https://dx.doi.org/10.4314/dujopas.v11i1d.24
ISSN (Print): 2476-8316
ISSN (Online): 2635-3490

Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 11 No. 1d March 2025*

Impact of Climate Change on Plant Disease Dynamics

Kabir Faisal Shamuwa[1] Nusaiba Abdullahi[1]
Badiyya Abdulfatah Tahir[3] Ibrahim Abubakar[4]

[1]Department of Environmental Science and Engineering,
Nanchang Hangkong University,
China.

[3]Department of Plant Science and Biotechnology,
Bayero University
Kano.

[4]Department of Science Laboratory Technology,
Jigawa State Polytechnic
Dutse.

Email: Shamuajr12@gmail.com

Abstract
Climate change represents a significant threat to global food security and ecosystem health, with plant diseases emerging as a major concern. This systematic literature review synthesizes current knowledge on how climate change impacts plant disease dynamics, identifies research gaps, and proposes future directions to enhance resilience against climate-induced plant diseases. The review findings demonstrate that climate change alters pathogen evolution, leading to increased virulence and the emergence of new strains. Geographic range shifts of pathogens expose previously unaffected regions to disease outbreaks. Climate change also affects host plants by altering susceptibility and phenology, with significant implications for disease incidence and severity. Biodiversity plays a crucial role in regulating disease dynamics, while interactions with other environmental stressors exacerbate the challenges posed by climate change. Effective management strategies include monitoring and early warning systems, integrated pest management approaches, and policy interventions that promote sustainable agriculture and biodiversity conservation. However, gaps remain in understanding the complex interactions between pathogens, hosts, and the environment under future climate scenarios. More research is needed on the evolutionary potential of pathogens, the role of microbial communities in plant health, validation of findings under real-world conditions and establishing robust monitoring systems that utilize climate data and pathogen surveillance can facilitate early detection of disease outbreaks.

Keywords: Climate Change, Plant Diseases, Pathogen Dynamics, Biodiversity, Integrated Pest Management (IPM)

INTRODUCTION
Climate change, driven by rising greenhouse gas (GHG) concentrations such as CO_2, CH_4, and N_2O, has caused global temperatures to increase by approximately 0.8°C over the past century, with projections of further rises up to 3.5°C by 2100 (IPCC, 2021). All three elements

**Author for Correspondence*

of the "disease triangle"-host plants, pathogens, and the environment-are impacted by these changes, which foster an environment that is conducive to the growth and dissemination of infections. Higher temperatures, for example, have been associated with more severe outbreaks due to rapid evolution and shorter pathogen incubation times (Garrett et al., 2006). Furthermore, severe weather conditions like floods and droughts make plants more susceptible to diseases. The intricate relationships between climate variables emphasize how urgent it is to address how climate change affects plant health (Pautasso et al., 2012).

Plant diseases are influenced by environmental conditions that affect pathogen virulence and host susceptibility. By changing the biogeography of pathogens, climate change modifies these processes and raises the incidence of disease in previously untouched areas. Warmer climates, for instance, make it easier for spores to travel by wind during storms or watery infections to spread during floods (West et al., 2015). By increasing the growth rates of pathogens, rising CO_2 levels also exacerbate the effects of disease (Chakraborty et al., 2000). Depending on local climates, several illnesses such as rice blast (Magnaporthe grisea) show how temperature variations can either raise or lower the probability of an epidemic (Sharma et al., 2017). Predicting future illness patterns under shifting climatic conditions requires an understanding of these changes (Pautasso et al., 2012).

Pathogen dynamics are highly sensitive to climate change. The rates of disease reproduction, survival, and dissemination are impacted by changes in temperature and precipitation patterns. According to Desprez-Loustau et al. (2006), drought stress, for example, impairs plant defenses and increases susceptibility to infections like Phytophthora, which causes dieback diseases. Furthermore, novel pathogenic strains that are able to circumvent conventional resistance mechanisms may evolve as a result of changes in pathogen-host interactions brought on by climate change (Bebber et al., 2013). According to West et al. (2015), these modifications necessitate the development of novel approaches for tracking and controlling pathogen behavior in agricultural systems.

