A Review on Impact of Climate Change on Plant Diseases: Perspectives, Patterns and Mitigating Measures

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Abstract

With the industrial revolution, the climate on earth has altered. The temperature has soared by 0.3 to 0.6 °C and atmospheric CO_2, a significant greenhouse gas, has increased by almost 30%. According to the Intergovernmental Panel on Climate Change, by the year 2100, the global mean temperature would have increased by 0.9 to 3.5 °C under the current emission scenario. These forecasts are, however, subject to a great deal of uncertainty. Although weather plays a significant role in plant diseases, a thorough review of the pattern these diseases affect primary production in agricultural systems may be impacted by climate change is currently lacking. Based on a review of the minimal research available, it appears that losses due to plant diseases, the effectiveness of disease management techniques, and the geographic distribution of plant diseases are the three areas where the effects of climate change are most likely to be felt. Specific plant diseases may be positively impacted, negatively impacted, or unaffected by climate change. Additional investigation is required to acquire foundational data on various disease systems. Several plant disease models use various climatic variables and operate at a different temporal and geographical scale than global climate models. To accurately evaluate the effects of disease on a worldwide scale, methodological advancements are required.

1. INTRODUCTION

Human civilization is inextricably linked to the climate, with agriculture emerging as the most significant consequence of these changes in human dietary patterns and environmental conditions. Anthropogenic activities such as pollution, long-distance introduction of exotic species, urbanization, etc., are responsible for the most unexpected and dramatic changes in pace of climate, which are inevitable as the earth ages naturally. Currently, one of the greatest threats to humanity is climate change, which results in over 0.4 million fatalities annually and costs the global economy more than US$ 1.2 trillion (McKinnon *et al.*, 2012). As long as climate change continues unchecked, temperature rises of 3.4 °C and CO_2 concentrations of 1250 ppm is predicted by 2095, along with significantly increased climate variability and an increase in extreme weather-related occurrences (Savary *et al*., 2012).

The implications are most noticeable in developing nations like India, where decreased agricultural productivity due to climate change-related extreme weather is a major cause of death from diseases linked to poverty and hunger (Gautam, 2009). Numerous factors related to climate change impact agriculture, such as variations in mean temperatures, precipitation patterns, and climate extremes (including heatwaves), pests and disease outbreaks, atmospheric CO_2 levels, ground-level ozone concentrations, and food quality (Porter *et al*., 2014). Crop productivity in low-latitude countries is expected to be adversely affected by future climate change, whereas northern latitudes may see favorable or negative consequences.

The likelihood of food insecurity will most likely increase due to climate change. Weather and climate are major factors that affect the distribution and abundance of all species. The majority of organisms, including humans, are dependent on weather in the short and long term (Andrewartha and Birch, 1954). Aside from the dynamics of pests and illnesses and how natural enemies control them, weather and climate have an impact on agricultural productivity and quality. This regulation is mostly ignored by humans (DeBach, 1964). Plant diseases annually generate large losses in agricultural yield that are economically significant, according to several reports (Sharma *et al*., 2017). Depending on the crop, Oerke (2006) observed crop losses ranging from 25 to 50 percent. According to their estimates, pre-harvest losses caused by infections account for 13% of the output's potential value. A post-harvest loss of an additional 10% was projected. According to Strange and Scott's (2005) research, disease alone accounts for 10% of global harvest losses. However, Bentley *et al*. (2009) calculated that plant health issues could account for as much as one-third of global harvest losses.

In a nutshell, this review paper discusses many elements of how plant diseases are affected by climate change and what can be done to effectively manage them.

