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Climate Change Potential Impacts on Plant Diseases and their Management

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ABSTRACT

Yet a comprehensive analysis of how climate change would influence the dissemination of plant diseases and impact the primary production in most agricultural ecosystems is at the moment missing. There are hardly any studies on the impacts of climate change on the dissemination of diseases in field crops. Multifactor studies under realistic in situ field situations ecosystems are a way forward. No doubt, the realistic assessment of CO_2 free air or air enriched with increasing CO_2 and O_3 concentrations always incorporating spectral reflectance measures on plant growth. Ecologists are now addressing the role of plant disease on the varied ecosystem processes and the challenge of scaling up from individual infection probabilities to epidemics and broader impacts. Plant diseases are considered an important component of plant and environmental health that might be arise through either infection with biotic pathogens as well as abiotic factors. Biotic plant diseases are caused by organisms such as fungi, bacteria, viruses, nematodes, phytoplasmas as well as with parasites. Abiotic diseases, on the other hand, are for all time associated with chemical and physical climatic factors, such as temperature or moisture extremes, farming factors such as nutrient deficiencies, mineral toxicities and pollution. At the genomic level, advances in technologies for the high-throughput analysis of gene expression have made it possible to begin discriminating responses to different biotic and abiotic stressors and potential trade-offs in responses. Most plant diseases models use deferent climatic variables and operate at a deferent spatial and temporal scale than do the global climate ones. The current review describes environmental factors that influence severity of crop disease epidemics in order to assess the predicted impacts of climate change on plant growth and their harvest as well as on the severity of disease epidemics. Effects of a changing climate on chemical and biological controls of plant diseases are also discussed in the context of the changing global outlooks on environmental demands for the future.

Key words: Climate change, plant diseases, food security, CO_2, temperature

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INTRODUCTION

Plant Disease Epidemiology

Plant diseases are one of the most imperative factors that have an undeviating adverse impact on global agricultural productivity and it is likely that climate change will foster the frustrations of the contemporary situation (Fig 1). Plant diseases are predicted to cutback almost 20% of harvests in cash crops worldwide [1]. Plant diseases are core component in relating plant growth and environmental health. Nearly all of the plant diseases arise from either *biotic* pathogens or *abiotic* stresses.