Biodiversity plays a vital role in ecosystem resilience against plant diseases. However, by upsetting ecological balances, climate change threatens biodiversity. For example, changes in temperature and precipitation patterns can cause species to migrate or go extinct, which reduces genetic diversity within plant populations and weakens natural resistance mechanisms against pathogens (Thompson et al., 2010). In addition, invasive species may flourish in altered climates, outcompeting native species and bringing new diseases into ecosystems (Pautasso et al., 2012; Garrett et al., 2006).

Integrated Pest Management (IPM) offers a holistic approach to managing pests and diseases under changing climatic conditions. IPM blends therapeutic acts like targeted pesticide usage with preventive ones like crop rotation and biological control (Bajwa & Kogan, 2002). By postponing the emergence of pest and disease resistance and optimizing management tactics, an evolutionary approach to IPM design can increase its efficacy (Holt et al., 2016). For instance, by blocking the channels that pathogens use to propagate, intercropping different plant species can stop the development of disease (Zhang et al., 2018). Sustainable agriculture depends on implementing IPM techniques that are adapted to climate-related issues (Pautasso et al., 2012).

Plant disease dynamics and climate change interact in a variety of ways. By speeding up pathogen life cycles and extending their geographic ranges, rising temperatures exacerbate the severity of disease (Bebber et al., 2013). Extreme weather events also cause disruptions to conventional farming methods, making farmers more susceptible to outbreaks (West et al., 2015). Although drier circumstances may reduce some hazards, process-based models predict latitudinal increases in disease pressure as a result of warming trends (Garrett et al., 2006). To handle these changing difficulties, effective management necessitates combining predictive modeling with flexible techniques like IPM (Pautasso et al., 2012).

Impact of Climate Change on Pathogen Dynamics

Alteration of pathogen evolution

Climate change can significantly alter the evolution of plant pathogens, leading to increased virulence, resistance, and the emergence of new strains. Pathogens often have shorter generation times and smaller genome sizes compared to their plant hosts, allowing them to accumulate genetic variation more rapidly in response to changing environmental conditions (Burdon & Zhan, 2020). This evolutionary advantage enables pathogens to quickly adapt to directional changes in climate means.

Studies have shown that the pathogenicity of pathogens like *Phytophthora infestans* and *Colletotrichum gloeosporioides* can rapidly recover or increase after exposure to heat stress or elevated CO_2 levels (Bebber et al., 2013). In contrast, plant immunity has not yet documented such a rapid rate of adaptation to climate change. The evolutionary gap between pathogens and their hosts is particularly concerning in the early stages of climate change, potentially contributing to increased vulnerability of ecosystems to diseases like root rot caused by *Phytophthora citrophthora* and canker caused by *Phytophthora cinnamomi* (Pautasso et al., 2012).

Geographic range shifts of pathogens

Climate change is also facilitating the geographic range shifts of plant pathogens, allowing them to expand into new areas that were previously unsuitable due to temperature or precipitation constraints. As climatic conditions change, pathogens can move into regions where their host plants are present but have not evolved resistance, leading to potentially devastating disease outbreaks. Chen et al. (2022) in their study titled "Climate change and the global distribution of wheat stripe rust," which delves into the effects of climate change on the global distribution of wheat stripe rust. This disease is caused by *Puccinia striiformis* f. sp. *tritici*, a pathogen that poses significant threats to wheat production worldwide. The study analyzed extensive data on climate trends and disease outbreaks to elucidate the impact of rising temperatures on the pathogen's geographic range. The study found that climate change has enabled *Puccinia striiformis* f. sp. *tritici* to expand its range to higher elevations and latitudes. This expansion is primarily driven by rising temperatures and altered precipitation patterns, which create favorable conditions for the pathogen. As global temperatures increase, regions that were previously too cool for the pathogen to thrive are becoming more conducive to its survival and spread. For instance, the Himalayas and East Africa, which were once less affected by wheat stripe rust, are now experiencing increased disease pressure due to these climate-driven changes (Chen et al., 2022).

