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Current scenario of climate change and its impact on plant diseases

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Abstract

The change in global climate is because of expanding convergence of greenhouse gases (GHG) in the environment. Climate changes observed on Earth in recent years are mostly the result of various human activities. The global temperature has risen by around 0.8 °C over the past hundred years and is expected to ascend by between 0.9 and 3.5 °C by 2100. Climate change does not only affect the holistic crop growth but also influence the spread, multiplication, incidence and severity of many phytopathogenic agents. These effects will be seen not only on the other elements of the agroecosystem but also on plants and other organisms. Climate change involving rise in temperature and CO_2 level in the atmosphere, and other weather events such as drought and flooding, all affects the host plant resistance to pathogens. Climate change has the potential to alter host-pathogen interactions and ultimately pose great impact on development of disease epidemics. However, determining these effects is difficult, so experts from various fields must look beyond their own disciplinary boundaries and put the effects of climate change in a larger context. Various plant disease models have been created to integrate modern climate forecasts at different levels. According to climate change scenario, there is great need to modify the methods of disease management in terms of their geographic and temporal distribution. This review uses appropriate examples to demonstrate the many implications that climate change has on plant diseases and their repercussions.

Keywords

CO_2; global warming; UV radiation; food security; plant diseases

Introduction

Nowadays, all agricultural industries are significantly impacted by the problem of climate change. Impacts of climate change are already becoming apparent for both natural and human systems, with most crops experiencing more negative than positive effects on yields (Figure 1). The earth's surface is heated by greenhouse gases in the atmosphere, which capture the reflected energy (1). Increased atmospheric temperature, CO_2 concentration, change in precipitation patterns, and the frequency of extreme weather events all have a negative impact on agricultural productivity (2). In addition to anthropogenic factors, climate change would also have an impact on plant diseases (3). Diseases like sudden oak death spread more easily as a result of these circumstances (4). Plant-parasitic interactions are impacted by increased temperature and CO_2 concentration (5). Human

