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Impact of Climate Change on Host, Pathogen and Plant Disease Adaptation Regime: A Review

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An aberrant and harsh climate of arid and semi-arid regions of the world coupled with a continuous rise in temperature and CO2 concentration has adversely affected production and productivity of crops, livestock and fisheries in the region. Some of the minor pest species have acquired serious status due to fluctuating environmental conditions in the recent years revealing higher numbers of pest occurrences that may result up to 40% loss in agriculture yield by the year 2100 in South Asia including India. The global average temperatures are expected to arise around 1–2°C by the year 2100. Consequently, more frequency of high temperatures, storms, or drought, a quantum jump in use of insecticides, change in virulence pattern, the emergence of pathogens in new areas has been anticipated. Simulation models have been advocated to be a better approach for the evaluation of the upcoming climate change impact on agriculture and forest plant disease. New gene discovery and their deployment would be a better approach to combat the effect of climate change. Abiotic stress tolerant varieties and integrated pest management (IPM) have increased yield and productivity under climate change scenario. A new innovation in pest management and commitment in anticipatory research against emerging pathogens through multidisciplinary techniques may be better strategies under climate change.

Keywords: Climate Change; CO2 Concentration; Host; Moisture Regime; Pathogen; Plant Diseases; Temperature.

Climate change affects the entire flora and fauna with their multitrophic interactions are complex to understand (Chakraborty *et al* 2012). The agriculture of the drylands experiences the number of challenges. These challenges are assumed to be more complex due to the effects of climate change. The water insufficiency, salinity, land degradation and drought condition have always been burning issues in the arid and semi-arid regions. The changes in climatic conditions have boosted the magnitude of these severities. Climate change is the consequence of the continuous rise in temperature and CO_2 concentration. It has been projected that temperature and CO_2 concentration may increase by 3.4°C and 1250 ppm by 2095, respectively (Savary *et al* 2012) accompanied by more climatic variabilities and adverse weather events (Pachauri and Reisinger 2007). These changes would directly or indirectly affect the agriculture crops, forest plants and animals and on their interaction. The continued increase in the occurrence of diseases with a change in the climatic

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conditions due to precipitation and increased temperature has been predicted from the increased use of pesticides (Chen and McCarl 2001).

The climate change comprises a serious impact on the mountain glaciers, rivers and its sea coastline. The global climate changes influence on the components of plant disease viz., pathogen, host and environment (Legreve and Duveiller 2010, Pachauri *et al* 2014). The continuous increase in CO_2, rising of temperature, change in the duration of rainfall, alteration in relative humidity with other weather factors not only affects the crop growth and production but also alters the severity of the diseases (Chakraborty and Newton 2011). It has been observed that the pathogens with short life cycle adapt the climate change faster with high reproduction rate and dispersion mechanisms (Coakley *et al* 1999).

Plant diseases play a very crucial role in the agricultural productivity (Agrios 2005) and the changing climatic conditions have exaggerated the circumstances due to change in the distribution pattern, epidemic development and new pathotypes of pest/disease (Yanez-Lopez 2012). Some of the inoffensive pests species have acquired serious status due to fluctuating environmental conditions in the recent years revealing higher numbers of pest occurrences. For example, In-frequent late rainfall caused severe *Ascochyta* blight and caused pod infection in chickpea, resulting in yield and quality losses (Abang and Malhotra 2008). The alteration in rainfall pattern due to an El Nino event in Ethiopia has ruined the entire crop of late planted lentil due to rust during 1997-1998 (Varma and Winslow 2004). It has been estimated that plant diseases caused about 20 % global yield loss in the important crops (Thind 2012). Nevertheless, the pests/diseases during the last decades have been effectively managed but 10-15% of the major global crop yield is still seriously affected by pathogens (Chakraborty and Newton 2011). The rising of temperature, unpredictability in rainfall and shrinkages in irrigated soil water table may result in up to 40% loss in agriculture yield by the year 2100 in South Asian countries including India (IPCC 2008).

Although, presently scientists are able to produce a sufficient quantity of food grains the extreme weather conditions may impose the severe risk on crop production. Weather conditions coupled with the cropping system, soil conditions and varieties improve the production and productivity of crop on controlled plant disease conditions (Gautam *et al* 2013). The improved agricultural technology and plant protection measures have doubled the crop production in the last 40 years but the crop loss proportion has also increased during this period. The increased (15-20 folds) use of insecticides resulted into the higher incidence of pest outbreaks and losses (Oerke 2006). The increasing world population will require more food and to secure the food requirements under the changing climatic conditions, pesticide usage will also be higher.