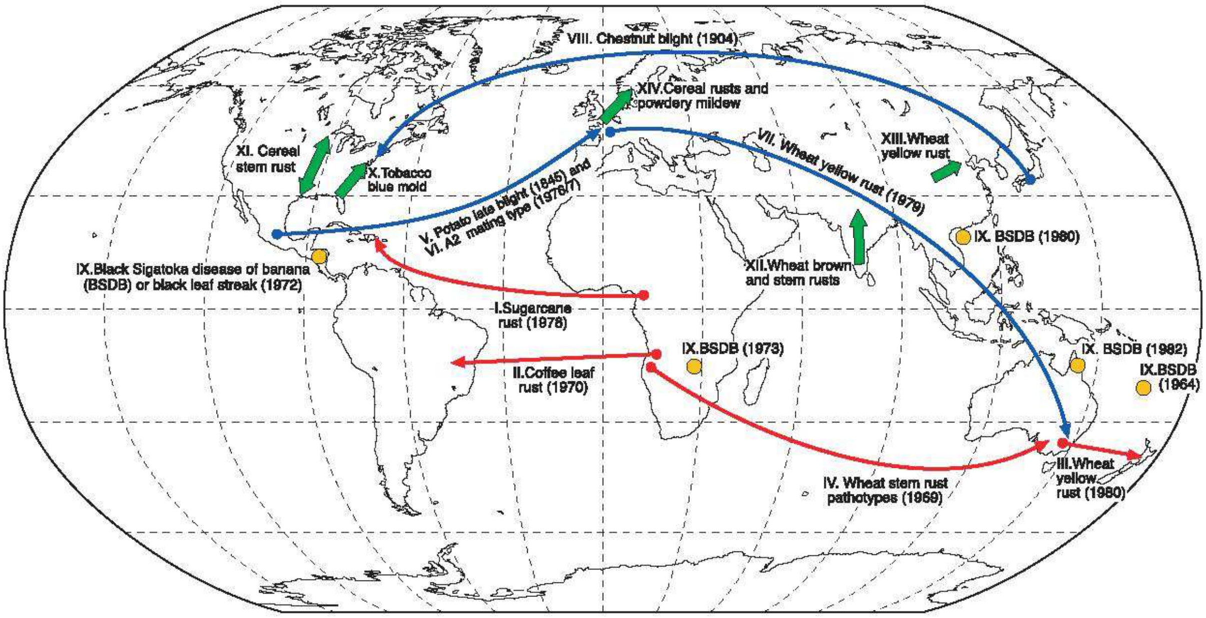

Fig. 1: Examples of invasions of plant pathogens [2]

The *Biotic* plant diseases are caused by organisms such as fungi, bacteria, viruses, nematodes, phytoplasmas and/or parasitic plants. On the other hand, *abiotic* diseases are always associated with chemical and physical factors such as temperature, moisture extremes, nutrient deficiencies, mineral toxicities and pollution as well (Fig. 2).

Biotic Diseases

It is well known that Fungi cause most *biotic* plant diseases. Most of the fungi are non-motile, filamentous microorganism lacking chlorophyll and fulfill their nutrient need from dead or living organisms. Over 100,000 species of fungi are known now and over 10,000 of them are able cause diseases in plants. Bacteria, on the other hand, are single-celled organisms, most of which possess the capacity to mineralize. Nearly 100 out of the known 1,600 species of bacteria can cause disease in plants.

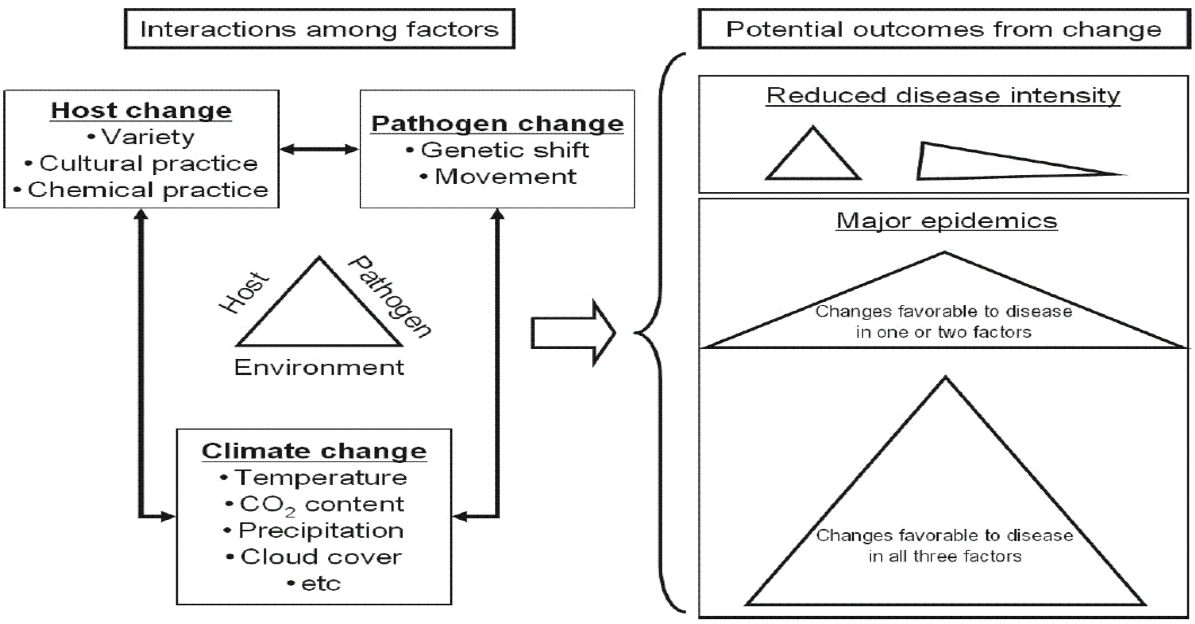

Fig. 2: Climate change and the disease triangle [3]

Viruses are nucleoproteins that are parasitic in plant cells and cause host cells to produce more virus particles. These viruses interfere with the host metabolism, causing disease. About 2,000 different viruses have been identified, and about 500 of them cause disease in plants.