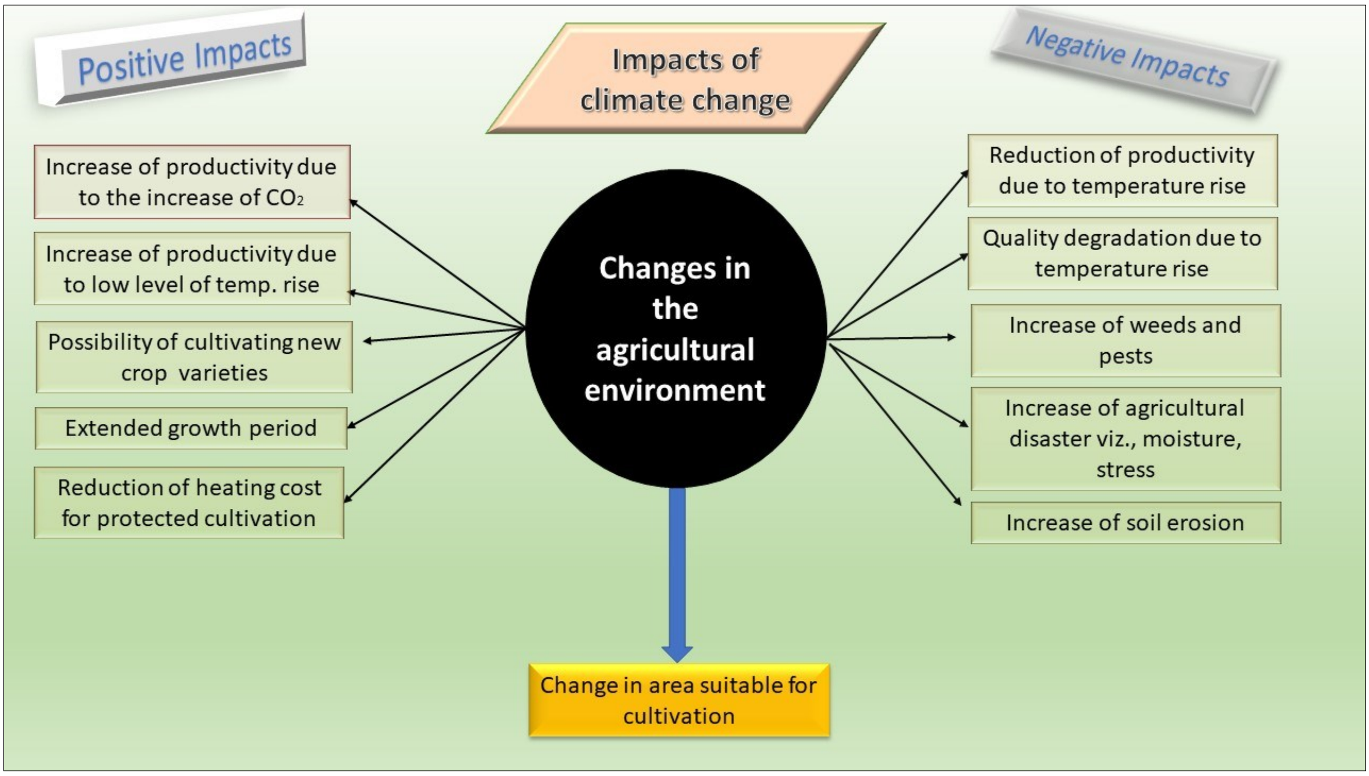

Fig. 1. Impacts of Climate Change

activities also accelerated global climate change, which has great influence on ecosystems (6). Signs of Global warming have been observed in the west coast, inner peninsula, central region and northeastern regions of India (7).

According to the Intergovernmental Panel on Climate Change (IPCC), climate change resulted in increase in atmospheric CO_2 by 30% and temperature by 0.3 to 0.6 °C (8). The host, pathogen, and environment components of the disease triangle are all impacted by the world's changing climate (9) (Figure 2). A model was used to study the impact of climate change on Phoma (*Leptosphaeria maculans*) in rapeseed, that foresee temperature and precipitation under CO_2 discharge situations for the years 2020 and 2050s in UK (10) and spore production by teleomorphs on climate change (11). The impact of climate change on plant diseases involves a number of trade-offs with varying climatic preferences, such as optimum temperature and humidity (Figure 3).

