Global challenges facing plant pathology: A review on multidisciplinary approaches to meet the food security

Abstract

Outbreaks of plant diseases result in a loss of primary productivity and biodiversity, which has a detrimental effect on the environmental and socioeconomic conditions of affected places. They also represent serious challenges to the sustainability of the environment and global food security. By changing host-pathogen interactions and pathogen evolution, as well as by promoting the formation of new pathogenic strains, climate change further raises the likelihood of outbreaks. Plant diseases can spread more quickly in new locations due to shifts in the range of pathogens. In this review, we look at how future climate scenarios will likely affect plant disease pressures and how that would affect plant production in both natural and agricultural settings. We investigate the present and potential consequences of climate change on the biogeography of pathogens, the occurrence and intensity of diseases, and their influence on natural ecosystems, agriculture, and food production. In order to reduce the likelihood of disease outbreaks in the future, we suggest that the conceptual framework now in use be modified and that eco-evolutionary theories be incorporated into research to enhance our mechanistic understanding and forecast of pathogen propagation in future climates. In order to ensure long-term food and nutrient security as well as the sustainability of natural ecosystems, we emphasize the need for an interface between science and policy that collaborates closely with pertinent intergovernmental organizations to provide effective monitoring and management of plant disease under future climate scenarios.

Keywords

Climate change, Fungicide resistance, ecological plant disease management, evolutionary principle, food security, plant disease economy

Introduction

Growing hazards to primary productivity, global food security, and biodiversity loss are posed by the increasing frequency and severity of plant disease outbreaks in many sensitive regions of the world [1,2,3,4,5,6,7]. Both yield and ecological losses result from these disease outbreaks. For instance, it is estimated that the yearly loss of agricultural output due to pests and pathogens (microorganisms that cause diseases and reduce host health and productivity) alone is worth US$220 billion [3,4,5,6]. This has a direct effect on food security, local economy, and other related socioeconomic factors. Post-harvest loss brought on by pathogenic bacteria such Xanthomonas euvesicatoria and Penicillium spp. aggravates this even more [1]. Additionally, there is a greater chance that plant diseases will worsen due to climate change, endangering both the natural plant biodiversity and the world's food supply [7,8,9].

It is predicted that changed disease pressure brought on by existing and developing pathogens as a result of climate change will negate any possible yield gains over the next fifty years [10]. In a similar vein, the world community regards the spread of infections associated with climate change as one of the primary dangers to forest health [11]. Therefore, to establish agricultural and natural ecosystems that are climate resilient, better understanding of the effects of climate change on the molecular, epidemiological, and ecological interactions between diseases, plants, and the accompanying microbial communities is required [4,6].

A wide variety of pathogens, such as bacteria, fungi, oomycetes, viruses, and nematodes, can infect plants. These pathogens vary in their target plant tissues (such as xylem, phloem, roots, or leaves), their modes of infection (from intracellular to extracellular), and their lifestyles (from biotrophs, which obtain nutrients from living cells, to necrotrophs, which obtain nutrients from dead cells). Understanding how these various pathogens interact with and react to various disease drivers (such as other pathogens, host/vectors, commensal microorganisms, and environment) as well as how they collectively react to climate change is a critical challenge in predicting plant diseases in space and time. Theoretically, there are several ways in which climate change may promote plant infection. These include modifications to host-pathogen interactions and vector physiology, as well as the introduction of new pathogen strains that have the potential to undermine host-plant resistance [7,12,13]. Plant diseases may spread faster into new regions as a result of host and pathogen range alterations brought on by climate change [8,10,14,15]. However, our understanding of how many aspects of climate change like variations in temperature and precipitation interact with human activity to affect plant pathogens in both wild and agricultural ecosystems is still limited. For instance, under anticipated climate change scenarios, the number of fungal soil-borne plant diseases is expected to rise in the majority of natural ecosystems, with considerable but as-yet-unquantifiable effects for primary productivity worldwide [14]. Comparably, changes in relative humidity have an impact on pathogen abundance and infectivity [16].