Nematodes are microscopic worm, several thousand of these species have been identified, and several hundred of them are able to attack plant roots. Root-feeding species of nematodes often decrease the ability of plants to take up water and nutrients, while other nematodes produce biochemical ingredients when injecting their saliva into the host plant. Removal of nutrients by nematodes typically becomes important only when the nematode population is intensive. However, cuts caused by feeding nematodes could also act as entry sites for other pathogens.

Phytoplasmas are microorganisms without cell walls that live in infected plants and insect vectors causing over than 200 plant diseases.

When considering the potential influence of climate change on plant diseases, it is weighty to understand some of the epidemiological factors that influence how *biotic* plant diseases initiate, develop, and spread. In general, primary inoculums are the initial ones that start any epidemic in each crop.

Climatic Variations and Plant Disease

Literature provides more or less roughly background on the potential impact of climatic variations on plant diseases. Much of the literature focuses on the diseases of agricultural crops and includes discussion on the influence of temperature, precipitation, CO_2, ozone, ultraviolet light as well as insects on plant disease [4]. Potential effects of climate change on agriculture, according to the IPCC [5] include reduced yields in warmer regions as a result of heat stress; damage to crops, soil erosion and inability to cultivate land due to heavy precipitation events and land degradation resulting from increasing drought. Indubitably, the increased incidence of extreme weather events will result in diminishing the significance of abiotic stresses under prospect climate circumstances. The uncertainty of climate change might increase the production of many crops in tropical countries, including many developing countries, where these crops represent an imperative basis of the gross domestic product. Plant pathologists constantly consider the environmental impacts in their studies. The classic disease triangle emphasizes the interactions between plant hosts, pathogens and environment in causing disease [6]. Climate change is just one of the many behaviors that environment might move in the long term from disease-suppressive to disease-conducive or vice versa [7]. Hence, plant diseases could be even used as indicators of climate change, although there are other bio-indicators that are easier to monitor. Long term data sets on plant disease development under changing environmental conditions are rare, but, when available, could demonstrate the key magnitude of environmental change for plant health [8]. For instances, analysis of archive samples from the Rothamsted long-term (1850) indicate that wheat production and fertilizer experiment shows that historical records of SO_2 emissions are well correlated with the ratio of two pathogens (*Phaeosphaeria nodorum* and *Mycosphaerella graminicola*) [9]. Typically, the two most important environmental factors in the development of plant disease epidemics are temperature and moisture. In temperate regions, most plant pathogens are not active in late rainfall winter and early spring because of low temperatures. Some diseases are privileged by cool temperatures, while others are favored superior by moderate or hot conditions. Disease often occurs when temperatures are more stressful for the plant than for the pathogen. Moisture, in the form of free water or high humidity is compulsory for many pathogens to infect, reproduce, and spread, although some could cause disease under dry conditions. Plant diseases require varying environmental conditions to develop; thus, it is vital to understand the environmental requirements of individual plant pathogens before predicting their responses to climate change that could indirectly affect crop diseases through the adaptation strategies that it might induce, including altered crop rotations, different farming practices and different grown crop types, e.g. changes between winter and spring types [10]. Recent work exhibited that changes in the cropping practices through spring to autumn-sown crops might have serious impacts on diseases; e.g. in case of pasmo disease caused by *Mycosphaerella linicola*, it became very severe during winter [11]. These differences between winter and spring crops might occur because spring crops escape exposure to most of the primary inoculum (often released in autumn) or have fewer disease cycles in their shorter growing season.