Nevertheless, various models forecast continuing rise in the concentration of atmospheric CO_2 and temperature all over the world, but they fail to precisely predict future changes in local weather conditions i.e., sunshine, temperature, rain and wind. According to the various climate models, there are chances of more droughts, storms, floods, heavy rains and extreme weather conditions due to change in climatic conditions.

Effect of increased CO_2 concentration on host and pathogens

The atmospheric CO_2 concentration of the earth has increased from 379 ppm in the year 2005 to 406.36 ppm (http://www.esrl.noaa.gov) which is many folds higher than last centuries (Savary *et al* 2012). The increase in CO_2 concentration and temperature change the sense and responses of the plant and soil microbial communities (Chakraborty *et al* 2012, Ainsworth and Rogers 2007) and affect the plant pathogen interaction (Ferrocino *et al* 2013). The rising CO_2 concentrations and temperatures increase or block the metabolic performances and influence leaf physiology, morphology and simultaneously crop production (Ainsworth and Rogers 2007). The increased CO_2 level affects the host and the pathogen in various ways. Various workers have observed number of leaves, leaf area, branches, leaf area per plant, plant height, and crop yield due to elevated CO_2 levels (Bowes 1993, Pritchard *et al* 1999, Eastburn et al 2011). McElrone *et al* (2005) found that the increase in CO_2 level, decrease disease occurrence and severity of pathogen *Phyllosticta minima* caused red maple disease due to changes in host metabolisms.

Although both positive and negative effects of elevated CO_2 had been reported on plant diseases but it has been noticed that disease severity increased in the majority of cases (Manning an Tiedmann 1995). It has been assumed that the rising of CO_2 level together with climate change promote the growth of pathogenic microbes (Yáñez-López *et al* 2012). The raised CO_2 level would increase numbers and size of plant branches, resulting in an increase in biomass production and decomposition of plant litter becomes slow under elevated CO_2. The increased plant biomass, slower litter decomposition coupled with higher temperatures could enhance the pathogen survival and microclimates may be more favorable for the growth of rusts, mildews, leaf spots and blights (Lambers *et al* 2008). The rate of barley leaf infection is decline by *Erysiphe graminis* and expansion of latent period after infection in *Maravalia cryptostegiae* has been observed under elevated CO_2 level (Mina and Sinha 2008). These microclimatic conditions favor the development of biotrophic fungi (Chakraborty *et al* 2002) and chances of infection. Besides this, the mutation and subsequence evolution of new pathovars (Pathotypes) have also been envisaged (Chakraborty and Datta 2002). It has been observed that the plants were grown under high temperature and CO_2 level had increased photosynthesis and/or water and nutrient use efficiency (Kimball *et al* 2002, Von Tiedemann and Firsching 2000). The modified root morphology with branching pattern and exudation of chemical compounds in the rhizosphere has been reported due to rise in the CO_2 concentrations (Pickles *et al* 2012).

The elevated CO_2 resulted into altered stomata opening and leaf metabolism resulted in reduced leaf infection and disease severity of pathogen entering through stomata (Mcelrone *et al* 2005). Elevated CO_2 and O_3 concentrations altered the expression of downy mildew, and brown spot in soybean along with varied plant response has been observed (Eastburn *et al* 2010). Similarly, with higher CO_2 concentrations improved resistance to powdery mildew has been recorded in barley (Hibberd *et al* 1996).

Although some studies advocated the positive response of high CO2 concentration level on plant diseases but Manning and Tiedemann (1995) found increased disease severity in the majority of the cases. The changed host morphology, physiology and nutrients, water balance may be responsible for the host resistance. The decreased stomata density also leads to pathogens resistance that penetrates through stomata. Higher CO_2 level alone or amalgamated with higher O_3 concentration increased the severity of *Septoria* leaf spots. Kobayashi *et al* (2006) studied the response of high atmospheric CO_2 concentration on the infection of rice blast and sheath blight and observed that the plants were more prone to infection under higher CO_2 concentration. Besides these, it has also been reported that pathogens causing powdery mildew of barley and anthracnose disease caused by *Colletotrichum gloeosporioides* reproduce faster at the higher CO_2 concentration (Hibberd *et al* 1996, Chakraborty *et al* 2000). Carter *et al* (1996) predicted the higher risk of potato blight under a higher concentration of CO_2, in the regions of Finland. It has been observed that the effects of the climate changes may influence on the pathogen *Fusarium* species on disease incidence (Chitarra *et al* 2015).

