



RESEARCH ARTICLE

Challenges and Opportunities in Plant Disease Management: A Brief Review

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ABSTRACT

Plant diseases can reduce human food availability. Modern plant disease management faces problems due to climate change, fungicide resistance, pesticide residues and biodiversity loss. This review discusses problems and challenges in plant disease management and future research needs for effective management. Plant disease forecasting models can be used to predict plant diseases ahead of time. Protected cultivation combats climate change. It is necessary to find more evidence that plant pathogen diversity has a dilution effect on disease incidence. Deep learning-based disease diagnosis will help detect diseases faster. More hybrid fungicides should be developed to minimize fungicidal resistance problems. Among the molecular methods of plant disease management, RNA interference-mediated gene silencing and genome editing with CRISPR is more promising in plant disease management.

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INTRODUCTION

Plant diseases are well known to reduce the food available to humans by interfering with crop yields. During the early agricultural era, plant disease management approaches were extremely limited and the people lived in fear of famine. People blamed disease outbreaks on vengeful spirits, the anger of the gods, or unfavourable orientations of the stars or moons. The Robigalia was an ancient Roman religious festival celebrated on April 25 each year for the deity Robigus. Its major ritual was to sacrifice red dogs, foxes, and cows to appease Robigus and prevent the rusts from destroying their crops. Food shortages resulting from disease epidemics cause severe consequences to human society, such as the Irish famine (1840s) caused by potato late blight and the Bengal famine (1943) caused by rice brown spot. Modern plant disease management began with Pierre Marie Alexis Millardet's accidental discovery of the Bordeaux mixture in 1882 to control grapevine downy mildew, and nowadays various components such as host-plant resistance, cultural practices, biological control, and chemical control are used in disease management. The scientific and technological advances in recent

times have contributed to a significant reduction in the frequency and intensity of epidemics (Oerke, 2006). Despite this, plant disease management is facing various problems due to climate change, fungicide resistance, pesticide residue loss of biodiversity and challenges in detecting plant diseases and developing new plant protection chemicals. In India, recently there has been an incidence of rice blast in Nagaland, coconut wilt in Kerala, mango anthracnose in Karnataka and southern rice black-streaked dwarf virus (SRBSDV) of paddy in Punjab, Haryana and Uttarakhand and gummy stem blight affects the cultivation of cucurbitaceous vegetables like cucumber, bitter melon, ash gourd, muskmelon, and ridge gourd. Recently, Mahapatra *et al.* (2020) reported gummy stem blight in watermelon. Future plant disease management should be strengthened to ensure food availability by overcoming these problems and challenges in an ecologically sustainable, environmentally viable and socially acceptable way. This review discusses various challenges in plant disease management and future research needs for their effective management.

Challenges in plant disease management

1. Climate change

Climate change entails long-term shifts in temperature and weather systems. These changes might be natural, such as variations in the solar cycle. However, since the 1800s, human activities have been the primary cause of climate change, owing mostly to the use of burning of coal, petroleum, and gas. A disease will develop when a virulent pathogen infects a susceptible host under favourable environmental conditions and at an appropriate time (Agrios 2005). Climate change can alter the environmental conditions to be favourable for pathogens or make the host susceptible to pathogen attack. Increases in temperature, moisture, and Carbon dioxide are the major consequences of climate change.

Due to favourable weather conditions, pathotype 78S84 of wheat yellow rust was first detected from northern India posing a major threat to cultivar PBW343 in wheat (Prashar *et al.* 2007) and wheat yellow rust started appearing early in the last week of December (Jindal *et al.* 2012). Temperature affects Arabidopsis susceptibility to *Pseudomonas syringae* pv. tomato considerably (Huot *et al.* 2017). The relative prevalence of soil-borne fungal plant diseases increases as temperatures rise. According to Delgado-Baquerizo *et al.* (2020), the relative abundance of plant pathogens will increase globally. The rice plants cultivated in elevated CO₂ concentrations were more susceptible to leaf blights than those planted in ambient CO₂ (Kobayashi *et al.* 2006). With increasing relative humidity and leaf wetness, infection of *Sclerotinia sclerotiorum* in lettuce and *Uromyces viciae fabae* in peas increased respectively (Clarkson *et al.* 2014; More *et al.* 2020).