Changes in Crop Loss

Diseases are responsible for losses of at least 10% of global food production, thus representing a threat to food security [12]. The annual losses by disease are estimated by US$ 220 billion [13]. Besides direct losses, the methods for disease control, especially the chemical ones, could lead to serious environmental contamination besides the chemicals residues invading food chain and the social and economic tribulations. The close relationship between the environment and plant diseases suggests that climate change would cause modifications in the current phytosanitary scenario. The impacts could be positive, negative or neutral, since there might be a decrease, an increase or no effect on the different pathosystems, in each region. The analysis of the potential impacts of climate change on plant diseases is essential for the approval of adaptation measures, as well as for the development of resistant cultivars, new control methods or adapted techniques are urgently needed in order to avoid more serious losses [14].

As under current climate, crop loss from diseases in a changed climate condition would be determined by a large number of interacting factors that directly and indirectly influence plant diseases. Among direct effects, altered physiology and morphology of the host under elevated CO_2 would change the interception of light and precipitation and modify canopy structure and disease epidemiology. Some diseases could cause more severe reduction in plant growth under twice ambient compared to ambient CO_2 at least in controlled environments. For example, in barley powdery mildew, an acclimation of photosynthesis at elevated CO_2 and an infection-induced reduction in net photosynthesis caused larger reductions in plant growth at elevated CO_2 [15]. To protect this crop from late blight, fungicide application would need to be extended by 10±20 days for each degree of warming. While the significance of such growth reductions on yield cannot be fully determined in the absence of field studies, their results suggest that predictions of bumper harvest due to CO_2, fertilization and increased water use efficiency that might be unrealistic. Among indirect effects, ozone could result in losses greater than those induced by sole pathogen, while the effect of UV-B is inconsistent [16]. However, increased severity under climate change does not always lead to increased losses [17].

A recent modeling approach had been used to determine the potential impacts of climate change on the most important diseases of coffee, sugarcane, eucalyptus, cassava, citrus, banana, pineapple, cashew, coconut, mango and papaya, employing detailed knowledge of environmental conditions favourable for disease development and predicted climate change projected for the next several decades.

In coffee, the potential impacts of climate change on the spatial distribution of the coffee nematode, races of *Meloidogyne incognita*, and leaf miner (*Leucoptera coffeella*) in Brazil were determined using a geographic information system [18]. The potential impacts of climatic change on black Sigatoka (*Mycosphaerella fijiensis*), which is considered the most damaging and costly disease of banana in the world [19], were measured using IPCC scenarios A2 and B2 to project distribution maps of the disease [20]. These maps projected a reduction of the favourable area to the disease in Brazil resulting froma reduction in relative humidity to levels below 70%. Such reduction is expected to be gradual for the 2020s, 2050s and 2080s and would be greater for scenario A2 than for B2. Despite that these extensive areas would remain favorable to this disease, especially from November to April, which is currently the most preferable period.

Impacts on Disease Management Strategies

Climate change impacts on plant health are likely to be ubiquitous, both in terms of direct and indirect ones. Maintaining plant health across the planet, in turn, is a key requirement for climate change mitigation, as well as the conservation of biodiversity and provision of ecosystem services under global change as disease management strategies depend on climate conditions (Fig. 3).

Fungi and bacteria play crucial roles in the ecosystem functions particularly in decomposing dead biological debris, mineral nutrient cycling. In the last few years, more attention had been drawn towards direct climate changes on these microorganisms when exposed to sunlight such as on foliage surfaces or litter. Changes in species composition and biodiversity of these microorganisms in response to climate changes had been documented and many of these changes appeared to be related to how well species and strains of fungi and bacteria tolerate [22].

Beneficial fungi that infect plant roots and assist in absorption of nutrients, known as mycorrhizae, although not exposed to solar radiation, might be indirectly affected by UV-Exposure of the host plant shoots [23]. Bacteria and fungi could also be pathogenic for both plants and animals, although beneficial microorganisms and plant pathogens had received more attention than animal pathogens with respect to climate changes [24].

