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The Impact of Climate Change on Changing Pattern of Maize Diseases in Indian Subcontinent: A Review

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Abstract

Climate change influences the occurrence, prevalence, and severity of plant pathogens. Global temperatures are predicted to rise by 2–4°C due to human activities and increased market globalization, coupled with rising temperatures, leads to a situation favorable to pest movement and establishment. Maize is an important crop after wheat and rice. Changes in rainfall distribution and temperature may result in temporary excessive soil moisture or water logging or drought in some maize producing areas leading to alterations in biotic stress factors. In Indian subcontinent warming trend in climate along the west coast, central, interior peninsula and northeast regions creates favorable conditions for diseases in maize like sorghum downy mildew (SDM) and Turcicum leaf blight (TLB). The decreasing trend of monsoon, seasonal rainfall in North India, Central India, parts of Gujarat and Kerala is suitable for post flowering stalk-rot (PFSR) which is gaining importance in maize. The outcome for any host-pathogen interaction under changing climate is not readily predictable. This review assesses the potential effects of climate change on maize pathogens and consequently on plant health. The evidence assessed indicates that climate change has already expanded pathogen's host range and geographical distribution increasing the risk of introduction of pathogens into new areas.

Keywords: climate change, maize diseases, Polysora rust, banded leaf and sheath blight, post flowering stalk rots

1. Introduction

Maize is one of the world's most widely produced and consumed cereal crops and contributes greatly to global food security. Currently 1147.7 million t is being produced jointly by over 170 countries from an area of 193.7 million ha with an average productivity of 5.75 t/ha [1]. Globally maize is being consumed as feed (61%), food (17%) and industry (22%). It has attained a position of industrial crop globally as 83% of its production in the world is used in feed, starch and bio fuel industries. Among the maize growing countries, India rank 4th in area and 7th in production, representing around 4% of world maize area and 2% of total production. In India during 2018–2019, the maize area has reached to 9.2 million ha [2].

India's production is 28.64 million t with productivity as 2.9 t/ha [3]. In India, maize is grown in two seasons, rainy (*kharif*) and winter (*rabi*). *Kharif* maize represents around 83% of maize area, while *rabi* maize correspond to 17% maize area. However, maize productivity is now threatened by global climate change [4] leading to increasing challenge by plant pathogens [5].

Climate change is affecting our agriculture due to 0.74°C average global increase in temperature in the last 100 years and atmospheric CO₂ concentration increase from 280 ppm in 1750 to 400 ppm in 2013 [6]. Throughout the twenty first century, India is projected to experience warming above the global mean. A warming trend has been observed along the west coast, in central India, the interior peninsula and Northeast India. The environment significantly, directly or indirectly, influences plants, pathogens, and their antagonists, which are strongly associated with differences in the level of losses caused by a disease, and environmental changes are often implicated in the emergence of new diseases [7]. Therefore, the changes associated with global warming may affect the incidence, severity of plant disease and influence the further coevolution of plants and their pathogens [8–12]. Plant diseases are one of the important factors which have a direct impact on global agricultural productivity and climate change will further aggravate the situation. Based on the prediction of Intergovernmental Panel on Climate Change [13], there would be an increase in 1–3°C in temperature in mid to high-latitude regions by 2050 which shows positive correlation with carbon dioxide (CO₂) concentration. The increase in CO₂ concentration and changes in rainfall pattern may have beneficial impacts on crop yields. However, moderate temperature increase (1–2°C) are likely to have negative impacts on yields of the major cereals in low-latitude regions. The regional distribution patterns of diseases getting modified as per the changes of climatic factors. On the other hand, pathogens also have the capacity to adapt to warmer conditions [14, 15]. Resistance of a disease of crop cultivars can be altered in future as per the changing situation of temperature/humidity [16, 17]. The increase in temperature and atmospheric carbon dioxide levels causes physiological changes in plants that result in increase in intensity of crop diseases. Warming may cause shifts in agro-climatic zones in which host plants migrate into new areas resulting in the emergence of new disease complexes.