In another study by Kessel et al. (2020) titled "*Phytophthora infestans*: A review of the current status of late blight in Europe." This research focuses on the current status and trends of late blight, caused by *Phytophthora infestans*, in European potato crops. The study reviews historical data and recent trends to understand how climate change affects the disease's distribution and severity. The study found that warmer spring temperatures have led to earlier outbreaks of late blight in Europe. This shift in disease timing poses challenges for potato farmers, as it can occur before traditional control measures are implemented. Rising temperatures and altered precipitation patterns have created more favorable conditions for

Phytophthora infestans, allowing it to infect potato crops earlier in the season. This change can lead to increased disease pressure and potential yield losses if not managed effectively. Climate change is altering the dynamics of late blight in several ways. Warmer temperatures accelerate the pathogen's life cycle, leading to faster disease progression and potentially more severe outbreaks. Additionally, changes in precipitation patterns can affect the moisture levels necessary for the pathogen's survival and spread (Kessel et al., 2020).

Table 1: Geographic Range Shifts of Pathogens as a Result of Climate Change

Pathogen	Geographic Range Shifts	Reference
Puccinia striiformis f. sp. *tritici*	Expansion to higher elevations and latitudes in Asia and Africa	Chen et al. (2022)
Phytophthora infestans	Earlier outbreaks in Europe due to warmer springs	Kessel et al. (2020)
Puccinia triticina	Shifts in distribution due to changing climate conditions	Hovmoller et al. (2011)
Magnaporthe oryzae	Potential expansion due to climate change	Sharma et al. (2017)
Colletotrichum gloeosporioides	Potential for increased disease incidence in new regions	West et al. (2015)
Fusarium oxysporum	Potential for increased presence in previously unsuitable regions	Pautasso et al. (2012)

Effects on Host Plants

Changes in Plant Susceptibility to Diseases

Climate change significantly alters plant susceptibility to diseases through various physiological and biochemical mechanisms. Elevated temperatures and increased atmospheric CO2 can enhance plant growth, but they may also make plants more vulnerable to certain pathogens. For instance, higher temperatures can stress plants, leading to reduced defense responses, which in turn increase susceptibility to diseases like downy mildew and powdery mildew (Ghini et al., 2011). Furthermore, changes in plant metabolism, such as alterations in sugar and starch content, can affect the interaction between plants and pathogens, potentially favoring pathogen colonization (Pertot et al., 2012).

Additionally, drought conditions can exacerbate this vulnerability. While some studies suggest that drought may activate general defense pathways, enhancing resistance against specific pathogens, others indicate that water stress can impair plant defenses, making them more susceptible to infection (Eastburn et al., 2011). The dual nature of these responses highlights the complexity of plant-pathogen interactions under climate stressors.

Phenological Changes in Plants Due to Climate Factors

Climate change also influences the phenology of plants-timing related to growth stages such as flowering and fruiting-which can have cascading effects on disease dynamics. Warmer temperatures can lead to earlier flowering and leaf-out dates, which may result in a mismatch between the timing of plant development and pathogen life cycles (Schwartz et al., 2013). This phenological shift can expose plants to pathogens at more vulnerable stages of their life cycle, potentially increasing disease incidence.

For example, studies have shown that earlier bud break in grapevines due to warmer winters can lead to increased susceptibility to fungal diseases such as *Botrytis cinerea* (Gessler et al., 2011). Similarly, changes in the timing of leaf emergence can affect interactions with insect vectors that transmit plant viruses, further complicating disease management strategies.

Correlation between Climate Variables and Disease Outbreaks

Plant disease dynamics are being significantly impacted by the severe effects of climate change on ecosystems and agricultural systems. Globally, the distribution and severity of plant diseases are changing due to factors like rising temperatures, changed precipitation patterns, and extreme weather events. Developing efficient management plans to guarantee food security and preserve ecosystem health requires an understanding of these changes.

Increased pathogen reproduction and quicker disease cycles have been associated with rising temperatures. For example, the cause of wheat stripe rust, *Puccinia striiformis*, spreads more readily in warmer climates, thriving in areas that were previously inappropriate because of lower temperatures (Milus et al., 2009). Wheat production is severely hampered by this increase of disease range, especially in areas like East Africa and the Himalayas.