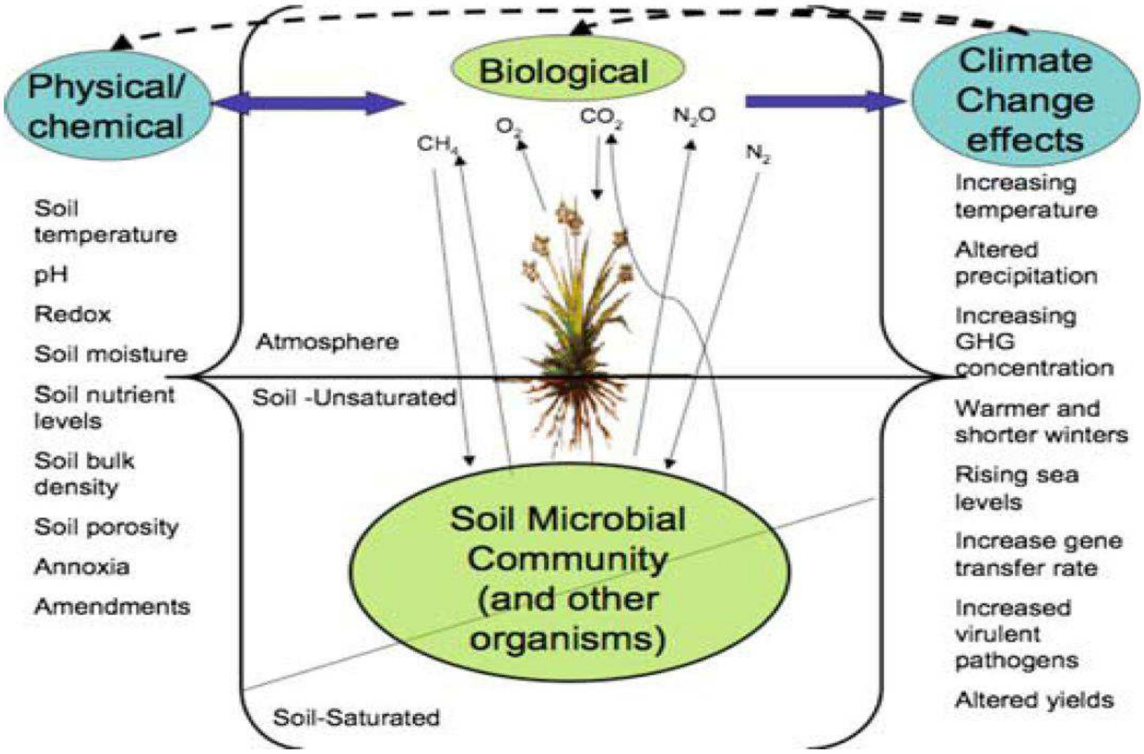

Fig. 3: Climate change, soil microbes and plant health [21]

Plant growth, disease incidence, productivity could be increased or reduced by several environmental factors. Fig 4 shows that increasing disease severity primarily involve modifications in the host plant tissues, while decreased severity appears due either to host plant changes or direct damage to the pathogen [24].

Pathogens of insects and other animals might also be influenced by climate changes. Studies involving biological control of insect pests using pathogens provide some indications of how change in climatic factors like UV rays, green house gas emission, water supply etc. affect pathogens. In general, there remains much uncertainty about how soil organisms directly respond to warming. For instance, it is unclear whether increases in microbial activity and carbon cycling in response to warming would be sustained due to short-term depletion of fast-cycling soil carbon pools, or whether soil communities would adapt to a warmer world [25].

Climate change would cause alterations in disease geographical and temporal distributions and consequently the control methods would have to be adapted to this new reality. There are few discussions on how chemical control could be affected by climate changes in temperature and precipitation that might alter fungicide residue dynamics in the foliage, and the degradation of products could also be modified (Fig. 5).