Crop plant diseases will presumably rise as a result of climate change. First, over the past few decades, globalization and international trade have increased agricultural pathogen migration between continents [17,18] raising the possibility of transfer from disease-prevalent to disease-free regions. In the new geographic area, plant species or cultivars that have not coevolved with the introduced pathogen are likely to promote pathogen prevalence and disease outbreaks. The wilt disease of bananas, often called Panama disease, is a prime illustration of how trade and transportation can contribute to the establishment of pathogens. This disease is caused by the soil-borne fungus Fusarium oxysporum f. sp. cubense, which most likely started in Southeast Asia and subsequently expanded throughout the world during the 20th century [19]. Second, it's possible that monocultures and high-density crops, together with other contemporary land management techniques, contributed to the emergence and adaptability of plant diseases that can spread beyond their typical geographic limits. For instance, a variety of pests and diseases severely limit the yields of soybean and wheat, which are widely cultivated in high-density monocultures. Among the most damaging diseases to these crops are soybean rust (produced by the fungus Phakopsora pachyrhizi) and wheat blotch (caused by the fungus Zymoseptoria tritici), with severe outbreaks known to inflict yield losses of over 50% [2,20]. Natural ecosystems are complex, with connections between biodiversity, for example, but they also face difficulties for productivity and wild plant communities from climate change and the associated development and evolution of pathogens [21].

For instance, the spread of Phytophthora cinnamomi due to global warming may have detrimental effects on native plant communities across the globe [22, 23]. Climate change-related increases in disease load might have catastrophic effects for societal tensions, food production and security, ecosystem sustainability, and many plant species. The review examines the potential changes in plant pathogen loads and disease pressure resulting from future climatic scenarios. We investigate the effects of land use intensification and climate change, both present and projected, on pathogen biogeography, interactions between plant pathogens and the plant microbiome, incidence and severity of plant diseases, and their combined effects on primary production and agriculture. We examine potential pathways through which pathogen invasion impacts the plant microbiome and discuss how this information could be used to reduce the likelihood of disease outbreaks through enhanced disease surveillance, predictive modeling, and practical sustainable management approaches [8,12]. In conclusion, we suggest various strategies that integrate disease surveillance with policy frameworks to guarantee the enduring viability of worldwide food security and environmental sustainability.

How to treat plant diseases rationally and ecologically

Modifications to the plant disease management paradigm

Plant disease control philosophy should change from managing pathogens (or insect vectors) to managing host R A Macro Micro E Ultra-micro Structure and function of agricultural ecology adverse to pathogen but favorable for plant plants; it should also move from focusing only on high productivity to multiple goals of high yield, efficiency, good quality, and safety in order to achieve logical and sustainable results.

Plant disease: ecological management

The key to sustainable plant disease management is to create an agro-ecological system that is adverse to pathogen evolution and epidemic development based on interactions between plants, pathogens, vectors, and environments [13, 14]. This management system consists of two main components: dynamic and integrated approaches guided by a thorough understanding of the evolutionary ecology of specific host-pathogen interactions, and multiple goals (high yield, efficiency, good quality, and safety). This integrated approach shows great promise in overcoming the issues and challenges associated with current plant disease management strategies in order to maximize its economic, ecological, and social benefits.

The foundation of managing plant diseases ecologically

The fundamental goal of ecological plant disease management is to balance the use of the RAER (resistance, avoidance, elimination, and cure) strategy in order to modify the surroundings of host-pathogen interactions in the hosts' advantage. The disease ecology, epidemic patterns, evolutionary potential, and economic impact of agricultural pathogens vary widely, and the RAER technique should be implemented in accordance with the particular circumstances of the host-pathogen interactions involved [13, 14]. Despite certain practical limitations, certain plant disease management strategies, such crop rotation, may simultaneously provide the effects of resistance, avoidance, elimination, and treatment [15, 16]. These strategies could be widely used in agriculture in the future.