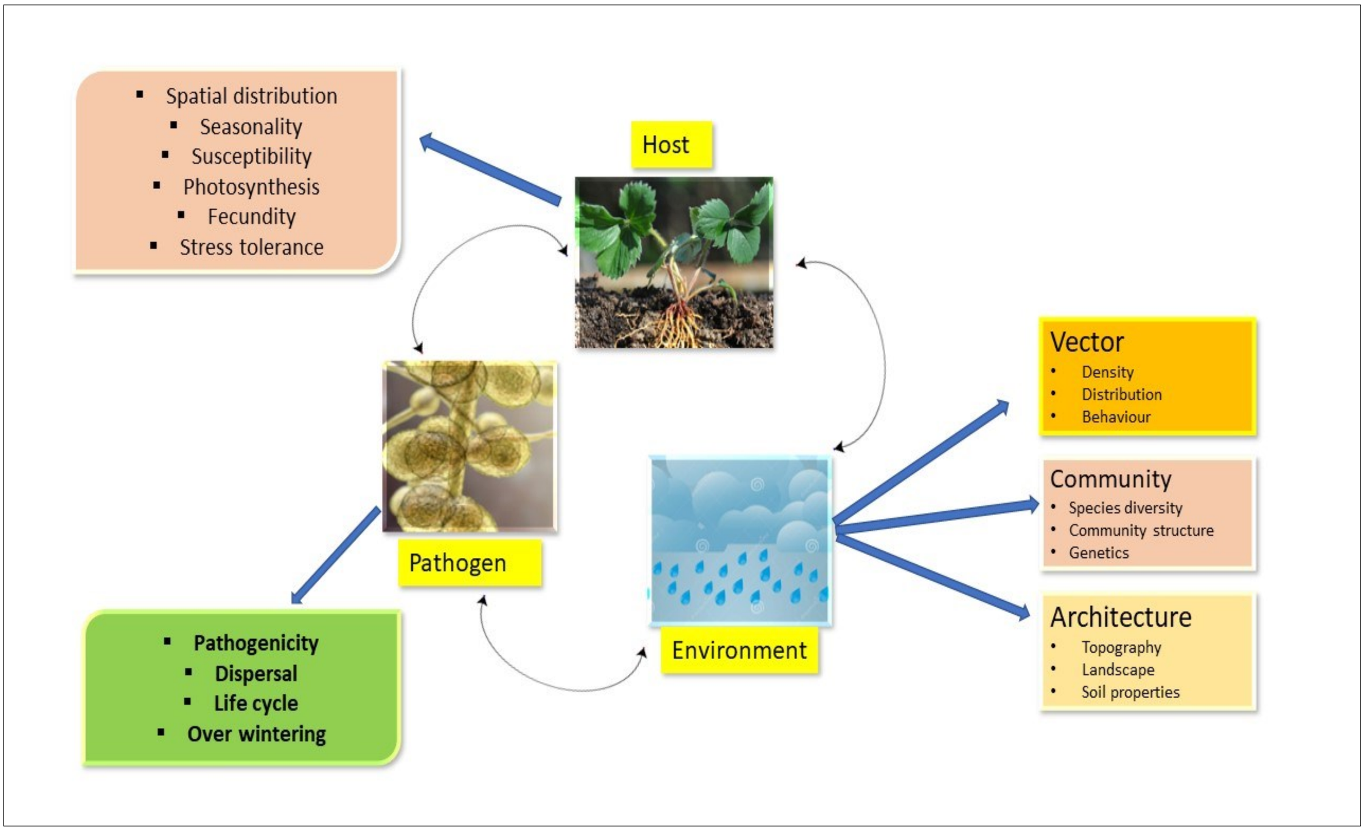

Fig. 2. Impacts of Climate Change on components of disease triangle

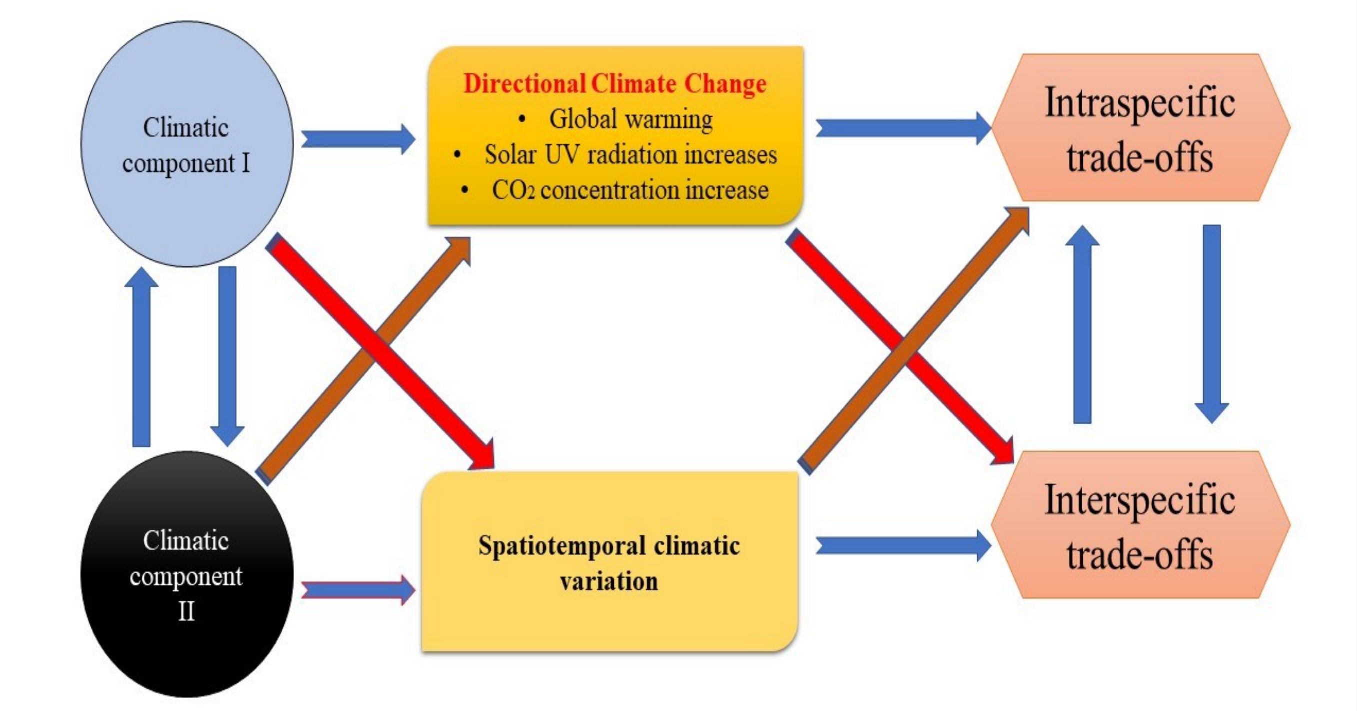

Fig. 3. Effects of climate change on the evolution of plant and pathogen trade-offs and their interactions

Trade offs happen when the expansion of one functional service causes the supply of another functional service to decline. Greater pathogenicity in pathogens frequently hinders other biological and ecological processes, including intrinsic metabolic rate, stress tolerance (12), spore production (13) transmission (14), and competitive ability (15). In plants, disease resistance is negatively correlated with photosynthetic rates, germination, cellular growth and seed production (16).

When simulating the effects of climate change on infectious plant diseases, relative evolvability is a crucial factor that must be taken into account. The processes by which plants and pathogens produce genetic variation for environmental adaptation are very different. The relative importance of both of these phenomena in explaining how species have evolved to cope with climate change can be estimated by plasticity and heritability. Different mechanisms for coping with short-term, erratic fluctuations and long-term, directional changes in climate events have developed within species (Figure 4).

In order to obtain sustainable food production in a changing climate, disease management procedures should be updated. Despite the fact that plant diseases are crucial to agriculture (17), limited amount of data on how climate change may affect plant diseases is available (18-19).

