

Effect of Elevated CO₂ and Temperature on Crop-Disease Interactions under Rapid Climate Change



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Abstract

A crop disease is usually defined as abnormal growth and/or dysfunction of a plant. Diseases are the result of some disturbance in the normal life process of the crop plant. Crop diseases are malfunctions caused by plant pathogenic organisms and those caused by other factors. Plant diseases play an important role in agriculture. Climate change is just one of the many ways in which the environment can move in the long term from disease-suppressive to disease-conducive or vice versa. Crop growth and production can be significantly affected due to high atmospheric CO₂ concentration, temperature, changes in precipitation patterns and frequency of extreme weather phenomena and diseases presence will altered under these condition. Increased CO₂ levels can impact both the host and the pathogen in multiple ways. New races may evolve rapidly under elevated temperature and CO₂, as evolutionary forces act on massive pathogen populations boosted by a combination of increased fecundity and infection cycles under favorable microclimate within enlarged canopy. Elevated CO₂ concentration and temperature have impact on plant-disease interaction. This review paper starts with highlighting the studies on effect of elevated CO₂ and Temperature on Crop- disease Interactions under enhanced greenhouse gas emissions, and implications on achievement of food security and development goal. Finally, the paper concludes that the facilities that are very crucial to study effects of elevated CO₂ and Temperature on Crop-disease Interaction to achieve food security and development goal under rapidly climate of change.

Keywords: Disease; Climate Change; Temperature; CO₂

Introduction

A crop disease is usually defined as abnormal growth and/or dysfunction of a plant. Diseases are the result of some disturbance in the normal life process of the crop plant. Crop diseases are malfunctions caused by plant pathogenic organisms and those caused by other factors. Plant diseases play an important role in agriculture [1]. A limited amount of information on the potential impacts of climate change on plant diseases is available. Plant pathologists have long considered environmental influences in their study of plant diseases: the classic disease triangle emphasizes the interactions between plant hosts, pathogens and environment in causing disease [2]. According to Intergovernmental Panel on Climate Change [3]; the planet earth is experiencing a climate change and atmospheric CO₂ is a major GHG, which increased by nearly 30% and temperature by 0.3-0.6°C [4]. With the continued use of fossil fuels to support our ever increasing energy consumption, levels of atmospheric carbon dioxide (CO₂) are rising and are projected to potentially double by the end of this century [5]. This increase in atmospheric CO₂ has direct biological impacts on many plants and is the key driver

for warming our planet at an accelerated rate, altering many biological functions of both plants and animals. Additionally, our population continues to grow and is estimated to exceed 9 billion by 2050 with a forecasted increase in global crop demand >100% from 2005 to 2050. Changes in global climate are generally projected to comprise an increase in global average temperatures of around 1.8-4 °C by 2100, alongside an increase in the frequency of extreme events including periods of high temperature, storms, or drought [6,7]. Climate change is just one of the many ways in which the environment can move in the long term from disease-suppressive to disease-conducive or vice versa [8,9]. These changes will influence pathogen emergence in new areas. Climate alters the susceptibility of the host, and influences the host cultivars planted. It also drives the distribution of hosts, both cultivated and wild, alters trade patterns, and determines ranges of competitor and biocontrol species [10,11]. Climate also affects the virulence of many pathogens [12]. In response to these changes in climate and their direct and indirect effects on crops and their pathogens, new crop varieties may be developed. This global climate changes by various factors [13,14] and change or

influence all the 3 major elements of disease triangle, viz., host, pathogen and environment [15]. Crop growth and production can be significantly affected due to high atmospheric CO₂ concentration, temperature, changes in precipitation patterns and frequency of extreme weather phenomena and diseases presence will altered under these condition [16-18]. Climate change directly impacts crops, as well as their interactions with microbial pests [19]. Changing weather can induce severe plant disease epidemics [20], which threaten food security if they affect staple crops [21] and can damage landscapes if they affect amenity species [22]. There is a paradigm shift in nature, time and type of occurrence of viral and other diseases of various horticultural crops due to climate change.

Increased CO₂ levels can impact both the host and the pathogen in multiple ways. New races may evolve rapidly under elevated temperature and CO₂, as evolutionary forces act on massive pathogen populations boosted by a combination of increased fecundity and infection cycles under favorable microclimate within enlarged canopy [23]. Elevated CO₂ concentration and temperature have impact on plant-disease interaction [24] and posing a higher threat perception of late blight (*Phytophthora infestans*) of potato and blast (*Magnaporthe grisea*) and sheath blight (*Rhizoctonia solani*) of rice [25]. Effects of climate change on Phoma (*Leptosphaeria maculans*) in rape seed was observed through a model in combination with climate change that predict temperature and rainfall under CO₂ emission scenarios for the 2020 and 2050s in UK [26]; and sporulation of teleomorphs on climate change [27]. Therefore, the focus of this literature review was to review studies related to the effects of elevated CO₂ and Temperature on crop- disease interactions.

