Climate Change and Its Impact on Plant Disease: A Comprehensive Analysis

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DOI: https://doi.org/10.31995/Book.AB334.A25.Chapter6

ABSTRACT:

Climate change is a pressing global issue that poses significant challenges to agriculture, particularly in the context of plant diseases. This comprehensive review analyzes the multifaceted impacts of climate change on plant pathology, exploring how rising temperatures, altered precipitation patterns, and increased atmospheric carbon dioxide levels affect disease incidence and severity. We discuss the physiological responses of plants to changing environmental conditions, which can enhance susceptibility to pathogens and disrupt existing plant-pathogen interactions. The review highlights specific diseases that have shown increased prevalence in response to climate change, including those caused by fungi, bacteria, and viruses. Additionally, we examine the role of shifting agro ecosystems and altered pest dynamics as secondary factors that exacerbate disease challenges. Furthermore, the review emphasizes the importance of predictive models and surveillance systems in understanding and mitigating the impacts of climate change on plant health. By integrating climate data with plant disease epidemiology, we can better forecast disease outbreaks and develop proactive management strategies. This paper aims to provide insights into the complex relationships between climate change and plant disease, underscoring the need for adaptive approaches in agricultural practices to enhance resilience and ensure food security in a changing climate.

Keyword: Susceptibility, Exacerbate disease, Resilience, Climate change

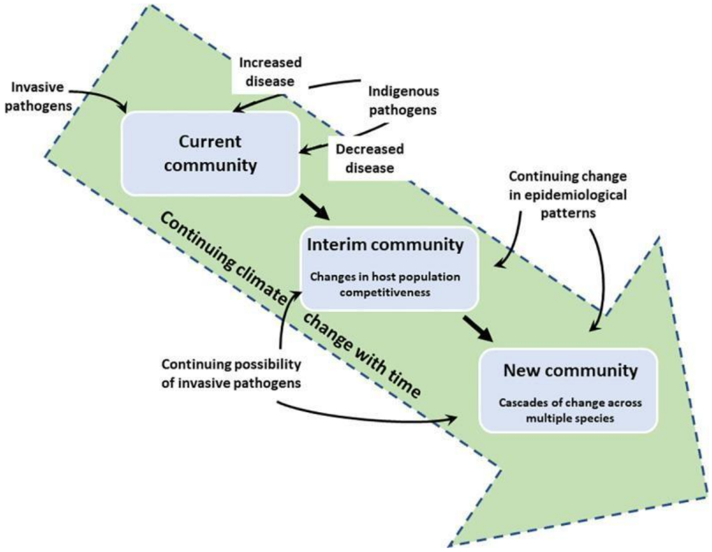
1. Introduction

Climate change has intensified over recent decade due to anthropogenic activities. Emissions of greenhouse gases like carbon dioxide, methane, and nitrous oxide have caused temperatures to rise, changed rainfall patterns, and increased extreme weather events. These changes affect plant health in complicated ways, impacting how plant diseases spread, their severity, and how plants defend themselves against them. Plant diseases significantly affect global agricultural productivity, with climate change exacerbating the problem. Combined infestations of pests and diseases can result in severe yield losses, such as up to 82% in cotton and over 50% in other major crops. When combined with post-harvest spoilage and quality deterioration, the impact becomes even more critical, particularly in resource-poor regions.

On a global scale, plant diseases alone account for an estimated 20% reduction in the yields of principal food and cash crops, posing a major challenge to food security and economic stability. This paper looks at how climate change is connected to plant diseases and discusses how these issues threaten our food systems and highlight the need for changes in farming practices (H. R. Gautam et. al., 2013).

2. Climate Change and Plant Disease Dynamic

The relationship between climate change and plant disease is complex and involves direct effects on plants, pathogens, and the organisms that spread diseases. It also includes indirect effects on their environments. To understand how these interactions work, it's important to look at how temperature, rainfall, and carbon dioxide levels influence the occurrence and severity of plant disease.



2.1 Effect of temperature

Temperature has a direct effect on the life cycles of both plants and pathogens. Many pathogens thrive within certain temperature ranges, and as temperatures rise, they can spread to areas where they previously couldn't survive. For example:

Fungal Pathogens: Warmer temperatures benefit fungi like Fusarium and Aspergillus, which cause issues like root rot and seed decay. Studies show that higher temperatures can speed up fungal reproduction, leading to more infections and more severe disease. Fusarium oxysporum f. sp. lactucae are caused by effect of temperature.