A plant disease occurs only in association of a virulent pathogen, susceptible host in the presence of favorable environment [18]. A susceptible host will not be infected by a virulent pathogen if the environmental conditions are not conducive for disease, hence suitable environment is an important factor to cause disease. Therefore, the climatic condition has the potential to modify host physiology and resistance resulting into the alteration of rate and stage of pathogen. The development of plant disease is highly influenced with the environmental conditions like rainfall, relative humidity (RH), temperature and sunlight. Changes in these factors under climate change are highly likely to have an impact on the prevalence of diseases and emergence of new diseases in new area.

The impact of climate change are consistently negative for four major maize producers, together responsible for two-thirds of global maize production—United States, China, Brazil and India. The rising temperature affects flowering and leads to pests and disease build-up with significant influence on crop yield along with other parameters like soil, seed, fertilizers and agronomic practices. Maize being the third most important and widely distributed crop, can be grown in tropics, sub-tropics and temperate regions up to 50°N and S from the equator to more than 3000 meters above sea level under irrigated to semi-arid conditions.

In Indian subcontinent majority of population, depends on climate sensitive sector i.e., agriculture, forestry and fishing for livelihood and the problem of food security in our country, is very alarming and this should be addressed timely otherwise

it will become more acute. Nearly one third of the population is estimated to be absolutely poor and one half of all children are malnourished in one way or another and it is going to be very difficult to ensure food security under the changing climate for the country [19]. In India 28% of the total maize produce is directly consumed as human food while 59% for poultry and animal feed, 12% for starch and dry milling and about 1% as seed. Diversified uses of maize in starch industry, corn oil, baby corns, popcorns, etc., and potential for exports has added to the demand of maize all over world. In present climate change scenario we can go for maize cultivation as being C₄ plant more suitable crop as it assimilates more CO₂ than C₃ plants. It utilizes half the quantity of water as compared to rice in *kharif* season. It is expected that the demand for maize will be double in developing world by 2050 and it will be the crop with the greatest production globally 2025 [20]. The productivity of maize is being affected adversely in present climate changing scenario, as it has direct impact on the occurrence and severity of diseases in pre and post-harvest stage in maize, which will have a serious impact on our food security. Indian subcontinent is prone to diseases like foliar diseases, ear rot and stalk rots caused by fungi and bacteria. Some economically most important diseases and major threat to the potential yield of maize are Turcicum leaf blight (TLB), Maydis leaf blight (MLB), banded leaf and sheath blight (BLSB), post flowering stalk rots (PFSR), common rust, Polysora rust, downy mildews, Pythium stalk rot (PSR) and bacterial stalk rot.

2. Present status of maize diseases in changing climatic situation

India, being a very large country, has much diversity in soils and climatic condition. Maize is grown in a wide range of environments, extending from extreme semi-arid to sub-humid and humid regions, in wet, hot climates, it has been said to thrive in cold, hot, dry or wet conditions. The impacts of climate change will vary regionally, therefore mitigation action is required immediately to limit atmospheric impact and accordingly there is a need for future studies on models which can forecast the severity of important pathogens of maize in pre-harvest and post-harvest conditions. Simultaneously, disease management strategies could be implemented in climate changing scenario with amalgamation of new strategies for sustainable food security.

In addition to climatic and atmospheric factors, the future maize productivity is dependent on climate change, as they are important for alterations in biotic stress factors [21]. Therefore, there is a risk that future maize grain yield potential might be over or underestimated if future altered effects from biotic stress factors such as diseases are ignored [22]. There is warming trend in the climate along the west coast, in central India, the interior peninsula and Northeast India [6]. However, at the regional level, increasing monsoon, seasonal rainfall has been found along the west coast, northern Andhra Pradesh and northwestern India, that creates favorable conditions for certain diseases like Polysora rust, sorghum downy mildew (SDM) and TLB, whereas excessive soil moisture or water logging is predisposing condition to bacterial stalk rot in maize. Trend of decreasing seasonal monsoon rainfall has been observed over eastern Madhya Pradesh, North India, Central India, some parts of Gujarat and Kerala such condition is suitable for post flowering stalk rot which is also gaining importance.