Resistance

The most practical and successful strategy for managing plant diseases is host resistance [17, 18]. It is possible for host resistance to be constitutive or induced, systemic or local, qualitative or quantitative. Plant breeding introduces most crop resistances from land-races or wild relatives [19, 20]. Major gene resistance, also known as qualitative resistance, is very effective. However, because plant pathogens have evolved more rapidly under modern agricultural practices, many qualitative resistances lose their effectiveness within a few years of being commercially released [21], especially when employed in large-scale monocultures [22-24]. Quantitative resistance is more enduring than qualitative resistance because it puts less selection pressure on pathogens and thus reduces disease epidemics rather than preventing infection. Conversely, it is believed that induced resistance outperforms constitutive resistance mainly because less resources are allocated when they are not required [25] . Apart from the genetics of host resistance, the resistance level of host plants can also be influenced by other factors known as the "ten principles of agricultural practices" [26-28]. These elements include soil, nutrition, water, seed, population density, plant protection, field management, farming machine technology, light, and air. Any one of these components can be changed to alter the Knowledge of disease triangles environment in a way that benefits or hurts the plant or pathogen. A whole farming system approach to managing plant diseases has been used successfully to control rice blast (Magnaporthe oryzae) and tungro (Rice tungro virus) disease on a large scale [29-30], though it may still allow some disease development, require more labor and other inputs, particularly on establishment, and require supplementary support from other strategies like the application of pesticides.

One of the most successful ecological strategies for managing plant diseases has been shown to be increasing host heterogeneity through intercropping or combining crop varieties with various genetic and physiological traits, such as kind of resistance (quantitative versus quantitative). This strategy prolongs the life of resistant varieties by improving soil fertility and slowing down pathogen evolution [31, 32]. It also decreases disease epidemics and boosts nutrition efficiency, productivity, and yield stability in the short term. For instance, increasing the variability of the host population through intercropping several rice varieties dramatically decreased the need to apply fungicides to manage rice blast while also greatly enhancing the amount and quality of production [33]. Potato late and early blights have also been effectively managed with varietal mixtures (data not given). Plant disease ecological management can also benefit from the application of various resistance gene deployment strategies, such as R gene rotation and pyramiding, in addition to mixing or intercropping technology [34]. By altering the host plant's cultivation pattern both spatially and temporally for example, by varying the planting time, location, or system this strategy seeks to create a mismatch between important stages of crop and pathogen growth. It's a sophisticated method that necessitates a thorough comprehension of host susceptibility through various phenological developmental stages, probable weather patterns, disease ecology, and pathogen and pathotype distributions. The key factors influencing the effectiveness of spatial avoidance, which includes varietal mixture and regional R gene deployment, are the distribution and mechanisms of transmission of pathogens.

Avoiding disease

The management of plant diseases brought on by bacteria or nematodes, as well as other soil- or water-borne pathogens, may benefit from spatial avoidance. However, airborne diseases, which can spread over large distances in a single epidemic course, are unlikely to benefit from this strategy. Crop rotation and alterations in planting dates are examples of temporary avoidance strategies. Changing the timing of plantings is not always an effective way to prevent plant diseases; this is especially true for polycyclic infections, where the primary inoculum is not the primary factor in disease epidemics. However, by skipping the peak stage of vector transmission, this strategy reduces the amount of time that plants are exposed to the pathogen during their most vulnerable period in the case of rice virus disease [35, 36]. Crop rotation, a second type of temporary avoidance, is anticipated to be especially successful in reducing plant illnesses brought on by soil-borne pathogens. Rotation has been proven to be highly successful in preventing bacterial wilt of potatoes, bananas, tobacco, and sweet potatoes [37], as well as black and root rot [38]. Understanding the ecology of the insects including their overwintering place, migration patterns, and wind direction as well as their reproductive biology is essential for preventing disease when it comes to infections carried by insect vectors, such as numerous viruses [39].