2. Fungicide resistance

Fungicidal resistance refers to an acquired, heritable reduction in the sensitivity of a fungus to a specific anti-fungal agent or fungicide (FRAC 2022). A few individuals in the fungi population are naturally resistant to certain types of chemicals. When a chemical is used, it controls almost all the fungi in the population. Survivors are resistant to the action of the chemical and lead to the next generation. Applying the same fungicide with the same mode of action repeatedly enables the resistant population to multiply. Hence leads to the development of fungicide resistance.

Kaur *et al.* (2010) investigated the competitive fitness of metalaxyl-resistant (PI-24) and sensitive (PI-31) populations of *Phytophthora infestans* in three distinct combinations and the results revealed that metalaxyl-resistant isolates of *P. infestans* were highly pathogenic and showed competitive fitness in a mixed population. To minimise resistance development, fungicides with site-specific action should be used in combination with fungicides of other modes of action. The fungicide trend is that if a particular mode of action fungicide becomes popular in controlling diseases, more fungicides are developed with a minor difference with the same mode of action group. Such fungicides have resistance risk and thus have an impact in terms of resistance management (Thind 2021).

3. Pesticide residue

Pesticide residue refers to the pesticide substance that remains on or in food after they are applied to food crops. Carbendazim was regularly higher than the EU MRLs despite the consignments being tested in India. There have been cases where “organic basmati rice” consignments have been rejected in the EU for the presence of carbendazim (Mukherjee *et al.* 2019). In 2017, the EU lowered the MRL for tricyclazole in Basmati rice from 1 PPM to 0.01 PPM. Between 1st January 2017 and 30th October 2022, there were 47 notifications on the RASFF (Rapid Alert System for Food and Feed) window regarding basmati rice exported from India that did not comply with European Union (EU) standards. Ten of the 47 alerts were rejected at the border, indicating that the consignment was denied entry into the EU due to its risk to human and animal health or the environment. The presence of pesticides such as tricyclazole (10 notifications), propiconazole, thiamethoxam, carbendazim, and bromide beyond the allowed level was the most prominent reason for the rejection of Basmati rice consignments. Other major causes of rejection were mycotoxins such as Ochratoxin A and Aflatoxin B1 (RASFF 2022). To reduce the pesticide residue problem in basmati rice exports, alternative pesticides should be used if a pesticide is banned/prohibited by the importing countries. Basmati Export Development Foundation (BEDF) conducts awareness drives, where the scientists explain the pesticide residue problem in basmati rice export to farmers and exporters due to the injudicious use of pesticides. Farmers are advised to stop spraying tricyclazole at least 40 days before

harvesting to avoid its residue (PPQS 2021). To reduce mycotoxin problems in basmati rice, the moisture content of seeds should be lowered to less than 14 per cent within 24 hours of harvesting. Preservatives like benzoic acid, sodium benzoate, propionic acid, sorbic acid and sodium diacetate should be used to prevent fungal contamination during storage. Appropriate storage conditions (Ultra Hermetic storage) to avoid favourable conditions for aspergillus growth (Naik and Sudini 2011).

4. Loss of biodiversity

Plant biodiversity, which is critical for sustaining long-term production, is under threat. Our farmed crops, which are genetically homogenous, are extremely sensitive to external shocks such as biotic and abiotic stresses (ICAR 2015). The disease is most prevalent in cultivated plants, intermediate in wild plants managed by humans, and least prevalent in completely wild plants. On the other hand, biodiversity is highest in wild plant environments and lowest in cultivated plant ecosystems. Spillover occurs when a virus spreads from its normal host (domestic or wild) to a new host (wild or domestic). Spillover happens when a virus spreads from the new host to the native host. The term “natural host” refers to the source of the virus in this environment, however, it may not always refer to the host where the virus first emerged (Roossinck and Garcia-Arenal 2015).

Not only the diversity of plants but also the biodiversity of plant pathogens is also important. According to Ingram (1999), studies on pathogen diversity and ecology receive little attention until they represent a threat to agriculture. There is a need to catalogue the diversity of plant pathogens in natural environments, with a focus on species-rich ecosystems like rainforests, grasslands, and seas, and a red data book for plant pathogens also needs to be created. A policy for the conservation of plant pathogens is required since pathogen diversity is particularly important for plant breeders when it comes to identifying novel disease resistance elements in both natural populations of host plants and plant breeding experiments (Ingram 2002). Biodiversity loss frequently increases disease transmission and preserving intact ecosystems and their endemic biodiversity reduces the prevalence of infectious diseases (Keesing *et al.* 2010).