Disease can fluctuate according to climate variation and this relationship between day to day weather and disease development is used for disease forecasting and managing epidemics [23, 24]. Widespread occurrence of particular disease in a particular time is in climax when environmental conditions are conducive for disease development resulting in epidemics. However, increase in yield of winter maize indicates favorable changes in climate for its growth and suitability of the

S no	Disease & their distribution	Affected part	Pathogen	Favorable condition	Unfavorable condition for disease
1.	Seed and seedling blights	Seedlings	Species of <i>Fusarium</i> , <i>Rhizoctonia</i> , <i>Pythium</i> <i>Penicillium</i> , <i>Aspergillus</i> , <i>Acremonium</i> , <i>Cephalosporium</i> etc.	Cool (10–15°C) moist conditions, slow germination favors disease. Disease severity is affected by planting depth, soil type, seed quality, mechanical injury to seed etc.	Severity of disease reduces with the rise of temperature
2.	Turcicum leaf blight (TLB)	Foliar part at knee high stage	<i>Exserohilum turcicum</i> (Pass) Leon. & Sugs	Overwinters as mycelium and chlamydospores on debris and sporulate when cool/moderate temp. (18–27°C) coupled with high humidity.	Dry and slightly high temperature reduces disease intensity
3.	Maydis leaf blight (MLB)	Foliar part at knee high stage	<i>Drechslera maydis</i> Niskado Syn. <i>H. maydis</i>	Warm & humid conditions temp (20–32°C) and damp condition. Severe infection causes a premature death and up to 83% yield reductions.	Dry, sunny periods are unfavorable for the disease
4.	Common rust (C. rust)	Foliar part	<i>Puccinia sorghi</i> Schw	Temperate environments at tem (15–20°C) with high humidity. Uredinospore can survive at 4–30°C.	Dry weather and high temperature < 30°C is unsuitable for disease
5.	Polysora rust (P. Rust)	Foliar part	<i>Puccinia polysora</i> Underw.	Favored by high humidity at 24–28°C coupled with extended periods of dew or high humidity favors disease.	Dry weather and high temperature < 30°C is unsuitable for disease
6.	Brown stripe downy mildew (BSDM)	Foliar part	<i>Sclerophthora rayssiae</i> var. <i>zeae</i> Payak and Renfro	Favored by cool and high humid conditions coupled with dew droplets. Oospores can be viable for four years. Warm soil temperatures (28–32.5°C) favors disease.	Dry weather and high temperature < 35°C is unsuitable for disease
7.	Sorghum downy mildew (SDM)	Foliar part & in severe case tassels	<i>Peronosclerospora sorghi</i> (Weston & Uppal) Shaw	Suitable temp. for sporangia production, 17–29°C, and 21–25°C coupled with high humidity and free water droplets on leaf surface.	Dry weather and high temperature < 32°C is unsuitable for disease
8.	Rajasthan downy mildew (RDM)	Foliar part	<i>Peronosclerospora hetropogoni</i> Siradhana <i>et al.</i>	Prevails in hot and humid with temp ranges from 22.9 to 28.6°C and RH > 85.0%.	Temp. > 20.0°C and < 30°C with dry weather is unfavorable for disease
9.	Brown spot	Leaf & mid rib	<i>Physoderma maydis</i> Miyake	High humidity with temp. 23–30°C and continuous rainfall is favorable for the disease.	High temp. < 30°C with less humidity is unfavorable
10	Banded leaf and sheath blight (BLSB)	Started from lower leaf & whole plant	<i>Rhizoctonia solani</i> f. sp. <i>Sasakii</i> Exner	Hot and high humidity are highly favorable condition. Suitable temperature for infection is 15–35°C.	Dry weather with high temperature is unfavorable condition

S no	Disease & their distribution	Affected part	Pathogen	Favorable condition	Unfavorable condition for disease
11.	Curvularia leaf spot	Leaf area	<i>Curvularia lunata</i>	Prolonged leaf wetness for several consecutive days. Disease occurs at temperatures, 25–35°C with 90% relative humidity.	Extreme dry weather with high temperature is unfavorable
12.	Pythium stalk rot (PSR)	Stalk at pre flowering stage	<i>Pythium aphanidermatum</i> (Eds) Fitz	High rainfall and water logged in the field with high humidity (80–100%) with high temperatures (25–35°C) favor disease severity. Free water is essential for sporangia germination.	Dry and cool weather is unfavorable for disease development
13.	Bacterial/Erwinia stalk rot (ESR)	Stalk at pre flowering stage	<i>Erwinia chrysanthemi</i> p. v. <i>zeae</i> (Sabet) Victoria, Arboleda & Munoz	High humidity, stagnant water logged condition coupled with high temperature (30°C and above).	Cool and dry weather is unfavorable for the disease
14.	Post flowering stalk rots (PFSR)	Stalk at post flowering stages	a. <i>Macrophomina phaseolina</i> b. <i>Fusarium moniliforme</i>	Warm soil temperature (30–40°C) with low moisture conditions favors disease.	Low soil temperature and wet climate is unfavorable for disease
15.	Late wilt	Stalk at post flowering stages	<i>Cephalosporium maydis</i> Samara, Sabeti & Hingorani	In India, maximum disease occurred at a constant 24°C or when the temperature varied naturally between 20 and 32°C.	Constant high temperature > 36°C is unfavorable.