2. CLIMATE CHANGE'S IMPACT ON AGRICULTURE

Agriculture and climate change are two worldwide phenomena that are tied to one another. Agriculture is already being impacted by climate change, but in different ways globally. In a similar vein, agriculture fuels global warming through the release of greenhouse gases (GHGs) into the atmosphere and the conversion of non-agricultural land, such as forests, into agricultural land (Blanco *et al*., 2014). About 20–25% of the world's yearly emissions of greenhouse gases in 2010 came from land-use change, forestry, and agriculture (Porter *et al*., 2014). According to Smith *et al*. (2014), there are several strategies that can lower the likelihood that agriculture will suffer from the effects of climate change and lower greenhouse gas emissions from this industry. Agricultural crops and pests are particularly impacted by climate change in agriculture. Depending on the species and how they grow, this effect may have different magnitudes. Plant infections have the potential to partially or completely offset the enhanced agricultural output. Because of this, it's critical to consider all biotic factors while analyzing altering climatic trends (Kumar *et al*., 2013).

3. RELATIONSHIPS BETWEEN GLOBAL CHANGE FACTORS

Increased atmospheric concentrations of CO_2 and other greenhouse gases, together with the ensuing temperature shifts, nitrogen deposition, biotic invasions, modified disturbance regimes, and land-use are examples of anthropogenic drivers of global change (Franklin *et al*., 2016). The easier entry of foreign, dangerous species will have direct effects on plant health due to global warming, increasing pollution, and CO_2 concentrations (Chakraborty *et al*., 2000). Changes in the climate are probably going to make it easier for them to grow and spread. It is widely acknowledged that the prediction and management of the effects of climate change on plant health are complicated by the interplay of factors such as pollution, globalization, changing climate, and an increase in pests, diseases, and harmful plant species (Pautasso *et al*., 2010).

4. IMPACT OF CLIMATE CHANGE ON HOST - PATHOGEN INTERACTION

For pests, diseases, and related antagonistic species, climate change will alter the timing of lifecycle stages and their rates of growth (Chakraborty *et al*., 2012). Global warming and climate change will enable plants and pathogens to survive outside of their current geographic range. Climate variations in temperature, precipitation, and other atmospheric parameters, in addition to primarily elevated CO_2 concentrations, might hasten the reproduction period of a number of plant diseases, hence intensifying their infection load on agricultural plants (Boonekamp, 2012). According to Pedapati *et al*. (2016), it may alter host resistance mechanisms and host-pathogen interactions. Both hosts and diseases will have a shift in their geographic distribution (Mina *et al*., 2012). According to Coakley *et al*. (1999), for example, higher temperatures increase the susceptibility of host plants like wheat and oats to rust infections, but they also increase the resistance of some forage species to fungi. Similarly, in the USA and the Sahel region of Africa, the root pathogen *Macrophomina phaseolina*, which causes general char coal rot, has become a serious soybean disease (Groenewald and Crous, 2014). Particularly climate change models anticipate *M. phaseolina* to spread to new places, with the species being especially harmful in hot, arid environments (Fones and Gurr, 2017). Oak decline is another illness whose distribution is predicted to grow because of climate change. Throughout southern Europe and up the west coast of France, oak trees are infected with the causative agent, *Phytophthora cinnamomi*, a soil-borne disease that requires warmth and moisture (Fones and Gurr, 2017).