Effect of increased temperature on host and pathogens

The significant increase in cumulative temperature may affect crop physiology and resistance to a disease. Sometimes a shift in the geographical distribution of host pathogens has also been reported due to change in the climatic conditions (Mina and Sinha, 2008). Temperature plays an important role in the development of plant and plant-pathogen interactions. Both the rising temperature and duration of its exposure are playing a major role in determining the consequence of climate change on plant disease severity. The epidemics of plant disease depend on the stability of the plant in a particular environment (Evans *et al* 2008) and variability in the temperature increase (Elad 2009). The changes in the temperatures particularly ambient temperature (Li *et al* 2013) influence the microbial pathogens, host and simultaneously diseases incidence (Suzuki *et al* 2014, Ashoub *et al* 2015).

Temperature is essential for the growth of plants as well as pathogens and affects the penetration, survival, development, reproduction rate and dispersal of many pathogens. With the increases in the temperature, the growth and reproduction rate of pathogens may be modified

(Ladanyi and Horvath 2010). It has been observed that the host plants converted into resistant to susceptible against rust diseases with rising of temperature but some species become resistant to pathogenic fungi (Coakley *et al* 1999). The change in the temperature influences infection, reproduction, dispersal and survival of a pathogen between seasons along with other critical stages in its lifecycle. The inactive races of different pathogens may cause even sudden epidemic due to change in the temperature. The rising temperatures are the major cause of alteration in the disease incidence, occurrences, epidemic and development of new pathovars (strains) affecting the crop plants. The increased temperature stress leads to desiccation and makes the plant prone to parasitic attack. The pathogens may acquire altered development stages, its rate and pathogenicity due to deviations in the temperature and rainfall patterns similarly the biochemical pathways and resistance of host may also change under the fluctuating weather conditions (Chakraborty *et al* 2002, Chakraborty and Datta 2003). The spore germination of *Puccinia substriata* increases with increasing temperatures (Tapsoba and Wilson 1997). Agrios (2005) reported that the initiation of disease development, germination and proliferation of fungal spores becomes faster under high moisture and temperature conditions. Richerzhagen *et al* (2011) reported shift of leaf spot disease of sugar beet due to increasing annual mean temperature by 0.8-1°C in Lower Saxony.

Various rust resistance gene i.e., Pg3 and Pg4 of oat stem, Lr210 and Lr217 of wheat leaf are temperature sensitive and becomes susceptible to the temperature influence (Das *et al* 2016). The bacterial pathogens such as *Burkholderia glumea, Acidovorax avenae* and *Ralstonia solanacearum* becomes virulent with higher temperatures and proliferates in the areas where temperature-dependent diseases caused by these pathogens have not been seen earlier (Kudela 2009, Ahanger *et al* 2013). Besides this, the incidence of viral, vector-borne diseases and survival of aphids also altered due to temperature fluctuations (van Munster *et al* 2017). The global average temperatures are expected to arise around 1–2°C by the year 2100. Simultaneously, the more frequency of high temperatures, storms, or drought has also been projected (Cook *et al* 2016). The changes will affect the virulence (Garrett *et al* 2011) distribution and emergence of pathogens in new areas (Albouy *et al* 2014). The sunlight favors the accumulation of defensive pigments or phytoalexins in host tissue.