Table 1.
Major disease of maize in Indian subcontinent.

region for its cultivation. Climate change is likely to lead to increase in water scarcity in the coming decades [25, 26]. If changes in atmospheric composition and global climate continue in the future as predicted, there may be chances of relocation of maize crop and relocation with occurrence of new diseases and with impact in terms of crop loss. In present scenario, the major disease of maize in Indian Subcontinent along with distribution is summarized in **Table 1**.

3. The effect of climate change on change in disease pattern scenario

Climate change modify characteristics of the pathogen, the environment, and the host, which can then drive the emergence of novel, uncommon, or adapted pathogen species, as a result there is a major shift in disease pattern during the past years as major diseases like *Pythium* stalk rot and bacterial stalk rots, which are gradually becoming diseases of lesser economic importance due to change in climate availability and use of sources of resistance in the development of new hybrids and varieties. However disease like *Turcicum* leaf blight used to occur in temperate region, now it is very common in tropics where winter maize is popular like Bihar, eastern UP, Karnataka etc., where low temperature in cropping season is favorable for the fungus. The disease of minor importance became increasingly severe and speculated epidemic proportion in coming years. In early 1960s the diseases like banded leaf and sheath blight, *Polysora* rust and pre harvest cob rots were considered as a disease of minor importance, however with the passes of time and changing weather condition, these diseases being arisen as major diseases not only in India but other maize growing countries of Asian region.

4. Emergence of minor diseases as major diseases due to climate change in Indian subcontinent

4.1 Banded leaf and sheath blight

Banded leaf and sheath blight (BLSB, **Figure 1**) is now become increasingly severe and economically important disease of maize during last three decades or so. During the past it was reported from Sri Lanka by [27] under the name 'Sclerotial' disease for the first time.

That time it was considered as disease of minor importance till it emerged in an epidemic form in the cooler low hills and foot hills region of Himalayas like in the district of Mandi in Himachal Pradesh. In India, this disease was recorded from Tarai region of Uttar Pradesh, for the first time in 1960 [28]. The optimum temperature for this disease is 28°C and high relative humidity (88–90%) in the first week of infection that favors rapid disease progress. However the disease development and spread becomes slow when relative humidity goes below 70% [29]. Additionally, high crop densities favors disease severity. In changing climate scenario the elevated temperature and CO₂ concentration are posing higher threat perception of BLSB and becoming severe and now it is considered as a major disease not only in Indian subcontinent but also in many part of tropical Asia wherever maize is grown in warm and humid conditions.

4.2 *Polysora* rust of maize

Polysora rust (**Figure 2**) also known as southern rust caused by *Puccinia polysora* is an important disease in tropical areas. It has been noticed in many parts



Figure 1.
Banded leaf and sheath blight.



Figure 2.
Polysora rust.

of the world, and it is observed in recent past from the peninsular India (coastal districts of Andhra Pradesh during winter and in Karnataka and Tamil Nadu during rainy season) on certain maize cultivars in Mysore district recorded in 1991 by [30]. The incidence of *P. polysora* has taken a heavy toll in majority of cultivars grown in Karnataka namely Mysore, Mandya, Hassan, Kolar, part of Coorg, Shimoga and Chitradurga district [31]. Disease is favored by wet/humid weather condition for infection and disease development at 12–27°C [32, 33]. Rain drizzle or even heavy dews allow spread of disease [34]. The maximum cardinal temperature for preceding infection period of *P. polysora* was estimated at 42°C and

for the infection period the value ranges from 27–32°C [35–37]. In future, milder winter in temperate areas will increase diseases. Plant biomass and the concentration of CO₂ is positively correlated, however it is regulated by the other factors like availability of water and nutrients, competition between weeds, pest and pathogens. Development of biotrophic fungi such as rust and other foliar diseases on plants, promotes high concentration of carbohydrates in the host tissues. It is therefore assumed that the severity of Polysora rust and common rust will be increased in the pocket areas where is prevalence of elevated CO₂.