Bacterial and Viral Pathogens: Increased temperatures can weaken plant immune responses, making them more vulnerable to bacterial and viral infections. In warmer climates, diseases like bacterial blights from Xanthomonas are more common, and viral infections like the tomato yellow leaf curl virus are spreading to new areas.

Additionally, temperature affects how well plants can defend themselves. Heat stress can weaken their immune systems, allowing pathogens to bypass plant defenses more easily. In some cases, rising temperatures can disrupt the coevolution between plants and pathogens, increasing plants' susceptibility to infections. (Anderson, P. K., et al., 2016; JC Scott, et. al., 2010)

2.2 Change in Precipitation Patterns

Changes in rainfall patterns, including both droughts and heavy rainfall, create favourable conditions for different pathogen. High humidity and long periods of wetness encourage waterborne pathogens like *Phytophthora infestans*, which causes late blight in potato. Excessive rain can also help pathogens survive longer in the soil. In contrast drought often increases vulnerability to diseases like root rot and Fusarium wilt in crops like wheat and maize.

Shifts in rainfall also affect where and when plant diseases occur. For instance, pathogens that thrive in wet environments may spread to areas with more rainfall, creating new disease hotspots and complicating farming practices (D.P. Bebber, et. al., 2013).

2.3 Increased CO_2 Levels

Higher levels of CO_2 in the atmosphere affect how plants grow and interact with pathogens by changing their structure, growth rates, and nutrient distribution.

Elevated CO_2 can increase photosynthesis and plant biomass, which might change leaf structure and make it easier for pathogens to invade. Higher CO_2

can lower nitrogen levels in plant tissues, potentially impacting pathogen nutrition. Plants grown under elevated CO2 concentrations exhibited lower leaf silicon content, which may have increased their susceptibility to leaf blast (B Pokhrel, 2021; T Kobayashi, et. al., 2006).

3. Impact of Climate - Induced Plant Disease on Agriculture and Food Security

Climate-driven plant diseases impact not only individual crops but also threaten global food security and the stability of agriculture. Fungal and oomycete pathogens threaten global food security by infecting staple and economically significant crops. Monoculture farming practices, global trade, and climate change contribute to the emergence and spread of these pathogens, including fungicide-resistant strains.

3.1 Crop Quality and Quantity

Climate change-related plant diseases cause major crop losses, reducing food production. For instance, wheat rust diseases, worsened by rising temperatures, have led to big yield drops in North America and Europe. Likewise, bananas are increasingly affected by Panama disease, as climate change helps the disease spread to new areas, causing significant declines.

3.2 Biodiversity and Crop Diversity

Climate change intensifies pathogens, threatening biodiversity, especially in tropical regions with diverse crops. Increased disease can harm multiple plant species at once. Large-scale monocultures are especially vulnerable, as climate-driven diseases can spread quickly through these genetically similar crops.

3.3 Livelihoods and Economies

Plant diseases can significantly harm farmers' livelihoods, especially in low-income areas where they lack resources to adapt. As diseases impact staple crops, food prices increase, leading to economic instability. For instance, coffee leaf rust has severely affected coffee production in Central America, causing major economic losses and displacing farming communities (Chakraborty, S. et. al.,; Helen N Fones., et. al., 2020)

4. Case Studies: Notable Impacts of Climate Change on Plant Diseases

4.1 Potato Late Blight (*Phytophthora infestans*)

Potato late blight is a highly destructive disease that is becoming more severe due to climate change. The pathogen thrives in the moist, moderate temperatures that are increasing in northern regions as global temperatures rise. In areas where potatoes are a staple food, late blight worsens food insecurity and adds financial strain on farmers. The pathogen is highly adaptable to new potato varieties and fungicides. Globally, the original A1 strain has largely been replaced by the more aggressive A2 strain. In India, A2 was first reported in the 1990s and has since dominated in temperate highlands, while A1 remains prevalent in subtropical plains (Ristaino, J. B., & Allen, J., 1996; RK Arora, et. al., 2014).