The environmental temperature plays a very crucial role on the spread and survival of pathogens but rainfall and its quantity act as deciding factor of the disease incidence, severity and spread (Woods *et al* 2005). Mboup *et al* (2012) studied the role of temperature-specific adaptation of European wheat yellow rust populations' and reported higher aggressiveness of stripe rust isolates revealing the adaptation of rust fungi at higher temperatures. The degradation of chemicals and mode of action of many systemic fungicides including diffusion, translocation etc. are affected by temperatures (Coakley *et al* 1999). The regions with low productivity index experienced common bunt (*Tilletia caries*) and Karnal bunt (*Tilletia indica*) in wheat under changing climatic conditions in the absence of proper seed treatment (Oerke 2006). The disease situation of some pulses has changed significantly over the time. For example, dry root rot of chickpea caused by *Rhizoctonia bataticola* and blight of pigeon pea caused by *Phytophthora drechsleri f. sp. cajani* have been reported as the major threat for their production under changed climatic conditions in India (Pande and Shanna 2010). Similarly, Dixon (2012) reported more risk of dry root rot disease in the chickpea variety resistant to *Fusariu*m wilt with the temperatures more than 33°C. Different temperature regimes affect virulence-resistance in chickpea and lentil caused by *Ascochyta*. During the year 2005 and 2006 pea cropping seasons, 14 days with the temperature above 25°C during flower pollination and fruits ripening period had significantly reduced productivity (Jeuffroy *et al* 2015).

The vector-borne diseases including viral diseases may also alter under the changed climatic conditions due to considerable influence of their development and distribution. Navas-Castillo *et al* (2011) studied the viral diseases transmitted by whiteflies and reported the appearance of tomato yellow leaf curl disease, cassava mosaic disease, cucurbits virus diseases, tomato chlorosis and the torrado-like diseases of tomato. On the contrary Gregory *et al* (2009) advocated the positive effect of temperature on disease resistance in host plants and reported temperature sensitivity to resistance for blight of rice caused by *Xanthomonas oryzae pv. oryzae,* leaf rust of wheat caused by *Puccinia recondita*, black shank of tobacco caused by *Phytophthora nicotianae* and broomrape disease of sunflower caused by parasite *Orobanche cumana*. Similarly, at a higher temperature, the forage species attained more lignifications in their cell walls and enhanced resistance to fungal pathogens (Wilson *et al* 1991).

The decline in an accumulation of carbohydrate and proteins synthesis has been observed with the plants grown at the higher temperature (Obrêpalska-Stêplowska 2015). Therefore, the impact of higher temperature would depend on the gene for gene interaction (host-pathogen) and defense mechanism for resistance. Simulation models can be a better approach for the evaluation of the future climate change impact on plant diseases. In a model simulation analysis, Salinari *et al* (2006) suggested that the effect of increased temperature has surpassed the effect of reduced rainfall on enhancing disease pressure and reported that temperature and moisture act together on the pathogens. Some models envisage that increased relative humidity coupled with rising temperature would also support the development of a disease. Some laboratory study with designed models predicts in disease incidence and epidemic with rising temperature, CO_2 concentration, relative humidity etc. for important microbial pathogens attacked on crop plants (Evans *et al* 2008; Ghini *et al* 2008, Kocmánková *et al* 2009).

Effect of altered moisture regime on host and pathogens

Moisture plays an important role in the interaction of host and pathogens. Higher temperature coupled with adequate soil moisture leads to a humid environment. The pathogens favoring the humid conditions may cause diseases with their enhanced potential (Mcelrone *et al* 2005). The evapo-transpiration rate increases with increase in temperature under sufficient soil moisture resulting in to humid microclimate which attracts diseases. More incidences of infections have been reported with higher moisture content by fungal pathogens responsible for late blight and apple scab disease. Lower moisture condition favored by pathogenic fungal species caused powdery mildew disease (Coakley *et al* 1999). The high relative humidity under canopies responsible for leaf wetness for the longer period increases the risk of pathogenic infection and disease incidence. The late blight of solanaceous plants (tomato and potato) caused by *Phytophthora infestans* occurs most frequently at high moisture and between the temperatures range of 7.2°C and 26.8°C (Fry *et al* 2013). Similarly, foliar diseases and some soil-borne pathogens become more vulnerable under high moisture conditions (Lindsey *et al* 2012). Some fungal pathogens may also become important under climate change due to dryness. For example, drought conditions can favor dry root rot disease and powdery mildew disease in legume crops (Gautam *et al* 2013). Similarly, *Armilaria* sp. favors infection during drought condition which is normally not very pathogenic (Lonsdale and Gibbs 1996). The drought conditions also affect incidence and severity of some viruses (Clover *et al* 1999). *Armilaria* sp. becomes virulent and cause infection during drought condition which is not biotrophic in nature in normal weather condition (Lonsdale and Gibbs 1996). The drought conditions also affect incidence and severity of some viruses (Clover *et al* 1999).