Plant diseases are impacted by changes in precipitation patterns in two ways. According to Chakraborty and Newton (2011), excessive rainfall can produce soils that are saturated with water, which can favor soilborne pathogens like *Fusarium* spp. that cause Fusarium wilt. On the other hand, drought stress impairs plant defenses, increasing them vulnerability to diseases. This contradiction highlights the necessity of adaptive management techniques that take drought and abundant precipitation into consideration. *Xanthomonas oryzae*-caused rice bacterial blight is one of the illnesses that are spread by extreme weather events like storms and floods, which accelerate pathogen distribution via wind and water (Mew et al., 1984). Crops may also sustain harm from these occurrences, increasing their vulnerability to infection. Climate change has made these occurrences more frequent and severe, which emphasizes how crucial resilient agricultural systems are.

Elevated CO_2 levels can alter plant physiology, affecting plant-pathogen interactions. For example, *Colletotrichum gloeosporioides*, which causes anthracnose, may show increased virulence under elevated CO_2 conditions (Bebber et al., 2013). This shows the complexity of climate change impacts on disease dynamics, as effects can vary depending on the specific pathogen and host plant.

Long warm seasons provide microorganisms a wider window for infection, enabling several disease cycles each season. By increasing the chances of infection and transmission, this helps pathogens like *Puccinia graminis*, which causes stem rust (Singh et al., 2016). According to Eastburn et al. (2011), plants that experience drought stress are less resilient and are therefore more vulnerable to diseases like *Verticillium dahliae*, which causes Verticillium wilt. This heightened vulnerability emphasizes the necessity of drought control plans that take disease risk into account.

Changes in wind patterns impact the transmission of illnesses like maize smut, which is brought on by *Ustilago maydis*, by affecting the distribution of airborne pathogens (Pautasso et al., 2012). Predicting disease outbreaks and putting targeted control measures in place depend on an understanding of these shifts. Natural disease resistance mechanisms are weakened by decreased biodiversity, which makes outbreaks more severe. For instance, low-diversity habitats are ideal for the growth of *Fusarium graminearum*, the causative agent of Fusarium head blight (He et al., 2021).

Table 2: Impact of Climate Variables and Disease Outbreaks

Climate Variable	Impact on Disease Outbreaks	Example Pathogen/Disease	Reference
Rising Temperatures	Increases pathogen reproduction, accelerates disease cycles, and expands geographic range.	*Puccinia striiformis* (Wheat Stripe Rust) thrives in warmer temperatures.	Milus et al. (2009)
Altered Precipitation Patterns	Excessive rainfall creates water-saturated soils, favoring soilborne pathogens. Drought stress weakens plant defenses.	*Fusarium* spp. (Fusarium Wilt) thrives in high moisture.	Chakraborty & Newton (2011)
Extreme Weather Events (Storms, Hurricanes, Floods)	Increases pathogen dispersal via wind and water; damages crops, making them susceptible to infection.	*Xanthomonas oryzae* (Rice Bacterial Blight) spreads through rain splash.	Mew et al. (1984)
CO_2 Elevation	Alters plant physiology and affects plant-pathogen interactions; can increase susceptibility or resistance depending on crop species.	*Colletotrichum gloeosporioides* (Anthracnose) shows increased virulence under elevated CO_2.	Bebber et al. (2013)
Longer Growing Seasons	Extends infection windows for pathogens, allowing multiple disease cycles per season.	*Puccinia graminis* (Stem Rust) benefits from prolonged warm seasons.	Singh et al. (2016)
Drought Conditions	Reduces plant resilience, increases susceptibility to pathogens and secondary infections.	*Verticillium dahliae* (Verticillium Wilt) becomes more aggressive under water stress.	Eastburn et al. (2011)
Changing Wind Patterns	Affects spore dispersal and long-distance movement of airborne pathogens.	*Ustilago maydis* (Corn Smut) spreads via wind-borne spores.	Pautasso et al. (2012)
Biodiversity Loss	Reduces natural disease resistance mechanisms, increasing outbreak severity.	*Fusarium graminearum* (Fusarium Head Blight) thrives in low-diversity environments.	He et al. (2021)

Management Strategies

Monitoring and Early Warning Systems

Effective monitoring and early warning systems are essential for managing plant diseases in the face of climate change. Integrating data from various sources, such as weather stations, satellite imagery, and field observations, can help predict disease outbreaks and guide management decisions (Magarey et al., 2011). Genomic tools can also aid in the rapid detection and identification of pathogens, enabling targeted interventions (Bebber, 2015).