4.2 Fusarium Wilt of Banana (*Fusarium oxysporum* f. sp. *cubense*)

Panama disease, caused by Fusarium wilt, impacts banana plants mainly in tropical and subtropical areas. Rising temperatures and increased rainfall have allowed this soil-borne fungus to spread, posing a serious threat to the banana industry. Since there is no effective treatment, preventive strategies like developing resistant banana varieties are essential (Randy C. Ploetz., 2015)

4.3 Coffee Rust (Hemileia vastatrix)

Climate warming has accelerated the spread of coffee rust, a disease highly sensitive to temperature and humidity. Warmer and wetter conditions in high-altitude coffee-growing areas have resulted in severe outbreaks, threatening the livelihoods of coffee farmers. The prevalence of nearly 37 races of coffee diseases in Indian coffee-growing regions has remained largely stable, with races I and II from the 1930s continuing to be predominant. Despite changes in climatic conditions, shifts in factors influencing the climate have not significantly impacted disease development. Diseases primarily occur when favorable conditions, such as lower temperatures (15-20°C) and diffuse light, allow spore germination. Therefore, in breeding strategies for sustainable coffee production, prioritizing the host plant's ability to tolerate pathogen attacks is crucial (N Suresh, et. al., 2012).

5. Mitigation and Adaptation Strategies

5.1 Disease-Resistant Cultivars

The development of durable, broad-spectrum resistance offers an eco-friendly and cost-effective way to control crop diseases, supporting sustainable agriculture. Advances in understanding the molecular mechanisms of pathogenesis and plant-pathogen interactions have led to innovative breeding strategies that go beyond the constraints of traditional methods. Creating plant varieties resistant to climate-related diseases is a highly effective strategy. Advances in genomic research and selective breeding have enabled the development of resistant crops, such as wheat varieties that can withstand rust and potatoes that can resist blight. Additionally, biotechnology tools like CRISPR provide new opportunities to boost plant resistance against emerging pathogens. Genome editing technologies, particularly CRISPR-Cas, have advanced significantly, enabling precise gene modifications and large-scale alterations. These versatile tools are increasingly crucial in plant disease management, overcoming limitations of earlier methods and offering a powerful platform for genome manipulation (Subhasis Karmakar, et. al., 2022; Qi Li. Et. al., 2021).

5.2 Integrated Pest and Disease Management (IPDM)

Climate change impacts the occurrence and severity of plant diseases, influencing crop-pathogen interactions and affecting disease management strategies. Changes in climate and atmospheric conditions will alter the timing, effectiveness, and choice of control measures, including chemical, physical, and biological approaches, within integrated pest management (IPM). Predicting future disease management needs is crucial for farmers, agro-industries, and extension services. Integrated Pest and Disease Management (IPDM) combines biological, chemical, and cultural practices to control the spread of diseases. This flexible and adaptable approach is particularly effective for managing climate-driven diseases, as it allows for adjustments based on changing environmental conditions. The focus is on non-chemical pest and disease management methods, including cultural practices, soil solarization, plant growth-promoting microorganisms, organic amendments, botanicals, and biocontrol agents (RC Sharma & JN Sharma, 201; Sahar Abdou., 2019).

5.3 Climate-Smart Agriculture Practices

Climate-smart farming methods are important to protect Indian agriculture from climate change. However, even with efforts from Indian and global organizations, few farmers are using these methods. Climate-smart practices like crop rotation, cover cropping, and agroforestry enhance biodiversity and create microenvironments that help plants cope with climate-related stress. For example, intercropping with non-host plants can minimize the spread of soil-borne pathogens by reducing their contact with susceptible crops (Jeetendra., et. al., 2018).

5.4 Monitoring and Forecasting

Technological advancements in disease monitoring and forecasting assist farmers and policymakers in anticipating outbreaks. Tools like remote sensing and data modeling enable early detection of climate-related disease risks, allowing for timely interventions.

Plant diseases can severely impact crop quality and yield, potentially destroying entire plants if not detected and managed early. Effective disease control is critical for global food security and sustainable agriculture. Traditional control methods are being replaced by electronic monitoring (e-monitoring) due to their limitations, such as being time-consuming, requiring specialized knowledge, and lacking portability. E-monitoring technologies, including electronic noses (e-nose), biosensors, wearable sensors, and electronic eyes, offer a practical and convenient approach for pathogen detection, identification, and quantification, and can complement conventional. (Ayat Mohammad-Razdari, et. al., 2022).

6. Conclusion

Climate change poses a major challenge to plant health, impacting agriculture, biodiversity, and food security. As environmental conditions become more favorable for plant pathogens, understanding these dynamics is essential for creating resilient agricultural systems. By utilizing genetic research, climate-smart practices, and integrated disease management, the agricultural sector can adapt to the changing climate. Future research should aim to improve disease models for different climate scenarios and develop region-specific strategies that account for local pathogens and environmental conditions. Effectively addressing the link between climate change and plant disease is vital for protecting global food supplies and promoting sustainable agriculture.

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