Effect of climate change on plant disease

The development of the disease is not governed by a single factor, it is a collective effect of different climatic factors that influence on both the pathogenic microbes and host plants. The relationship is also affected by the pathogen population and control agents along with the climatic conditions. The rate of reproduction of the pathogen is governed by the temperature and longer seasons. The higher temperatures increase the duration of seasons and simultaneously provides the longer time for pathogen evolution. So, there are more chances of pathogen incidence under over winter and over summer conditions. Climate change had a direct impact on the rise of temperature, carbon dioxide levels and on the moisture. Due to varied temperature conditions, the pathogen and vector come in contact with other hosts resulting into chances of pathogens hybridization (Brasier 2001) and on disease incidence and severity leading to serious impact on food security. Garrett *et al* (2006) suggested that while studying the effect of climate change on plant disease to observe the heritability of traits along with other characteristics for the rate of pathogen evolution.

Pfender and Vollmer (1999) studied the effect of freezing temperature on survival of *Puccinia graminis* and reported the significant effect on the survival of the grass stem rust pathogen due to variation in winter temperature across years. Studies of climate change on biotrophic and necrotrophic fungi revealed varied results in disease severity but the ratio of increased disease severity was higher for both the fungi due to changed climatic conditions (Chakraborty *et al* 2000, Chakraborty *et al* 2002,). The necrotrophic pathogen produces more inoculum in the presence of higher biomass and substitute of host crops. The inoculum has the ability to infect the succeeding crops and negatively affect the advantage of partially resistant varieties of the crop (Melloy *et al* 2010).

The changing climate also amends the host susceptibility towards the pathogens (Gassmann *et al* 2016). Various signalling phenomenon has been suggested for the host susceptibility viz., calcium sensors (Ranty *et al* 2016), reactive oxygen signalling (Baxter *et al* 2014), hormonal interactions (Nguyen *et al* 2016) and molecules priming (Thevenet *et al* 2017) that modify gene transcription, cell biology and physiology (Atkinson and Urwin 2012) of the host. It has been observed that the pathogens become more complicated under the stresses caused by climate change (Sturrock *et al* 2011)

The changes in the temperature regimes accelerate new gene allele recombination and provide chances for the development of more antagonistic pathotypes (McElrone *et al* 2005). Similarly, the elevated CO_2 and O_3 levels are also responsible to alter the diseases. The findings revealed that environmental conditions under the changed climatic conditions changed not only diseases incidence but also host response to the infection. Eastburn *et al* (2010) suggested that the study of the pathogen under climate change scenario is relatively more complex. The effects of increased level of CO_2 on opening and closing of stomata and leaves metabolisms have been addressed and suggested that the pathogens infecting through stomata may be decreased (McElrone *et al* 2005). The increased thermal time is expected to be responsible for an increase in the development of soil-borne pathogens infecting root and stem during autumn and winter (Evans *et al* 2008, Butterworth *et al* 2010). Pathogens viz., *Rhizoctonia, Sclerotium, Pythium* and *Phytophthora* causing soil-borne diseases particularly in pulses showed enhanced activity under the excess moisture conditions (Sharma *et al* 2010). Various components of the climate change had variable impacts on the soil microorganisms and biological processes of the soil (Pritchard 2011). Kaur *et al* (2008) studied that the impact changes in climatic factors on the occurrence of disease on wheat in Punjab, India and reported that the region experienced significant weather changes due to early warming in February. They further predicted that the changes in the climatic conditions will affect the wheat crop and alter the vulnerability due to host-pathogen interactions. The rise in the temperature coupled with humidity influence the susceptibility of wheat that lead to infection of *P. recondita* cause brown rust disease. In the absence of resistant wheat cultivars, stem and leaf rust, foliar blights and head blight may increase in the region due to change in the temperature and humidity conditions (Kaur *et al* 2008).

The changes in the climatic conditions lead to various factors including uncertain rainfalls and require frequent applications of pesticides for disease management. In the temperate Indian hill, the late blight disease earlier appeared at the temperatures ranging from 10–25°C and while now-a-days it appears at a wider temperature ranges from 14–27.5°C during November in the northern part and during February in the eastern part resulting about 40–85% yield loss every year (Luck *et al* 2012). Some pathogens viz., stem rust in wheat, banana wilt and late blight of potato have acquired potential for major losses in the important crops due to alteration in climatic changes leading to yield loss and use of pesticides in huge quantities (Duveiller *et al* 2007).