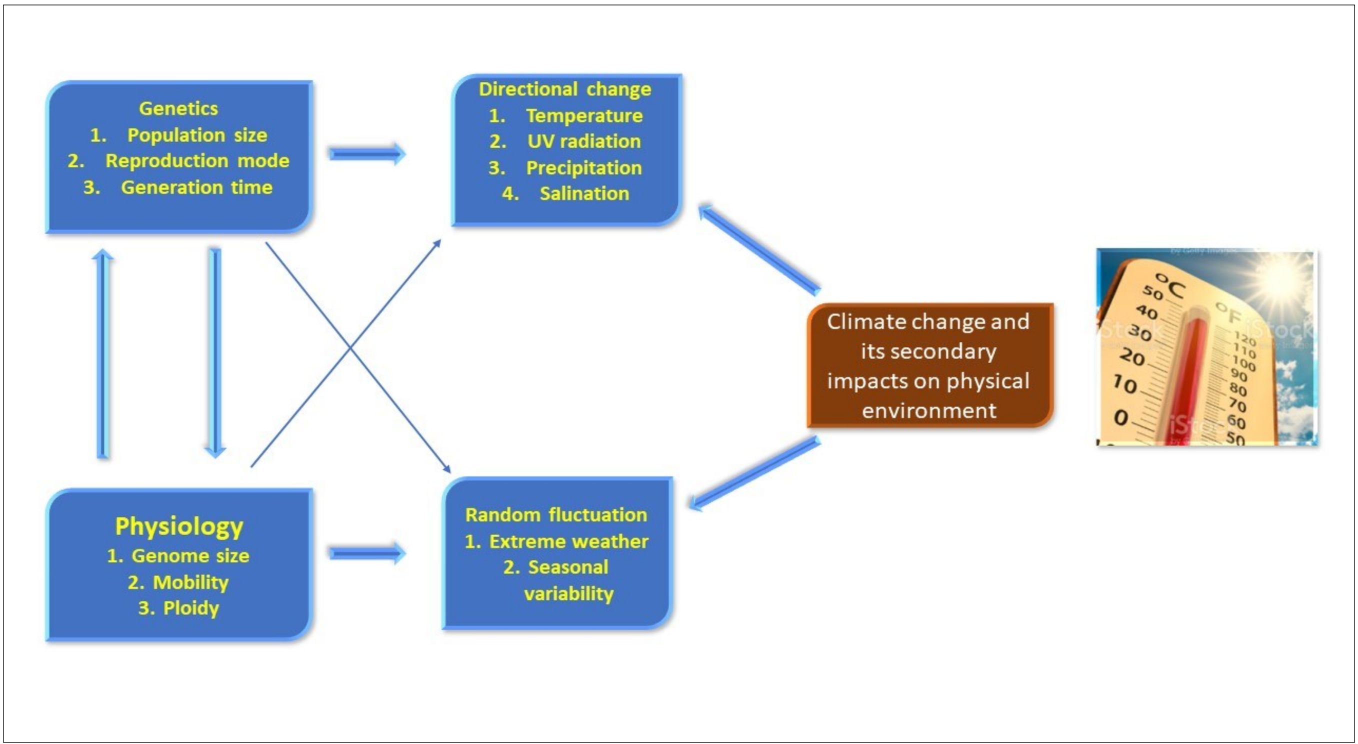

Fig.4. Adaptation strategies for various types of climate change

General effects of climate change

Current CO_2 concentration is about 350 ppm, which may increase to 550–750 ppm in coming years (20). Doubling of CO_2 concentration may lead to temperature increase by 2.3±1.6 ºC. It is anticipated that by 2080 AD, there might be reduction in the output of Indian agriculture by 30–40% under the assumption of 4 °C increase in world's temperature.

Effect of fluctuation in temperature on plant pathogens

Host and pathogen have co-evolved dynamically in their struggle for fitness and endurance. Environmental factors have a significant impact on microbial pathogenesis process and host immunization. Temperature fluctuation is a key factor determining invasion of microbes and host evasion. Plant temperature fluctuates daily in contrast to mammals, who maintain a steady body temperature. Invasive diseases may spread more quickly in warmer climates (21). Generally fungi engage in a variety of parasitic interactions with their host plants. Current environmental conditions, particularly temperature and moisture, have a significant impact on the development of diseases caused by fungal pathogens. Plants and pathogens both require a certain minimum temperature for their growth. Any fluctuation in temperature will considerably effect the fungal reproduction, infection rate, penetration, infection cycle, dispersal and off-season survival. Sudden outbreak of disease might result from a temperature change, reactivating dormant pathogen races. Due to sudden rise in temperature several pathogens migrate to new locations and will come in contact with new hosts present in that area.

Temperature influences the susceptibility of cereal crops to rust infections. Stripe rust (*Puccinia striiformis*) pathogen expressed high aggressiveness at elevated temperature making wheat or oat more vulnerable (22-23). Yellow rust of wheat has just started to appear in late December because of the favourable climate brought on by increasing temperatures (24-25). Under conditions of high temperatures, powdery mildew is expected to cause significant losses in winter wheat in China. (26). According to (5), increased temperature and CO_2 concentration raised concerns about the threat of blast and sheath blight disease in rice and late blight disease of potato (27). In *Fusarium* wilt-resistant cultivars of chickpea, a greater risk of dry root rot has been observed when temperatures surpass 33 °C (28). Wider possibilities for sexual stages to overwinter are created by temperature changes, which speeds up gene recombination and promotes the emergence of virulent strains of the pathogen (29). Karnal bunt and common bunt diseases of wheat might be significant under changing climatic conditions in locations with poor production, in case of improper seed treatment (30-31).

The incidence of bacterial pathogens i.e. *Ralstonia solanacearum*, *Acidovorax avenae*, and *Burkholderia glumea* is greatly influenced by temperature. Moreover, bacteria thrive in places where temperature-dependent diseases have not yet been reported (32). High temperature (34.5 °C), reduced virulence of soft rot bacterium (*Erwinia carotovora* subsp. *carotovora*) except in strain EC153, which generated large amounts of rRNA, N-acyl homoserine lactone and extracellular proteins causing widespread maceration of Chinese cabbage and celery petioles (33). Temperature also influence the prevalence of viruses and vector-borne diseases. A mild winter increases the survival of aphids and thus increase the incidence of viral diseases of sugar beet and potato and spread of Barley Yellow Dwarf Virus (34-35).