Integrated Pest Management (IPM) Approaches

Adopting Integrated Pest Management (IPM) strategies is crucial for building resilience against climate change-induced plant diseases. IPM combines multiple control methods, including cultural practices, host resistance, biological control, and judicious use of pesticides, to manage diseases in a sustainable manner (Lamichhane et al., 2015).

Policy Implications for Agriculture and Conservation

Addressing the impacts of climate change on plant diseases requires policy interventions at multiple levels. At the international level, agreements like the International Plant Protection Convention (IPPC) can facilitate the sharing of information and best practices for disease management (Pautasso et al., 2012). National and regional policies should promote sustainable agriculture, incentivize the adoption of IPM, and support research on climate change and plant health. Conservation policies should prioritize the protection of biodiversity hotspots and the management of invasive pathogens to maintain ecosystem resilience.

CONCLUSION

This systematic literature review has highlighted the profound impacts of climate change on plant disease dynamics, emphasizing several critical areas. Climate change alters pathogen evolution, leading to increased virulence and the emergence of new strains, while also facilitating geographic range shifts that expose previously unaffected regions to plant diseases. Additionally, the effects of climate change on host plants-such as changes in susceptibility and phenological shifts-further complicate disease dynamics. The correlation between climate variables and disease incidence shows the urgency of understanding these interactions. Furthermore, biodiversity plays a crucial role in regulating disease dynamics, while environmental stressors like pollution and land use changes exacerbate the challenges posed by climate change. Future studies should focus on the evolutionary responses of pathogens to climate change, including their adaptation mechanisms and potential for increased virulence and the adoption of IPM strategies that combine cultural practices, resistant cultivars, and biological control methods can improve resilience against climate-induced plant diseases.

REFERENCES

Bebber, D. P., Ramotowski, M. A., & Gurr, S. J. (2013). Crop pests and pathogens move polewards in a warming world. *Nature Climate Change, 3*(11), 985-988.

Burdon, J.J. & Zhan, J., 2020. Climate change and plant disease: implications for food security. *Nature Reviews Microbiology*, 18(1), pp.11-18.

Chakraborty, S., & Newton, A. C. (2011). Climate change, plant diseases, and food security: An overview. *Plant Pathology, 60*(1), 2-14.

Chen, W., Wellings, C. R., Chen, X., Kang, Z., & Liu, T. (2022). Climate change and the global distribution of wheat stripe rust. *Nature Communications*, 13(1), 1–10. doi: 10.1038/s41467-022-29444-4

Cooke, D.E., Cano, L.M., Raffaele, S., Bain, R.A., Cooke, L.R., Etherington, G.J., et al., 2012. Genome analyses of an aggressive and invasive lineage of the Irish potato famine pathogen. *PLoS Pathogens*, 8(10), p.e1002940.

Cooke, D.E.L., Cano, L.M., Raffaele, S., et al., 2011. Genome analyses of an aggressive and invasive lineage of the Irish potato famine pathogen. *PLoS Pathogens*, 8(10), p.e1002940.

Eastburn, D. M., & McElrone, A. J. (2011). Effects of drought stress on plant disease development. *Plant Disease*, 95(10), 1104–1110.

Eastburn, D.M., McElrone, A.J. & Bilgin, D.D., 2011. Influence of atmospheric and climatic change on plant–pathogen interactions. *Plant Pathology*, 60(1), pp.54-69.

Fry, W. E. (2008). *Phytophthora infestans*: The plant (and R gene) destroyer. *Molecular Plant Pathology, 9*(3), 385-402.

Garrett, K.A., Dendy, S.P., Frank, E.E., Rouse, M.N. & Travers, S.E., 2006. Climate change effects on plant disease: genomes to ecosystems. *Annual Review of Phytopathology*, 44(1), pp.489-509.

Gessler, C., Pertot, I. & Perazzolli, M., 2011. *Plasmopara viticola*: A review of knowledge on downy mildew of grapevine and effective disease management. *Phytopathologia Mediterranea*, 50(3), pp.3−44.