Crop Diseases and Major Causative Agents

Definition of Crop Disease

A crop disease is usually defined as abnormal growth and/or dysfunction of a crop. Diseases are the result of some disturbance in the normal life process of the crop. Crop diseases are malfunctions caused by Crop pathogenic organisms and those caused by other factors. A disease can be defined as any deviation from what may be considered 'healthy'. In a larger sense, this includes diseases caused not only by pathogens but also by environmental or physiological factors. So generally we split diseases into two categories; biotic and abiotic. Biotic for diseases caused by living organisms and abiotic for diseases caused by non- living components (Agrios, 2005). Plant diseases continue to cause serious problems in global food production.

Major Causative Agents of Crop Diseases

Crop diseases can be broadly classified according to the nature of their primary causal agent, either infectious or noninfectious. Infectious plant diseases are caused by a pathogenic organism such as a fungus, bacterium, mycoplasma, virus, viroid, nematode, or parasitic flowering plant. An infectious agent is capable of reproducing within or on its host and spreading from one

susceptible host to another. Noninfectious plant diseases are caused by unfavorable growing conditions, including extremes of temperature, disadvantageous relationships between moisture and oxygen, toxic substances in the soil or atmosphere, and an excess or deficiency of an essential mineral. Because noninfectious causal agents are not organisms capable of reproducing within a host, they are not transmissible. Plant pathogen groups include fungi, prokaryotes (bacteria and mycoplasmas), oomycetes, viruses and viroids, nematodes, parasitic plants and protozoa.

Climate Change and Crop Pathosystems

Plant diseases play an important role in agriculture [28]. A limited amount of information on the potential impacts of climate change on plant diseases is available. Plant pathologists have long considered environmental influences in their study of plant diseases: the classic disease triangle emphasizes the interactions between plant hosts, pathogens and environment in causing disease [29]. Climate change is just one of the many ways in which the environment can move in the long term from disease-suppressive to disease-conducive or vice versa [30,31]. Therefore, plant diseases could be even used as indicators of climate change [32], although there may be other bio-indicators which are easier to monitor. Long-term datasets on plant disease development under changing environmental conditions are rare [33], but, when available, can demonstrate the key importance of environmental change for plant health [34]. Plant health is predicted to generally suffer under climate change through a variety of mechanisms, from accelerated pathogen evolution and shorter incubation periods to enhanced abiotic stress due to mismatches between ecosystems and their climate and the more frequent occurrence of extreme weather events [35]. Drought is expected to lead to increased frequency of tree pathogens, mainly through indirect effects on host physiology [36].

Effect of Elevated CO₂ and Temperature on Crop-Disease Interactions

Elevated carbon dioxide concentrations and temperatures associated with climate change will have a substantial impact on plant-disease interactions. Changes in temperature affect both the host and the pathogen; thus, risk analyses must be conducted for each patho-system to determine the effects of climate change. Studies have been performed under controlled conditions, and the effects of high CO₂ levels have been identified; however, field responses such as the adaptation of pathogens over time may be different. The climate influences the incidence as well as temporal and spatial distribution of plant diseases. The most likely effect of climate change in pole ward modifies agro-climate zones, this causing a shift in the geographical distribution of host pathogens. Elevated CO₂ concentration and temperature have impact on plant-disease interaction [37] and posing a higher threat perception of late blight (*Phytophthora infestans*) of potato and blast (*Magnaporthe grisea*) and sheath blight (*Rhizoctonia solani*) of rice [38]. Effects of climate change on Phoma (*Leptosphaeria maculans*) in rape seed was observed through a model in

combination with climate change that predict temperature and rainfall under CO₂ emission scenarios for the 2020 and 2050s in UK [39]; and sporulation of teleomorphs on climate change [40]. The major predicted results of climate change increases in temperature, moisture and CO₂ can impact all three legs of the plant disease triangle in various ways. Precisely predicting the impact of climate change on plant disease is tricky business. Other study indicated that colony area, number of hyphal tips, conidiophores and conidia per colony were significantly greater

at temperature ranging from 22 to 28°C compared to standard conditions. Disease indices (0-7) also varied in different trials due to the quantity of inoculum, but were never influenced only by increased CO₂. On the contrary, elevated temperature and CO₂ significantly stimulated disease index. There was a clear increment of growth of the pathogen, fecundity and severity of the disease observed at the higher temperature-higher CO₂ combination compared with control temperature combinations in particular with higher CO₂ at standard temperatures (Table 1).