Future forecasts indicate that in the years 2020, 2050, and 2080, regions that are favourable to the Black Sigatoka (*Mycosphaerella fijiensis*) disease of banana would substantially decline, although some areas will still favour the occurrence of the disease (36). Low temperature of 15 to 20 °C resulted in appearance of necrotic lesions on melon which in contrast to the high temperature of 20 to 25 °C exhibited latent infection or "Heat Masking" (37). Plant disease resistance is also affected by change in temperature, consequently influencing the overall disease development. For leaf rust (*Puccinia recondita*) in wheat, black shank (*Phytophthora nicotianae*) in tobacco, broomrape (*Orobanche cumana*) in sunflower and bacterial blight (*Xanthomonas oryzae* pv. *oryzae*) in rice temperature sensitivity to resistance has been documented (38).

Effect of increased CO2 concentration on plant pathogens

Increased CO_2 effect on a specific disease depends on how it affects the host plant, it is difficult to generalize and suggests that the influence might be either positive or negative (7). Increased CO_2 levels improve plant growth, photosynthesis, leaf area, sugar content and crop yield (39). Increased CO_2 concentrations favour the quick sporulation of plant pathogenic fungi (40). Increased fecundity in some pathogens due to rising CO_2 levels in the atmosphere might lead to disease epidemics (41). Alteration in expression of different soybean diseases i.e. brown spots, downy mildew and sudden death syndrome was observed due to elevated CO_2 concentrations (42). Increased virulence of *Fusarium graminearum* was reported under high CO_2 levels (40) whereas low diseases severity was reported in *Peronospora manshurica* (39).

Bacterial wilt and spot infections in pepper were exacerbated by higher ambient CO_2 concentrations (43). Moreover, increased CO_2 has been demonstrated to have a significant influence on disease development under controlled settings. Blast and sheath blight infection risk in rice rose when CO_2 concentration was raised by 200–280 μmol mol−1 over ambient values (27). Elevated CO_2 (650 mol mol−1) concentrations resulted in increased incidence of yellow dwarf disease and BYDV-PAV titre (44). Symptom expression is not always linked with elevated virus titres. Despite having a high viral titre, inoculation of *Nicotiana benthamiana* plants with PVX and CMV under higher CO_2 conditions had little effect on symptom expression (45).

Increased CO_2 inhibited resistance against PVY in tobacco plants (46), and tomato YLCV (47) and TMV in tomato plants (48). High CO_2 levels may also reduce pathogen-induced viral resistance (19). As a result, while rising temperatures affect the duration, frequency and development, virus epidemics by modifying host resistance, altering virus multiplication rates and physiology of host-virus interactions, rising CO_2 concentrations may lessen the impact of temperature on epidemics by boosting viral resistance.

Effect of changed moisture regime on plant pathogens

Most bacterial and fungal diseases thrive in moist conditions. Moisture is often required for bacterial growth and penetration, fungal spore germination, and to kick-start an infection. In general, moisture is necessary for the germination of spores, the growth and penetration of bacteria, and initiation of infection. Many climate change models predict that as temperatures rise, rainfall events will become more frequent and intense, and there will be more water vapour in the atmosphere. Crop canopies retain moisture in the form of wetness in the leaves and relative humidity (RH) for a long time, which encourages the growth of pathogens and diseases including late blights and vegetable root diseases (49). High moisture favors the growth of soil-borne pathogens like *Phytophthora, Pythium, R. solani,* and *Sclerotium rolfsii*. Drought stress has an impact on the occurence of viral diseases like Beet yellows virus (BYV) and Maize dwarf mosaic virus (MDMV) (50 and 51). At low soil moisture, *Ralstonia solanacearum* exhibits reduced growth in tomatoes (52). In apple, the incidence of various canker diseases caused by fungal pathogens is increasing as a result of less rain during the rainy season and more severe summers (53). Likewise the incidence of apple scab (*Venturia inaequalis*) has also decreased as a result of less rainfall in the winter and in March and April, which is required for the maturation of the disease-spreading sexual spores.