Evidence to support the dilution effect of plant pathogen diversity on the disease incidence or any of

its negative effects should be studied in future to get a clear impact of the loss of diversity on plant diseases.

5. Development and use of new plant protection chemicals

Forecasting the market changes is challenging, thus being a factor in the complexity of a new product invention and development. In chemical crop protection, the investment of companies into research and development represents only 6-7 % of sales (Leadbeater 2015). The cost of developing new products is high, and the regulatory hurdles continue to be stringent (Jeger *et al.* 2021). With increasing awareness and concerns for humans and wildlife, regulatory measures were initiated and the guidelines are revised from time to time, which makes the introduction of new fungicides and other pesticides quite challenging (Thind 2021). Controlling a wide range of diseases in a wide range of crops and countries with a single blockbuster fungicide makes the research and development investment most cost-effective (Leadbeater 2015). So, from a business perspective, only broad-spectrum chemicals like Demethylation Inhibitors (like triazoles), strobilurins and SDHI (succinate dehydrogenase inhibitor) fungicides are very attractive. However, due to biochemical specificity in the mode of action, these fungicides can experience faster development of resistance in pathogens (Thind 2011).

Opportunities in plant disease management

1. Plant disease forecasting models

Forecasting of plant diseases means predicting the occurrence of plant disease in a specified area ahead of time so that suitable control measures can be undertaken in advance to avoid losses. EPIDEM (potato early blight), EPIMAY (maize southern leaf blight), EPIVEN (Apple scab), BLITE CAST (potato late blight), MELCAST (watermelon gummy stem blight) and MARYBLIGHT (apple fire blight) are some of the computer simulation models which are used for forecasting plant disease epidemics.

JHULSACAST, a system for forecasting the potato late blight in western Uttar Pradesh, India, was developed using disease and weather data collected over a decade (Singh *et al.* 2000). Potato late blight was successfully forecasted using JHULSACAST model in Punjab, Tarai region of Uttarakhand and plains of West Bengal (Arora *et al.* 2012; Pundhir *et al.* 2014; Chakraborty *et al.* 2015)

Tang *et al.* (2017) investigated the impacts of climate change on wheat powdery mildew outbreaks from 1970 to 2012 in China. They built a multi-regression model by combining the per cent acreage of powdery mildew and the pathogen's temperature requirements to estimate changes in epidemics in the 2050s and 2080s under various representative concentration pathways. According to the findings, wheat powdery mildew acreage will increase by 2050 and 2080, creating a larger threat to China's winter wheat in the future. For the prediction of sterility mosaic disease occurrence in pigeon pea, support vector regression, artificial neural networks, and their combination with autoregressive integrated moving average models were used by Paul *et al.* (2020). At S K Nagar (Gujarat), Gulbarga (Karnataka), and Vamban (Tamil Nadu), hybrid models outperformed individual models, whereas individual models outperformed hybrids with autoregressive integrated moving average models at Rahuri (Maharashtra).

2. Protected cultivation

Protected cultivation is very promising in combating the problems due to climate change. Low tunnel technology was adopted by farmers of the Jaipur district of Rajasthan as protected cultivation. Under this technology, the cucurbitaceous vegetables are grown inside the low tunnels during winter, creating congenial weather conditions and preventing the crops from frost injury and aphid infestation. The incidence of *Cucumber Mosaic Virus* (CMV) was very low in low tunnels in comparison to open field cultivation and the yield of cucurbitaceous vegetables grown in low tunnels was significantly superior to the open field cultivation (Gangwar *et al.* 2015). Low tunnel systems allow for increased environmental control and improved marketable fruit yield and quality compared with the open-field plots of strawberries (Anderson *et al.* 2019).

3. Deep learning-based rapid disease diagnosis

Accurate and quicker identification of plant diseases and pests might aid in the development of an early treatment approach while significantly decreasing economic losses. However, due to a lack of sufficient technical infrastructure, timely detection of plant diseases remains challenging. Deep learning is a machine learning approach that trains computers to do what people do instinctively: learn by doing. Fuentes *et al.* (2017) created a deep learning-based method for detecting diseases and insect pests in

tomato plants. Their findings show that the suggested system can efficiently distinguish nine distinct kinds of diseases and pests, as well as cope with complicated scenarios from the surrounding region of a plant. The convergence of rising worldwide smartphone adoption, advances in computer technology, and advances in deep learning have opened the path for smartphone-aided plant disease detection (Mohanty *et al.* 2016). Plantix, Agrio-Precision Agriculture and Crop Doctor are some of the deep learning-based mobile applications available for disease detection.