Table 1: Mean pathogen parameters and disease indices for powdery mildew on zucchini plants grown in different temperature and CO₂ regimes. Data are shown as means ± SE (n ≥5).

Temperature (°C)	CO ₂ (ppm)	Colony Area (mm ²)	Hyphal tips (Number/Colony)	Conidiophores (Number/Colony)	Spores/Colony (Number)	Disease Index (0-7) ^b
18–24	450	0.35±0.033 a ^a	10.3±0.83 a	0.4±0.35 a	5315±840 a	2.8±0.33 a
18–24	800	0.31±0.031 a	9.5±0.71 a	2.0±0.89 a	4199±645 a	2.9±0.35 a
22–28	450	0.52±0.058 b	13.4±0.69 b	4.1±0.37 b	8491±684 b	3.4±0.41 ab
22–28	800	0.68±0.133 b	17.3±1.81 c	11.4±2.27 c	9871±721 b	4.0±0.36 b

^aMeans of each parameter accompanied by the same letter are not significantly different at P =0.05 (Tukey's test).

^bThe disease index refers to combined assessments at 8, 10 and 15 dai.

Effect of Elevated Temperature on Crop-Disease Interactions

Temperature has potential impacts on plant disease through both the host crop plant and the pathogen. A change in temperature may favor the development of different inactive pathogens, which could induce an epidemic. Due to changes in temperature and precipitation regimes, climate change may alter the growth stage, development rate, pathogenicity of infectious agents, and the physiology and resistance of the host plant [41]. Temperature is one of the most important factors affecting the occurrence of bacterial diseases such as *Razoctonia solanacearum*, *Acidovorax avenae* and *Burkholderia glumea*. Thus, bacteria could proliferate in areas where temperature-dependent diseases have not been previously observed [42]. As the temperature increases, the duration of winter and the rate of growth and reproduction of pathogens may be modified [43]. Similarly, the incidence of vector-borne diseases will be altered. Climate can substantially influence the development and distribution of vectors. Changes may result in geographical distribution, increased overwintering, changes in population growth rates, increases in the number of generations, extension of the development season, changes in crop-pest synchrony of phenology, changes in interspecific interactions and increased risk of invasion by migrant pests. Research has shown that host plants such as wheat and oats become more susceptible to rust diseases with increased temperature; but some forage species become more resistant to fungi with increased temperature [44].

Generally, fungi that cause plant disease at cold average temperatures are likely to experience longer periods of temperatures suitable for pathogen growth and reproduction if climate is warm. For example, predictive models for potato and tomato late blight (caused by *Phytophthora infestans*) show

that the fungus infects and reproduces most successfully during periods of high moisture that occur when temperatures are between 45°F (7.2°C) and 80°F (26.8°C) [45]. Earlier onset of warm temperatures could result in an earlier threat from late blight with the potential for more severe epidemics and increases in the number of fungicide applications needed for control. The effects of elevated temperature on plants will tend to vary greatly throughout the year. During colder parts of the year, warming may relieve plant stress, whereas during hotter parts of the year it may increase stress. A striking example of the potential effect on the yield of crop plants in response to elevated temperature, rice yield in the Philippines was estimated to decline 10% for each 1°C increase in the minimum temperature during the dry season [46]. Temperature affects the chain of events in disease cycles such as survival, dispersal, penetration, development and also reproduction rate for many pathogens. Some study conducted on the relation between elevated temperature and viral pathogen at molecular study stages indicated that when temperature increases may affect two types of antiviral resistance mechanisms in plants: gene-silencing based on ribonucleic acid (RNA) interference (RNAi) some types of resistance based on protein-protein recognition. RNAi defends plants against viruses by using small interfering RNA (siRNA) to target and destroy viral RNA. RNA silencing increases with increasing temperature, and it is manifested in the appearance of less symptomatic newly developed leaves [47,48] considered the consequences of warmer temperatures on host-pathogen interactions and concluded that there will be 3 main effects:

- a) Increases in pathogen development rate, transmission, and generations per year,
- b) Increases in overwintering of pathogens, and

c) Changes in host susceptibility to infection

Furthermore, they suggested that the most severe and unpredictable consequences would occur if populations of pathogen and host, which were formerly geographically separated due to climate constraints, converged. In many cases, temperature increases are predicted to lead to the geographic expansion of pathogen and vector distributions, bringing

pathogens into contact with more potential hosts and providing new opportunities for pathogen hybridization [49]. For example Stewart's wilt, a bacterial (*Erwinia stewartii*) disease of generally sporadic importance in sweet corn in the northeast, is vectored by the corn flea beetle (*Chaetocnema pulicaria*). In the following table some of crop diseases affected by elevated temperature are listed (Table 2).