Elimination

Finding the right primary inoculum sources is the main challenge in managing plant diseases with an elimination strategy. The misidentification of primary inoculum sources leads to resource waste as well as a decrease in management efficiency. If a disease continues to show epidemics years after significant human intervention, it is important to reevaluate management strategies, confirm that critical points in the disease cycle have not been overlooked, and assess whether eradication at those locations is truly possible. Many agricultural strategies that modify farming systems to remove diseased plant tissues, volunteer host plants, secondary crops, etc. have shown to be highly effective in removing or reducing sources of pathogen inoculum. Primarily, crop rotation is a practical approach to disease control that can eradicate the pathogen (particularly soil-borne ones) and possible reservoir hosts. It can also enhance soil quality, including its physical structure and nutritional balance, thereby promoting healthier crop populations. By lowering the number of overwintering sites for the insect vector Nephotettix virescens, plowing soils after harvesting significantly lowers the population density of this vector and, consequently, the viral source of rice tungro disease [40]. A disease-elimination strategy should be based on a thorough understanding of the various interactions that occur among hosts, pathogens, and vectors in an ecological and epidemiological context, as well as with due consideration of the economic threshold of management. This is similar to disease resistance and avoidance strategies. China's wheat stem rust is an effective example of using an elimination method to control plant disease. Between 1948 and 1965, there were multiple significant outbreaks of the disease in China's spring wheat and winter wheat in the southern province of Fujian, despite the widespread use of chemical pesticides and key resistant types. According to an investigation, the cause of wheat stem rust, Puccinia graminis var. tritici, overwintered on cultivated winter wheat planted in August in Putian County, Fujian Province.

Since Putian farmers were convinced to switch from planting winter wheat to potatoes and broad beans, eliminating these P. graminis tritici overwintering locations, there have been no significant outbreaks of wheat stem rust. In fact, after the 1990s, the illness all but vanished in China [41]. Rice stripe disease provides another effective illustration of the use of an elimination strategy to control plant disease. For almost ten years, Jiangsu Province, China's primary rice-producing region, has seen an outbreak of the disease (2001–2010). The illness was mostly managed by applying insecticide to eliminate the insect vector, Laodelphax striatellus, as there were no resistant types. But after 2008, the management approach for rice stripe virus changed from using only insecticides to using a combination of insecticides and primary inoculum source elimination, which was accomplished by giving up the local custom of rotating rice and wheat, which eliminated the vector's overwintering sites. In the last many years, the illness has now been completely under control. Solution In situations where alternative methods are unable to accomplish the necessary degree of pathogen population density reduction and epidemic amelioration, the application of pesticides to eradicate diseases and/or their insect vectors is an essential component of plant disease management. In an integrated disease management system, the goal of using pesticides is to control the illness to the greatest extent possible while adhering to ecological and financial standards.

Factors like pathogen resistance and pesticide action modalities should be taken into account when using pesticides[42]. Pesticides should be used in conjunction with disease forecasts and understanding of the genetic structure of the pathogen population to increase application efficiency and decrease adverse environmental effects [43]. This will help in determining the most effective time and frequency of application as well as the type and dosage of pesticides to use [44, 45]. Other strategies, such as naturally occurring plant substances with biological control function, such as protein y3, which is isolated from edible fungus and other bacteria (Bacillus spp.), could also be successful in remedying the situation [46, 47]. A deeper comprehension of these biopesticides' characteristics and application process, as well as knowledge of pertinent biological traits and pathogen transmission mechanisms, are crucial for ensuring their effective usage. For instance, using 1-2 sprays of biological control agents or viral therapeutic agents during the rice seedling and turning green stage can both protect the plant from additional infection and lower the density of viruliferous insects [48]. Long-term management of tomato and lettuce root rot has shown to be greatly aided by the combination of pesticides with other biotic and abiotic techniques such biological agents, soil pH modification, and UV irradiation [49].

The control of plant diseases in the future

By thoroughly comprehending the mechanisms underlying plant disease epidemics, the operation of robust agro-ecosystems, and the individual and collective roles of RAER approaches on disease management, sustainable plant disease management necessitates a multifaceted consideration of the impacts of management approaches on economics, sociology, and ecology. This plant disease management approach aims to safeguard natural resources and the ecological environment in addition to raising agricultural output and enhancing food quality. Future studies in ecological plant disease control should concentrate on the following areas in order to meet this goal: (i) plant disease epidemic and evolutionary patterns under changing settings and agricultural production philosophies; (ii) how ecological factors affect crop health and agricultural productivity; (iii) technological development for fusing ecological concepts with the treatment of major crop diseases; (iv) social-economic analysis of plant disease epidemics and management.

Conclusions

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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