicated interactions that can either be stimulatory or suppressive. Extraradical hyphae or mycorrhizal root debris, as well as the survival and timely germination of AMF spores in the soil, are both important variables that contribute to the best possible colonisation of plant roots, especially in disturbed ecosystems like agricultural fields. This process can be altered by a number of biotic and abiotic variables, particularly when they interact with soil microorganisms. In fact, certain bacterial populations known as mycorrhiza helper bacteria (MHB) promote extraradical hyphal growth, improve mycorrhizal root colonisation, and aid in the germination of AMF spores, all of which have positive effects on AMF growth [9]. For Actinomycetes, Pseudomonas, Corynebacterium, and Bacillus species, the latter impact has been demonstrated. For rhizobacteria that improved the root's capacity to form symbiotic relationships with ectomycorrhizal fungi, researchers proposed the moniker MHB. He proposed several potential mechanisms for the helper effect, such as promoting the growth of roots, making the roots more susceptible to fungal colonisation through ectomycorrhizal growth, or improving the process of root-fungus identification. Additionally, a number of research have shown that the presence of PGPR increases the levels of AM fungal colonisation in roots.
The application of T. harzianum and mycorrhizae enhanced the agronomic parameters of aubergine and tomato plants when compared to other treatments. It also significantly reduced dwarfing at very low levels and leaf alteration indices [18].

CONCLUSION

Plant diseases cost the economy $220 billion annually, accounting for 40% of crop losses. Detection techniques for plant diseases should have sensitivity, speed, accuracy, dependability, affordability, and ease of use. Immunological methods, which combine antibodies with enzymes, fluorescence detectors, or nanomaterials, can identify plant pathogens. Despite their low sensitivity, cultivation-based techniques are commonly used. Biocontrol, a sustainable approach, is essential for agriculture's sustainable development. Combination of chemical and biological methods is the best strategy. Integrated plant disease management (IPDM) aims to create integrated management strategies for plant diseases and pathogens.

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