Table 2: A summary of the influence of elevated Temperature on some host and pathogen interaction and pathogen fitness.

Author/Reference	Crop/Host	Disease/Pathogen	Climate Change	Change in Disease Severity
Yang et al. [50]	Wheat	Stripe rust – <i>Puccinia striiformis</i>	Elevated average annual temperature	Decrease
Boland et al. [5]	Wheat	Dwarf bunt <i>Tilletia controversa</i>	Elevated temperatures	Increase
Milus et al. [39]	Wheat	Wheat Stripe rust – <i>Puccinia striiformis</i>	Higher Temperature	Increase
Jesus Junior	Citrus	Anthraxnose <i>Colletotrichum acutatum</i>	Elevated Temperatures	Increase
Jesus Junior	Citrus	<i>G uignardiacitricarpa</i> ,	Elevated Temperatures	Increase
Hannukkala et al. [26]	Potato	Late blight – <i>Phytophthora infestans</i>	Elevated temperatures causing earlier seasons	Increase
Jesus Junior	Papaya	Asperisporium caricae	Elevated temperatures and lower relative humidity	Decrease
Matos et al. [36]	Pineapple	Fusarium subglutinans	Elevated temperatures	Decrease
Ghini et al. [24]	Coffee	<i>Meloidogyne incognita</i>	Elevated temperatures	Increase

Effect of Elevated CO₂ on Crop-Disease Interactions

Experimental research on the effects of high atmospheric CO₂ concentrations on plant-pathogen interactions has received little attention, and conflicting results have been published. Elevated levels of CO₂ can directly affect the growth of pathogens. Increased CO₂ levels can impact both the host and the pathogen in multiple ways. New races may evolve rapidly under elevated temperature and CO₂, as evolutionary forces act on massive pathogen populations boosted by a combination of increased fecundity and infection cycles under favorable microclimate within enlarged canopy [50]. Some of the observed CO₂ effects on disease may counteract others. Researchers have shown that higher growth rates of leaves and stems observed for plants grown under high CO₂ concentrations may result in denser canopies with higher humidity that favor pathogens. Lower plant decomposition rates observed in high CO₂ situations could increase the crop residue on which disease organisms can overwinter, resulting in higher inoculum levels at the beginning of the growing season, and earlier and faster disease epidemics. Pathogen growth can be affected by higher CO₂ concentrations resulting in greater fungal spore production.

However, increased CO₂ can result in physiological changes to the host plant that can increase host resistance to pathogens. An increase in CO₂ levels may encourage the production of plant biomass; however, productivity is regulated by water and nutrients availability, competition against weeds and damage by pests and diseases. Alternatively, a high concentration of

carbohydrates in the host tissue promotes the development of bio trophic fungi such as rust. Thus, an increase in biomass can modify the microclimate and affect the risk of infection. In general, increased plant density will tend to increase leaf surface wetness duration and regulate temperature, and so make infection by foliar pathogens more likely. However, once the pathogen infects the plant, the fungus quickly develops and achieves sporulation. In contrast, the rate of germination sporulation was greater at high concentrations of CO₂ (700 ppm). Both the host and the pathogen are influenced by increased CO₂ levels in various ways. Increased size of plant organs, leaf area, leaf thickness, and more numbers of leaves, higher total leaf area/plant, stems and branches with greater diameter are resulted from increased CO₂ levels. Dense canopy favors the incidence of rust, powdery mildew, *Alternaria* blight, *Stemphylium* blight and anthracnose diseases. Higher CO₂ concentrations induce greater fungal spore production. Increased CO₂ also enhances photosynthesis, increased water use efficiency and reduced damage from ozone; and leaf area, plant height and crop yield are increased at higher doses of CO₂. The physiological changes on the host plant due to increased CO₂ can conversely result in increase host resistance to pathogens.