5. IMPACT OF CLIMATE CHANGE ON PLANT DISAESES

Climate change will exacerbate the problem of plant diseases, which are one of the major factors directly affecting agricultural productivity worldwide. The destruction caused by pests and diseases results in a loss of 20–30% of agricultural yield (Kashyap *et al*., 2017a, 2017b). According to Oerke (2006), biotic stress can result in yield losses of 28.2% for wheat, 37.4% for rice, 31.2% for maize, 40.3% for potatoes, 26.3% for soybeans, and 28.8% for cotton. Additionally, every year, numerous abiotic stress factors cause the loss of roughly 42% of crop productivity. Although efficient pest and disease control has doubled food production over the past 40 years, infections still account for 10–16% of global crop (Chakraborty and Newton, 2011). Diseases cause the loss of 14.2% of potential production in Asia, which is estimated to cost US$ 43.8 billion (Oerke, 1994). One of the biggest issues facing agriculture worldwide is climate change. Climate uncertainty has led to new insect emergences, altered agricultural cultivation techniques, and devastating global droughts, hailstorms, and floods (War *et al*., 2016). Environmental changes that increase the likelihood of some pests and diseases spreading northward, the speed at which pathogens multiply each season, and their improved capacity to adapt to survive the winter, all of which increase the fitness, number, and range of these organisms. Farmers' crops will be vulnerable to new illnesses and pests as they adjust their cropping patterns and crops to the changing environment, which will further exacerbate the issue. Ho Won Chung *et al*. (2009) suggest that there is a chance that physiological alterations in the host result in increased resistance to disease. Gautam *et al*. (2013) predict that as global warming continues, the severity of plant diseases caused by bacteria, fungus, viruses, and insects will rise. For example, the combination of many elements including temperature rise, atmospheric CO_2 concentration increase, and moisture concentration variations is associated to the pests population and other insect vectors that cause plant illnesses (Chander *et al*., 2009). Due to potential climate changes, the Indo-Gangetic Plains, which presently make up 15% of the world's wheat production, may by 2050 have up to 51% of its area reclassified as a heat-stressed, irrigated, short-season production mega-environment (Duveiller *et al*., 2007). However, the Plains still have high potential for growth and development. Should the forecast come to pass, wheat-growing regions where the disease is not already prevalent may expect an increase in the severity and prevalence of spot blotch. According to Zhang (2005), the incidence of *M. graminicola* has increased over the past three decades in Europe, while the presence of *Phytophthora nodorum* has gotten smaller in significance. According to an assessment of significant horticultural crop diseases in India, The effects of climate change are evident in epidemic outbreaks of *Phytophthora meadii*-caused fruit rot in arecanuts and *Phyllosticta arecae* and *C. gloeosporioides*-caused leaf spot in arecanuts, *Phytophthora palmivora*-caused coconut bud rot, *Phakopsora euvitis*-caused yellow rust in grapes, Alternaria bunch rot in grapes caused by *Alternaria* spp., Botryodiplodia dieback of grapes caused by *Botryodiplodia theobromae*, Macrophoma in bananas, Cercospora leaf spot and wilt in chillies, blossom blight in mangos, and wilt and nodal blight in pomegranates in some areas. Since 1952, Phytophthora blight has been a significant factor restricting the production of potatoes in India; nevertheless, other vegetable crops have never been at risk from these diseases. Significant Phytophthora disease outbreaks have been observed since 2008, including late blight on potatoes and tomatoes (*P. infestans*), fruit rot on brinjal (*P. parasitica*), wilts in capsicum and chilli (*P. capsici*), blights in cucurbits (*P. capsici*), fruit rot in okra (*P. parasitica*), and root rot in cauliflower and cabbage (*P. megasperma/P. drechsleri*). A few important diseases, namely rice blast, sheath blight, and grain discolouration, have caused large yield losses in the current rice-cropping environment. Furthermore, the impact of diseases on rice production has increased with time in the Jammu and Kashmir valleys of India. Due to new illnesses that would not have reached the commercial threshold in the absence of climate change, the rice crop is facing fierce competition (Ahangar *et al*., 2014). The agricultural disease spectrum will therefore likely shift as a result of climate change in some areas, and pests or diseases that are now thought to be inconsequential may become possible new concerns in the future.