Effect due to UV radiation

Increased UV radiation may have positive as well negative impact on pathogen population (54-55). Even at lower doses, the most potent radiation, UV-C, kills microorganisms more effectively but frequently damages plants. Indirect effects such as regulation of plant defence mechanisms, ROS accumulation and production of secondary metabolites like phenolic compounds can be attributed to UV-B-specific pathways (56). UV inactivates microorganisms by framing pyrimidine dimers in RNA and DNA, that obstruct gene expression process (57-58). UV rays harms structure of pathogens and bio-control agents directly and interferes with host resistance. UV radiations are the result of depletion of ozone layer because of release of greenhouse gases (59).

Impact of climate change on diseases caused by vectors

Climate change impacts the growth and dispersion of insect vectors, subsequently which affects occurrence and development of plant disease (6, 31). Higher temperatures promote insect reproduction and aid in the spread of invasive pathogens (21). The climatic conditions needed by disease vectors restrict the risk of vector-borne diseases in an area. It also affects the duration of incubation period of pathogen in an insect vector. In order to function, plant viruses require both host plants and vectors. Climate change influences the populations of host plants and insects that serve as plant virus vectors (60). Primary infection of the host, disease development inside the host, horizontal transfer of the virus to other hosts via the vector are all impacted by change in climatic conditions. The host's phenology and physiology are also impacted by climate change, which has an impact on the host's vulnerability to infection and viral susceptibility. Climate change modelling is necessary to determine when significant pathogens or vectors are likely to invade regions where conditions were previously unsuitable for them.

Climate change and microbial interactions

The three principle greenhouse gases that microorganisms produce and consume are carbon dioxide, methane, and nitrous oxide. Climate change can accelerate the diseases that certain bacteria can spread to people, animals, and plants. Significant effects on the carbon cycle and the functioning of many ecosystems are caused by elevated CO_2 levels in the atmosphere. Key parameters impacting soil microbial populations include temperature, CO_2 concentration, and nitrogen deposition amount (19). Alteration in abiotic environments over the short and long terms have an impact on both the populations of microorganisms that live on plant surfaces as well as plant development and production. Every modification in the phyllosphere's microbiota has an impact on plant development and resistance to aggressive disease attack.

Impacts of soil pH

Climate is a primary variable that impacts all other aspects of an ecosystem, and it will have an impact on soil characteristics, including pH. The host plant is also impacted by soil pH. At high pH, plants come under stress and become susceptible to the pathogen's attack. The pH of the soil may have an impact on the nature of the root exudates, which attracts soil borne pathogens. It also influence the nutrients that are available to the plant. In crucifers, club root (*Plasmodiophora brassicae*) incidence is high in acidic soil as compare to alkaline soil. A pH of 5.2 favours *Streptomyces scabies* which shows decreased development and occurrence at pH 8.5 (61). At neutral pH of 7.0, *Fusarium* wilt of flax is controlled (17). Accessibility of soil nutrients, plant growth and vigour is affected by soil response and this indirectly influences disease development and infection (62).

Effect of climate change on crop loss

Climate change has an impact on food supply and quality as well. Reduced agricultural productivity may be a result of projected temperature rise, modifications in precipitation patterns, extreme weather events and decrease in water availability. Plant diseases account for about 10 per cent losses of global food production, putting food security at risk (63). Apart from direct losses, disease control measures, particularly chemical ones, may cause substantial environmental damage, in addition to chemical residues breaching the food chain and social and economic upheavals. It is crucial to analyze the probable consequences of climate change for the endorsement of adaptive tactics, development of resistant varieties, novel management approaches are urgently required to avert more significant losses (64). Fungicide treatment and host-plant resistance make a significant contribution to sustainable crop production systems and climate change mitigation to ensure global food security (65). The potential influence of changing atmospheric composition and climate on selected plant disease management strategies is discussed in Table 1.