Ghini, R., Bettiol, W. & Hamada, E., 2011. Diseases in tropical and plantation crops as affected by climate changes: Current knowledge and perspectives. *Plant Pathology*, 60(1), pp.122-132.

He, D., Qian, H., Liu, X., & Wang, R. (2021). Biodiversity and plant disease control: A meta-analysis of experimental studies. *Ecology Letters, 24*(6), 1173-1185.

He, D.C., Zhan, J., Xie, L.H. & Burdon, J.J., 2021. Problems, challenges and future of plant disease management: from an ecological point of view. *Journal of Integrative Agriculture*, 20(2), pp.2-12.

Hovmøller, M.S., Sorensen, C.K., Walter, S. & Justesen, A.F., 2011. Diversity of *Puccinia striiformis* on cereals and grasses. *Annual Review of Phytopathology*, 49(1), pp.197-217.

Kessel, G. J. T., Cooke, L. R., & Evenhuis, A. (2020). *Phytophthora infestans*: A review of the current status of late blight in Europe. *Potato Research*, 63(2), 147–164. doi: 10.1007/s11540-020-09444-4

Mew, T. W., Alvarez, A. M., Leach, J. E., & Swings, J. (1984). *Xanthomonas campestris* pv. *oryzae*: A threat to rice production in the tropics. *Plant Disease*, 68(5), 436–439. doi: 10.1094/PD-68-436

Milus, E. A., Kristensen, K., & Hovmøller, M. S. (2009). Evidence for increased aggressiveness in a recent widespread strain of *Puccinia striiformis* f. sp. *tritici*. *Phytopathology, 99*(1), 89-94.

Nature Reviews Microbiology, 2023. Climate change impacts on plant pathogens, food security and paths forward. Available at: https://www.nature.com/articles/s41579-023-00900-7 [Accessed 22 Sept. 2024].

Pautasso, M., Döring, T. F., Garbelotto, M., Pellis, L., & Jeger, M. J. (2012). Impacts of climate change on plant diseases—opinions and trends. *European Journal of Plant Pathology*, 133(1), 295–313. doi: 10.1007/s10658-011-9936-1

Pautasso, M., Döring, T. F., Garbelotto, M., Pellis, L., & Jeger, M. J. (2012). Impacts of climate change on plant diseases—Opinions and trends. *European Journal of Plant Pathology, 133*(1), 295-313.

Pautasso, M., Döring, T.F., Garbelotto, M., Pellis, L. & Jeger, M.J., 2012. Impacts of climate change on plant diseases-opinions and trends. *European Journal of Plant Pathology*, 133(1), pp.295-313.

Pertot, I., Elad, Y. & Garbelotto, M., 2012. Climate change impact on plant pathogens and plant health: An overview. *Environmental Change*, pp.2-14.

Savary, S., Willocquet, L., Pethybridge, S.J., et al., 2019. The global burden of pathogens and pests on major food crops. *Nature Ecology & Evolution*, 3(3), pp.430-439.

Schwartz, M.D., Ahas, R. & Aasa, A., 2013. Onset of spring starting earlier across the Northern Hemisphere. *Global Change Biology*, 9(2), pp.100-111.

Sharma, S., & Duveiller, E. (2017). *Magnaporthe oryzae* pathotypes and rice blast management. *Journal of Plant Pathology*, 99(2), 257–275.

Shaw, M. W., Bearchell, S. J., Fitt, B. D. L., & Fraaije, B. A. (2008). Long-term relationships between strains of *Zymoseptoria tritici*, climate, and wheat disease severity. *Global Change Biology, 14*(1), 205-216.

Singh, R. P., Hodson, D. P., Huerta-Espino, J., Jin, Y., Bhavani, S., Njau, P., ... & Govindan, V. (2016). Emergence and spread of new races of *Puccinia graminis* f. sp. *tritici*. *Annual Review of Phytopathology, 54*(1), 379-402.

West, J. S., Townsend, J. A., Stevens, M., & Fitt, B. D. L. (2015). Comparative biology of different plant pathogens to estimate effects of climate change. *Global Change Biology*, 21(1), 288–303. doi: 10.1111/gcb.12693