5.1 : IMPACT OF TEMPERATURE ON PLANT DISAESES

Climate change's impact on the severity of disease is influenced by temperature and the length of exposure (Chakraborty, 2013; Ferrocino *et al*., 2013). Temperature changes may bring to the emergence of previously dormant disease races, which could spark an unexpected epidemic (Parvatha Reddy, 2013). Milus *et al*. (2006) observed that pathotypes of *Puccinia striiformis* f. sp. *tritici* that originated in the USA after 2000 were aggressive due to their adaptability to higher temperatures. Because of this, compared to the previous isolates, the new isolates are more aggressive at higher temperatures due to their improved adaptation. According to Gautam *et al*. (2013), changes in temperature can also have an impact on a pathogen's ability to reproduce, infect new hosts, spread its spores, and survive between seasons. Although a higher rate of increase is anticipated from 2020 to 2030 compared to 2000 to 2020, the overall pattern of soil-borne pathogen response in Europe's coldest regions indicates growing growth. A notable acceleration of growth rate has been observed in the soils of northern European and Baltic states, according to projections of winter cereal diseases such as *Pythium ultimum, Sclerotinia minor*, and *M. phaseolina* (Manici *et al*., 2014). According to research on the impact of rising global temperatures on late blight, warmer regions (13 °C) will see a decrease in late blight risk with an early commencement of epidemics, with a 2 °C increase in global temperature (Singh *et al*., 2013). When there is sufficient soil moisture and a rise in temperature, evapotranspiration can increase, creating a humid microclimate in crops and increasing the likelihood of diseases that thrive in those conditions (McElrone *et al*., 2005). For example, in low-productivity areas, Karnal bunt (*Tilletia indica*) and common bunt (*Tilletia caries*) in wheat may become significant under changing climate circumstances if suitable seed treatment is not applied (Oerke, 2006). When temperatures rise over 33°C, Fusarium wilt chickpea-resistant cultivars have been shown to be more susceptible to dry root rot (Dixon *et al*., 2012). According to Madden *et al*. (2007), there is evidence of needle blight (*Dothistroma septosporum*) migrating northward in North America as temperatures rise and precipitation increases. Average temperatures in Northern Germany are expected to benefit oil seed rape diseases including *Alternaria brassicae, Sclerotinia sclerotiorum,* and *Verticillium longisporum,* especially when considering a long-term (2071–2100) perspective (Siebold and Von Tiedemann, 2012). Additionally, temperature influences a plant's ability to fend against illness, which in turn influences the frequency and intensity of disease. Bacterial blight (*Xanthomonas oryzae* pv. *oryzae*) in rice, leaf rust (*Puccinia recondita*) in wheat, and black shank (*Phytophthora nicotianae*) in tobacco have all been shown to be sensitive to temperature (Gregory *et al*., 2009). In regions where temperature-dependent diseases have not previously been documented, bacteria (*Acidovorax avenae, Ralstonia solanacearum,* and *Burkholderia glumea*) may proliferate and disperse, according to Kudela (2009). Warming temperatures generally cause plant diseases to spread more widely and become more severe.

5.2 : IMPACT OF DROUGHT ON PLANT DISAESES

The single biggest problem affecting the world's food security is unpredictable drought, which fosters the spread of diseases. According to Desprez-Loustau *et al*. (2006) and Elad and Pertot (2014), drought is predicted to increase the prevalence of infections, primarily through indirect impacts on host physiology. Consequently, it is anticipated that a higher frequency of dryness will raise the likelihood that root diseases, wound colonizers, and latent sapwood colonizers may infect trees (Sturrock *et al*., 2011). Plants located in areas where drought and other stressors occur more frequently may be vulnerable to root infection from *Phytophthora, Armillaria* species, and fungi that cause canker, such as *Botryosphaeria* and *Diplodia*. Studies conducted by Clover *et al*. (1993) and Olsen *et al*. (1990) have revealed that viruses like *Beet yellows virus* and *Maize dwarf mosaic virus* are also impacted by drought stress in terms of both incidence and severity. It seems that *Heterobasidion irregulare*, an invasive foreign species in Italy, is just as suited to spreading throughout the Mediterranean environment as the native *H. annosum* (Garbelotto *et al*., 2010).