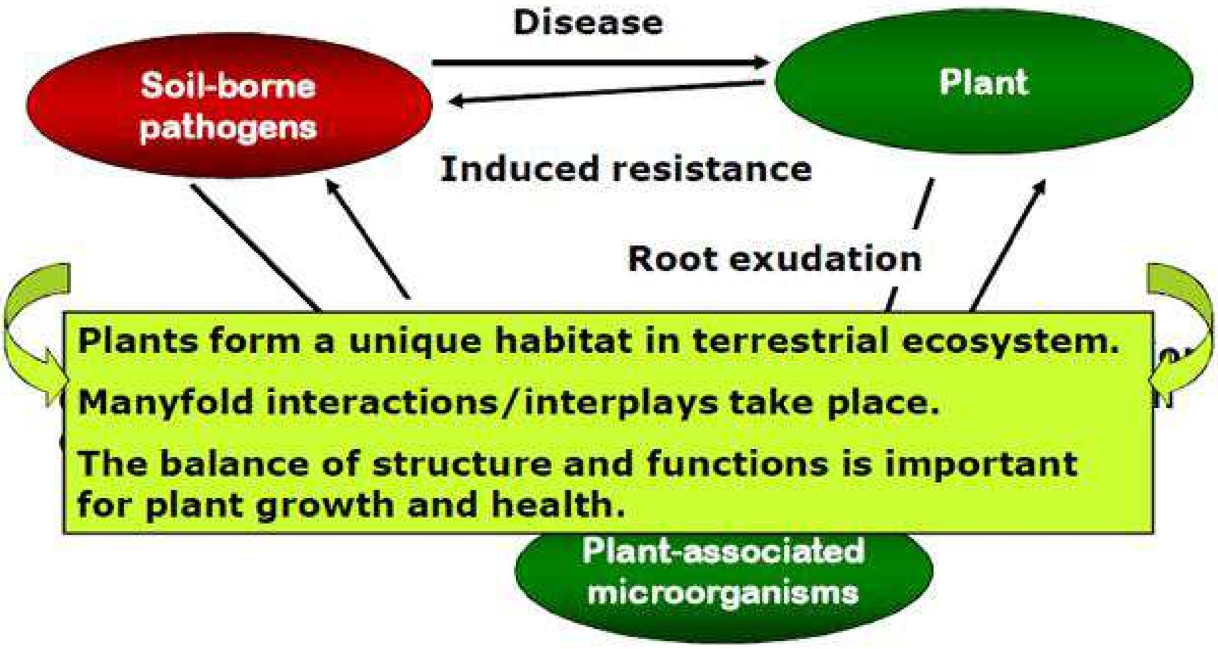

Fig. 4: Plant - microorganism interactions

Alterations in plant morphology or physiology, resulting from growth in a CO_2-enriched atmosphere or from different temperature and precipitation conditions, could affect the penetration, translocation and mode of action of systemic fungicides. Besides changes in plant growth could alter the period of higher susceptibility to pathogens that could determine a new fungicide application calendar [26, 27].

Because of the little available information about the impacts of climate changes on tropical and plantation crop diseases, pests and weeds, it is difficult to predict the effects on integrated pest management.