Under elevated CO₂ conditions, potential of dual mechanism i.e., reduced stomata opening and altered leaf chemistry results in reduced disease incidence and severity in many plant pathosystems where the pathogen targets the stomata. In soybean, elevated concentration of CO₂ and O₃ altered the expression of 3 soybean diseases, downy mildew (*Perenospora*

manshurica), brown spots (*Septoria glycines*) and sudden death syndrome (*Fusarium virguliforme*) and response to the diseases varied considerably. Elevated CO₂ also leads to production of papillae and accumulation of silicon by barley plants at the site of appressorial penetration of *Erysiphe graminis* and changed leaf

chemistry that decrease susceptibility to the powdery mildew pathogen. In general, the effects of elevated CO₂ concentration on plant diseases can be positive or negative, but majority of the cases disease severity increased (Table 3).

Table 3: A summary of the influence of elevated CO₂ on some host crop and pathogen interaction and pathogen fitness.

Author/Reference	Crop /Host	Disease/Pathogen	Climate Change	Change in Severity
Manning & Tiedemann [34]	Wheat	Stem rust – <i>Pucciniagraminis</i>	Elevated CO ₂	Decrease
Manning & Tiedemann [34]	Wheat	Leaf rust – <i>Pucciniaatriticina</i>	Elevated CO ₂	Increase or decrease
Milus et al. [39]	Wheat	Stripe rust – <i>Pucciniastriformis</i>	Elevated CO ₂	Decrease
Melloy et al. [38]	Wheat	Crown rot – <i>Fusariumpseudograminearum</i>	Elevated CO ₂	Increase
Hibberd et al. [28]	Barley	Barley yellow dwarf virus	Elevated CO ₂	Decrease
Manning & Tiedemann [34]	Barley	Smut – <i>Ustilagohordei</i>	Elevated CO ₂	Increase
Hibberd et al. [28]	Barley	Powdery mildew – <i>Blumeriagraminis</i>	Elevated CO ₂	Decrease
Manning & Tiedemann [34]	Maize	Smut – <i>Ustilagomaydis</i>	Elevated CO ₂	Decrease
Milus et al. [39]	Maize	Fusarium verticilloides	Elevated CO ₂	Increase
Manning & Tiedemann [34]	Potato	Early blight – <i>Alternariasolani</i>	Elevated CO ₂	No change
Hannukkala et al. [26]	Potato	Late blight – <i>Phytophthorainfestans</i>	Elevated CO ₂	Increase
Kobayashi et al. [33]	Rice	Leaf blast – <i>Magnaportheoryzae</i>	Elevated CO ₂	Increase
Kobayashi et al. [33]	Rice	Sheath blight – <i>Rhizoctoniasolani</i>	Elevated CO ₂	Increase

Summary and Conclusion

Climate change is an important phenomenon that affects agricultural production. By anticipating the future, we can prepare ourselves for problems caused by climate change, especially those related to agricultural activities, which generate the greatest amount of food consumed by humans. Globally, plant pathogens destroy 10-16% of crop production even with improved pest and disease management measures. Since both CO₂ and temperature are key variables affecting plants and their diseases, potential influences of climate change on plant growth, global food supply and disease risk are attracting considerable research interest in many countries. Numerous studies have measured plant growth under conditions of elevated CO₂ and temperature. Despite the diversity of experimental approaches and study subjects, they concluded that increased CO₂ generally produced larger plants with more and/or larger organs, while warmer temperatures accelerated the rate of organ development and expansion but decreased organ life time. Elevated CO₂ influences the pathogenicity, host-pathogen interaction and epidemiology of fungal diseases. Temperature is one of the main factors in conjunction with the rain to determine the incidence and severity of disease, but the effect could be positive and negative. Considering this, climate change/elevated CO₂ and Temperature may affect the actual, spatial and temporal distribution of diseases; however, the magnitude of these effects remains unclear due to the uncontrolled behavior of CO₂ and Temperature under field conditions.

Generally, most of the reviewed materials studied on effect of elevated CO₂ and Temperature further were limited and

emphasized on the fungal pathogen and cereal crops (Wheat and Barley). However, the more focus should be given for other pathogens and crops as much as possible; experimental studies should be done for other crops specially pulse crops as well as the facilities that were needed for the study on the effect of elevated CO₂ and Temperature on crop production and crop-disease interactions should be available. Therefore, the consideration should be given for those facilities like open top chamber, Free-air CO₂ enrichment, Temperature Gradient Tunnel, Research facilities such satellite, GIS and Remote Sensing for diseases monitoring and surveying and for data collection and analysis for scientific communication as well as planning strategies to manage diseases to achieve food security and development goal.

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