5.3 : IMPACT OF RAINFALL ON PLANT DISAESES

Numerous studies showed that although rainfall variations have no impact on the leaf wetting time, they have no effect on the occurrence of epidemics (Ghini *et al*., 2008). On the other hand, fewer rainfall amounts might result in fewer grape downy mildew infections. According to Salinari *et al*. (2006), infections that begin earlier in the growing season give epidemics more time to spread, hence in warming environments, the rise in temperature more than makes up for the shorter duration of leaf wetness. Similar to this, *Drechslera teres*-caused net blotch of barley causes yield losses by reducing 1000-kernel weight; it is particularly severe in temperate locations with heavy rainfall and humidity (Deimel and Hoffmann, 1991). Increased Phoma stem canker disease severity on oilseed rape is anticipated in the UK in response to regional variations in rainfall and temperature (Evans *et al*., 2008). In addition, several *Phytophthora* spp. are more likely to become infected due to the higher mean winter temperatures, shift in summer to winter precipitation, and tendency toward heavier rain that have been observed in central Europe (Jung, 2009). These species are also to blame for the rising rates of root rot in forest trees in this area. According to Chakraborty and Newton (2011), the concentration of mycotoxin caused by Fusarium head blight in grain often rises with the frequency of wet days and days with high relative humidity (RH) but falls with low and high temperatures.

5.4 : IMPACT OF CO_2 ON PLANT DISAESES

Plant pathogen evolution could be accelerated by elevated carbon dioxide (ECO_2) linked to climate change, which could have an impact on virulence. According to Lake and Wade (2009), *Erysiphe cichoracearum* becomes more aggressive in the presence of elevated CO_2, and the model plant's leaf epidermal properties also alter. Similarly, when CO_2 climbed from 365 ppm to 550 ppm, so did rice blast and sheath blight, according to Kobayashi *et al*. (2006). However, according to Gória *et al*. (2013), elevated CO_2 had little to no impact on the incidence levels of the disease's panicle blast phase. Chakraborty *et al*. (2000) revealed that high CO_2 levels have been linked to increased reproduction and spread of infections, including barley powdery mildew and anthracnose, in addition to high disease incidence and severity caused by host alterations. Intriguingly, elevated CO_2 was found to increase susceptibility to brown spot *Septoria glycines*, while decreasing susceptibility to downy mildew *Peronospora manshurica,* in a Free-Air CO_2 Enrichment (FACE) study evaluating the effects of elevated CO_2 on soybean diseases (Eastburn *et al*., 2010). *Phyllosticta minima* is more resistant to red maple leaves at higher CO_2 levels, and this resistance is linked to a smaller stomatal aperture (McElrone *et al*., 2005). A relationship between a decrease in stomatal aperture and an increase in disease resistance was also reported in the tomato–*Pseudomonas syringae* pv. *tomato* DC3000 (Pst) interaction under elevated CO_2 conditions (Li *et al*., 2014). Higher CO_2 concentrations can generally have either beneficial or negative impacts on plant diseases, albeit most of the time they resulted in an increase in disease severity (Zhou *et al*., 2017).

6. STRATEGIES FOR ADAPTATION

According to recent estimates and predictions, there would be more climate extremes globally and eco-zone alterations, which could be signs of changes brought on by global warming (Elad and Pertot, 2014). To help decision-makers promote strong plans that involve collaboration between the public and private sectors, it is necessary to combine knowledge from local land managers and farmers with results and insights from the physical and social sciences. Apart from the alterations brought about by socio-economic factors, farmers will also need to adjust to the changing climate in the upcoming decades by utilizing a range of agronomical techniques that are currently effective in the current climate. These techniques include modifying or completely changing cropping systems, changing cultivars, and timing planting and harvesting operations (Rosenzweig *et al*., 2004). However, different agricultural systems, geographical locations, and global climate change scenarios require different adaptation tactics. As a result of the formation of new agricultural zonation's brought about by a changing climate, cropping systems and crop types may be altered completely at higher levels of adaptation, in addition to field management modifications (Reilly *et al*., 2003; Fischer *et al*., 2001). There would be less time for grain production and the accumulation of carbohydrates in warmer regions since crops would typically mature faster. So, crop potential under climate change may be returned to levels typical of current conditions by replacing current cultivars with genotypes requiring longer maturation times. Apart from modifying planting tactics and cultivar selection, land management frameworks may need to be adjusted to accommodate novel climate conditions. The easiest method is to switch from rainfed to irrigated agriculture, however there are things to think about including water availability, cost, and input from other industries (Rosenzweig *et al*., 2004; Elad and Pertot, 2014). To assume flawless future adaptation to shifting climatic conditions is unrealistic. While certain attempts at adaptation—such as modifying planting dates to prevent heat stress or developing new agricultural areas—might not always be successful in mitigating the damaging effects of droughts or floods on crops, other attempts—such as modifying varieties and breeds or crop rotations—might not always be unsuccessful. Crucially, depending on the dynamics of the society, there are also characteristics of adaptation linked to social and cultural factors that could either help or impede farmers' adoption of new practices (Smith *et al*., 2003; Smit and Skinner, 2002).