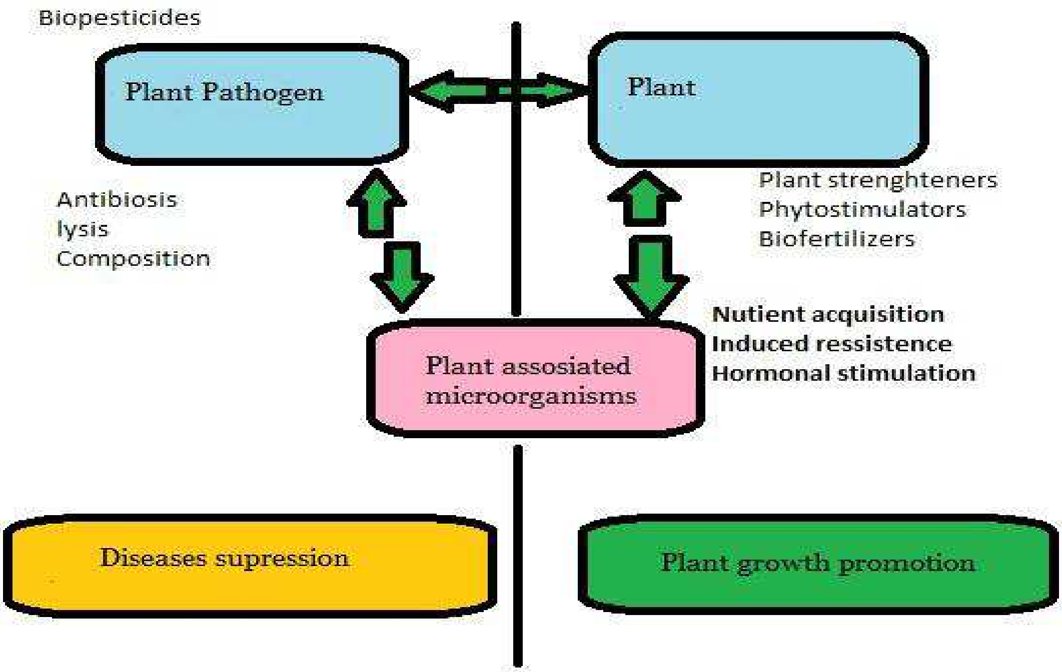

Fig. 5: Plant Pathogens interactions

Certainly, quarantine measures to control emerging pathogens, for example, would be very important in order to prevent the spread of the pathogens into new areas, because of the alterations in disease geographical and temporal distribution resulting from climate changes. Changes in temperature and precipitation could alter fungicide residue dynamics infoliage, and product degradation could thus be modified [28]. One of the direct consequences of climate changes in the pathogen-host relationship is the genetic resistance of plants to diseases. Many changes in plant physiology could alter the resistance mechanisms of cultivars obtained by both traditional and genetic engineering methods. Several studies provide evidences of these alterations, such as significant increases in photosynthetic rates, papillae production, silicon accumulation, higher carbohydrate accumulation in leaves, more wax content, additional epidermal cell layers, increased fiber content, reduction in nutrient concentration and alteration in the production of resistance-related enzymes [29]. One study was conducted to verify the effects of increased CO_2 concentration on disease control using resistant cultivars [30]. The authors reported that *Cupressussem pervirens*, a cypress clone resistant to canker caused by *Seiridium cardinale*, maintained the genetic resistance when cultivated at a high CO_2 content environment. Larger number of studies regarding the effects of temperature and other climate variables are reported [31], several of these studies provide evidence of these alterations [32]. Exposure to CO_2-enriched atmospheres changed inducible defense responses in soybean plants against pathogens [33]. Such changes occurred in individual metabolites and were dependent on cultivar resistance patterns. On the other hand, there are a larger number of studies regarding the effects of temperature and other climate variables. Models of the risk of movement of invasive pathogens to a new area are typically based on climatic variables such as temperature, rainfall, and humidity [34]. Such risk models are of great economic importance when they bear on what trade restrictions might be applied against regions where a pathogen such as *Tilletia indica*, causal agent of Karnal bunt, is present. For many invasive pathogens, models of climatic conditions and requirements need to be supplement by information about the availability of susceptible hosts and thelikelihood of transport of pathogens by tradeand other human networks [35]. Durable resistance was defined resistance as that remains effective during its prolonged and widespread use in an environment favorable to the disease [36]. If resistance is “inherently” durable, then climate change might have no influence on its continued efficacy. But “realized durability” would vary depending on the extent to which the conditions defined by [36] could be avoided through deployment decisions. Prolonged and widespread exposure of the pathogen population to host with a resistance gene is more likely and more important if pathogen overwintering increases along with the number of pathogen generations possible. There is almost no information on the impact of climate changes on biological control of plant disease [18].

Evidently, research on the likely patterns of change in plant disease attributable to predicted climate changes is important. Advances throughout the entire field of pathology would be helpful, but analyzing the questions specifically posed by climate changes points to some curiously neglected areas. Advices to growers and politicians regulating markets in land food and commodities, must emphasis the need for systems to beresilient and adaptive to the unexpected events. Finally, global climate changes would affect plant disease in concert with other global changes phenomena. The potential effects of introductions of new species were discussed in terms of new hosts that might boost pathogen inoculum levels, new vectors that might alter epidemic dynamics, and new pathogens themselves. Most importantly, research on climate changes and plant health needs to reflect affected variety of levels and the many viewpoints involved and tools available, from the molecular to the landscape scale, using network theory, meta- and risk analysis, in collaboration with various stakeholders, publics and scientists from varied disciplines.

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