Evans *et al* (2007) predicted that greenhouse effects can change the scenario of the severity of plant disease. Its effect may be seen not only on the pathogen but also on the host or the host-pathogen interaction (Huang *et al* 2005; 2006, Garrett *et al* 2006). The shift in warming and altered precipitation along with other climatic conditions may result in phenology, population dynamics and geographic distribution of wheat diseases (Juroszek and Tiedemann 2013). The pathogens having short life cycles responded quickly to climate change and adapted the climatic conditions rapidly in the presence of susceptible hosts (Coakley *et al* 1999). Harvell *et al* (2002) studied the effect of climate warming on the disease risks of terrestrial and marine biota and found that the higher night temperatures during winter seasons improve the survival rate of pathogenic bacteria, life cycles of insect (vector) and biotrophic fungi. The simultaneously higher incidence of fungal infection has also been reported. The change in temperature, moisture, CO_2 concentration conditions may alter the physiology and resistance of the host and developmental rates of pathogens. Mina and Sinha (2008) studied the effects of climate change on plant pathogens and reported that the climate change may lead to new disease complexes. Higher incidence of canker diseases in apple has been observed due to more rainfall in summer as compared to rainfall in the rainy season (Sharma 2012). Juroszek and Tiedemann (2015) linked plant disease models to climate change to project future risks of crop diseases and suggested that disease dynamics should include climatic factors. Predictions and assessment of pathogen risk and prospective yields in agriculture are convoluted by inter-relationships among host (crops), their pathogens, and climate factors with their changes scenario. Fones and Gurr (2017) suggested that the improvement in disease risk can be minimized with wide and flexible planning considering host and pathogens are the essential factors while climate changes (environmental factors) are the crucial factor for disease incidence.

Need for implementation of novel strategy

Adoption of the novel and eco-friendly approaches is required in disease management under the changing disease scenario due to climate change to sustain crop production (Boonekamp 2012). Weather-based disease monitoring, inoculum monitoring and rapid diagnostics may be some of the vital approaches for crop management practices. Healthy and disease resistance seeds, intercropping systems obligating natural biocontrol organisms and development of an early warning system for predicting disease epidemics should also be exploited to combat the effect of climate change. Botanical pesticides and plant-derived soil amendments also help in the mitigation of climate change as they reduce the nitrous oxide emission (Pathak 2010). New gene finding, sequencing of the genome, sequences data mining and anticipated efforts towards their exploitation would be a novel approach to combat the effect of climate change. In this context traditional plant breeding protocols coupled with marker-assisted selection may be a good choice for obtaining disease resistance and quality seeds in a shorter time.

The marker-aided selection has improved the understandings of the diversity of agriculturally important crops at variety and species (specific genes) levels for successful cross-breeding and accelerated the pace of genetic improvement in climate change circumstances (Muthamilarasan *et al* 2013, 2014). The identification of stress that affects growth and productivity of crops under certain climate change circumstances may be one of the better approaches for the development of new cultivar (Varshney *et al* 2005). The accessions from a particular stress-prone environment can be identified with the help of geographic information systems for preparation of passport data. The DNA fingerprinting and mapping of desired genes may be helpful for selecting the robust accessions. The molecular breeding strategies through genetic engendering approaches can be better approaches for enhancing the crop resilience under the changing climatic conditions. With the help of this technique, integration of important gene or manipulation in the existing gene in the target crop is possible to obtain a phenotype with desired characteristics. Studies on host response and its adaptation should be carried out to recognize the effects of climate change on diseases. Accordingly, adaptation and mitigation approaches should be developed using new tools and strategies after the evaluation of the effectiveness of existing physical, chemical and biological control techniques.

CONCLUSION

It is high time to understand how climate change affects plant diseases and responses of the host. The cultivation practices, use of pesticides and biological control strategy, including biotic stress-resistant varieties should be re-evaluated and accordingly, new tools and tactics should be developed. New agriculture innovative based packages such as stress tolerant varieties and integrated disease management programme have increased biomass and productivity under climate change scenario. Relevant research efforts in the endemic disease occurrence area may be useful to understand the biology of host and pathogens and economic impacts of increasing climatic risk. Improvement in disease management strategies and commitment in anticipatory research to develop disease-resistant varieties against emerging pathogens through integrated discipline with multi-task team approaches may be better strategies under climate change.

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