7. STRATEGIES FOR MITIGATION

The climate affects the tactics used to manage diseases. The geographical and temporal distributions of diseases will vary as a result of climate change, necessitating the adaptation of control strategies. Temperature variations and heavy precipitation can modify the dynamics of fungicide residue in foliage and the way these products degrade. Modifications in plant morphology or physiology brought on by elevated CO_2 levels in the environment, as well as variations in temperature and precipitation patterns, can impact the systemic fungicides' penetration, translocation, and mode of action. A new fungicide application may also need to be determined by variations in the time period of increased susceptibility to diseases, which can be affected by changes in plant growth and development (Coakley *et al*., 1999; Chakraborty and Pangga, 2004; Pritchard and Amthor, 2005). Consequently, the following are some crucial mitigation techniques for controlling plant diseases considering climate change:

- Choosing resistant/tolerant variety/cultivars at a higher temperature.
- Using novel compounds for disease control that are more effective at higher temperatures.
- Create a novel forecasting model to anticipate the onset of diseases.
- Changing the sowing date to prevent the spread of an epidemic.
- The integration of all currently available technology for the management of diseases.

- Tillage techniques that are effective for managing diseases.

8. CONCLUSIONS AND OPPORTUNITIES FOR FUTURE WORK

The employment of eco-friendly approaches in disease management and improved agricultural practices are necessary for sustainable crop production, since the changing disease scenarios brought about by global climate change have brought attention to this issue. Adapting crop management techniques to the current conditions is crucial, given the fluctuating environment and shifting seasons. Climate-driven disease surveillance, inoculum tracking, particularly for soil-transmitted illnesses, and quick diagnostics would be crucial in these circumstances. In order to stop the spread of diseases brought on by climate change, new strategies must be implemented. To reduce reliance on fungicides, techniques for integrated disease management should be created. Intercropping systems that provide havens for natural biocontrol organisms and healthy seeds with innate forms of broad and permanent disease resistance are two more multifaceted strategies. Additionally, for significant host-pathogens that directly affect farmer incomes and overall food security, early warning systems and monitoring programs for disease outbreaks should be established. Utilizing plant-based soil amendments and botanical insecticides can help mitigate climate change by reducing the emission of nitrous oxide through the use of nitrification inhibitors like dicyandiamide and nitrapyrin. The impact of climate change on plant diseases in field settings and disease control in light of climate change have both received little scientific attention. Nonetheless, evaluations are currently accessible for a select number of nations, areas, crops, and certain infections that affect food security. Impact assessment must now be less of a focus and more on creating options and plans for adaptation and mitigation. The effectiveness of current physical, chemical, and biological management strategies—including disease-resistant varieties—must be assessed in light of climate change. Secondly, any research targeted at creating new tools and procedures must take future climate scenarios into account. In order to comprehend how an impending change in the climate could affect plant diseases, disease risk analyses based on host–pathogen interactions should be handled and research on host response and adaptation should be carried out.

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