only a few factors are taken into consideration, it is difficult to predict how climate change will affect plant diseases. The majority of these studies mentioned above have been done on a small scale for brief periods of time and under restricted conditions that may be very different from those in the field. The presence of different climatic zones in our country allows us to cultivate diversified crops in same seasons in tarai, hills and Himalayas which may change in the changing climatic conditions. It has become crucial to locate areas where crop production have been affected by the temporal and spatial changes brought on by climate change. We couldn't find any data on how elevated levels of the greenhouse gases nitrous oxide or methane might affect any of the biological factors related to infectious plant diseases. We could find no information on the likely impacts of climate change on a number of biological parameters, such as pollen transmission, the capacity of vectors to reproduce, biological control, and cultural control measures against the pathogens. The impact of drought and flooding on plant diseases needs to be better understood.

Table. 1. Potential influence of changing climatic conditions on selected plant disease management strategies

Control Measure	Strategy	Impact of Climate Change	Potential for an adaptation strategy
Avoidance	Quarentine	Changes in pathogen dispersal due to climate, including changes in frequency, abundance, distance, and speed	Modified effectiveness of quarantine procedures
Preventive	Crop rotation	Despite having no direct impact, diversity in cropping systems will continue to be crucial for lowering disease risks.	Use of crop species that are better suited to the local climate.
Preventive	Sowing date	Adjustments are likely to be required, and there are cheap, simple ways to deal with biotic and abiotic stress, but there may also be drawbacks	Evidently a potent tool, but possibly constrained in excessively warm winters (for example, late sowing in autumn under temperate conditions)
Preventive	Host plant Resistance	Pathogens may be able to overcome temperature-dependent resistance, and changes in plant morphology and physiology may have an impact on resistance. Accelerated pathogen evolution may also prematurely erode disease resistance.	Altered host-plant resistance effectiveness (higher, same, or lower effectiveness depending on the resistance (R) gene, pathogen population, etc.)
Preventive and / or curative	Use of Antagonists	High vulnerability of antagonist	Altered efficacy (high, low, depends upon product and environment)
Preventive and / or curative	Use of contact/ systemic fungicides	High rainfall will require multiple application of contact fungicides Information about foliar uptake of systemic fungicides is required to make predictions	Altered efficacy (high, low, depends upon product and environment)

Impacts of climate change on interdisciplinarity sciences

It has been reported that a warmer environment along with improper food handling practises may increase the occurrence of food-borne diseases (66). The main issue with the interaction between fungal growth and mycotoxin generation caused by climate change is that mycotoxins have the potential to contaminate common cereals like wheat or maize, which are crucial for food security (67). Aflatoxin levels rise in cool, temperate climates due to an increase in *Aspergillus* occurrence, while they may decline in tropical climates due to unfavourable high temperatures for *Aspergillus* (68).

Global economic conditions are also affected by climate change. Severe weather conditions could hinder economic growth by harming the labour force and capital stock. Additionally, as the global economy adapts to the higher temperatures, labour productivity will decline. The rise in the price of food, energy, and insurance will cause inflation to increase. In order to fight the inflationary pressures brought on by climate change, monetary policy will be constrained. Extreme weather events and rising temperatures worsen economic conditions and social stress, which in turn influence political behaviour to some extent.

Conclusion

Climate change is a significant phenomenon that has an influence on agricultural productivity. Due to the fact that only a few factors are taken into consideration, it is difficult to predict how climate change will affect plant diseases.

Additionally, there has been little research on how CO_2 affects plant infections caused by mollicutes. Furthermore, while there was little information available about its effects on some insect vectors, no information was available for mite, nematode, or fungal vectors. There is enough data on effect of climate change on the plant pathogens but only few have been able to accurately predict potential future scenarios. The initiation of disease forecasting must be prioritized to protect the farmers from bearing loss. We can also contribute in reducing crop yield losses by adopting different climate resilient technologies and practices of climate resilient farming.

Authors contributions

GK carried out conceptualization and original draft preparation. HS participated in final draft preparation and investigation. AK carried out supervision. CK and SM helped in bibliography and reviewing of manuscript. All authors reviewed and agreed to publish this manuscript.

Compliance with ethical standards

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