4. Hybrid fungicides

Fungicide, which unites the disease-fighting power of botanical and conventional chemistries. Protective foliar applications of difenoconazole-TTO (Tea Tree Oil) in field trials were highly effective in controlling scabs of apples and generally provided significantly higher disease control than difenoconazole alone. Similarly, on apples and almonds, difenoconazole-TTO treatments were similarly or more effective than applications with other synthetic fungicides like DMI, QoI and SDHI groups, or their mixtures (Reuveni *et al.* 2022). Tea tree oil provides a unique set of terpenes that disrupt cell membranes while inhibiting sporulation, spore germination, respiration, ion transport and mycelial growth. TTO also battles bacterial pathogens, by inhibiting the infection process. Difenoconazole reinforces TTO by inhibiting fungal ergosterol biosynthesis for double kick-back curative control. So, these fungicides can be effectively used as a strategic approach in fungicide resistance management in orchards.

5. RNA interference (RNAi) Mediated Gene Silencing

The regulation of the expression of genes in a cell to prohibit the expression of a specific gene is known as gene silencing. The RNAi method includes the homology-dependent silencing of genes responsible for infection in the host plant before translation. It is also known as post-transcriptional gene silencing (PTGS). Silencing of OsERF922 using RNAi enhanced the resistance of rice against *Magnaporthe oryzae*. The elevated disease resistance of these RNAi plants was associated with increased expression of PR (Pathogenesis-Related), PAL (Phenylalanine Ammonia Lyase) and the other genes encoding phytoalexin biosynthetic enzymes (Liu *et al.* 2012). Pessina *et al.* (2016) reduced susceptibility to powdery mildew

in grapevine through the knockdown of MLO (Mildew Locus O) genes using RNAi-mediated gene silencing. Tomato leaf curl disease resistance is conferred by the expression of artificial microRNAs (amiRNAs) targeting the ATP binding domain of AC1 in transgenic tomatoes without affecting tomato yield (Sharma and Prasad 2020). Interference with viral β C1 ORF confers resistance to Yellow Vein Mosaic Virus (YVMV) in transgenic okra lines (Ganesh *et al.* 2022).

6. Genome Editing

Genome editing is a type of genetic engineering in which DNA is inserted, deleted or replaced in the genome of a living organism using engineered nucleases. Mega nucleases, Zinc finger nucleases (ZFNs), Transcription activator-like effector nucleases (TALENs), Clustered regularly interspaced short palindromic repeat (CRISPR)/ CRISPR associated protein system (CRISPR/Cas) are the different genome editing tools.

Advantages of CRISPR-based genome editing over Mega nucleases, ZFN and TALEN

- RNA guided (Recognition of the DNA site is controlled by RNA–DNA interactions).
- Possibility of multiplexing (modifying several genomic sites simultaneously).
- Can introduce multiple gene mutations concurrently with a single injection.
- CRISPR transfections also have higher efficiency.

Wang *et al.* (2016) reported the improvement of rice blast resistance by engineering a CRISPR/Cas9 SSN (C-ERF922) targeting the OsERF922 gene in rice and results revealed that the number of blast lesions formed following the pathogen infection significantly decreased in engineered lines compared to wild-type plants. Sequence-specific deleterious point mutations at the eIF(iso)4E locus in *Arabidopsis thaliana* introduced using CRISPR/Cas9 technology showed complete resistance to *Turnip mosaic virus* (TuMV), a major pathogen in field-grown vegetable crops (Pyott *et al.* 2016).

CONCLUSION

Timely changes to plant disease management strategies are required to face future challenges. Deep learning-based disease diagnosis will help in the identification of tomato diseases. In recent

years, various disease forecasting models such as JHULSACAST have made it possible to predict potato late blight successfully. More hybrid fungicides should be developed to minimize fungicidal resistance problems. RNA interference-mediated gene silencing reduced powdery mildew severity in grapevine. Genome editing using CRISPR appears to be a more promising technology for reducing disease incidence. Research on the impact of biodiversity loss on plant diseases should be increased. Basmati Export Development Foundation educates basmati farmers to stop pesticide indiscriminate use. The same kind of effort is also required in other crops to motivate farmers in this regard.

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Authors ensure that we have written and submitted only entirely original review article

Data availability

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