4.3 Post flowering stalk rot (PFSR)

The disease was first reported in 1957 from Mount Abu area of Rajasthan in India that time the disease was in traces. In recent years the severity of the disease has been increased and become an important disease, since then maize workers are quite concerned with this disease. The disease (**Figure 3**) is favored by high soil temperature (30°C–42°C) coupled with dry climatic condition. The fungi *Macrophomina phaseolina*, *Fusarium verticilloides* and *Cephalosporium* are collectively responsible for this disease. These soil-borne pathogens are favored by early spring climatic conditions when dry and slightly hot condition prevails, therefore the disease severity increases in Indian subcontinent when temperature start rising in dry weather condition. The disease is more common in hot and dry growing conditions [38]. The water stress at flowering and high soil temperature increases disease severity [39].

4.4 Curvularia leaf spot (CLS)

This is a foliar disease and caused by *Curvularia lunata*, (**Figure 4**) also common in many plant species in tropical, subtropical as well as sometimes in temperate regions. Earlier in 2000, in Indian subcontinent this disease observed in traces from most of the places. Now a days this disease (**Figure 5**) recorded in severe condition from some pockets of Rajasthan from Uttarakhand (Haridwar, Dehradun and Kashipur). Polysora rust and Curvularia leaf spot (CLS) are emerging as a potential threat in Karnataka & Rajasthan respectively. Hot and humid climate favor the development of disease during flowering to grain filling stage.



Figure 3.
Field view and symptoms of PFSR.



Figure 4.
CLS.

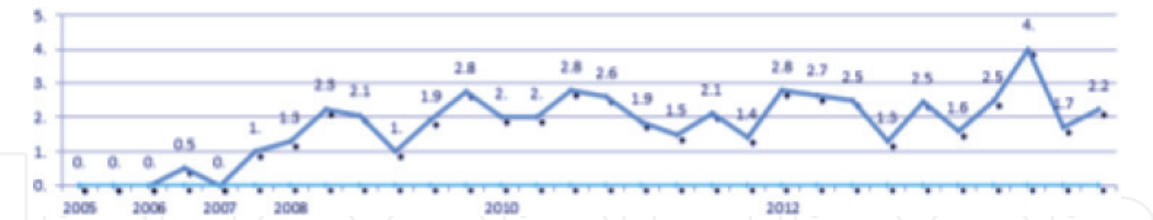


Figure 5.
Disease spectrum of *Curvularia* leaf spot from year 2005–2014 (source: [40]).

5. Declining of major diseases of maize with time due to climate change

5.1 Pythium stalk rots

During the past, in early 1980s *Pythium* stalk rot (**Figure 6**) was in severe condition and use to cause extensive damage to the crop in the lowlands of Indian subcontinent. This disease caused by *Pythium aphanidermatum*, temperature and relative humidity are the main factors to determine severity of the disease. Most favorable condition for the disease development is high temperature range 30–35°C with relative humidity of 80–100%. In past decades the disease was considered as major disease, now over the year passed the incidence/occurrence of the disease reduced [40] due to altered precipitation, various changes in this pathogens may occurred



Figure 6.
Pythium stalk rot.

which in general include coincidence of pathogen lifecycle events with host plant stages and/or natural antagonists/synergists. Therefore regional precipitation and distribution patterns led to unfavorable condition for development of sporulation for secondary infection. However, projected warmer and drier summers may hinder most fungal diseases, and finally slow down or completely inhibit disease progress of other foliar diseases. As a result the regional distribution patterns of this diseases may be modified and stated to infect *rabi*/winter maize due warming effect.

6. Potential climate change effects on ear rots and related mycotoxin contamination

Mycotoxins contamination in pre and post-harvest maize is most important and the attention focused this important disease in terms of their presence and toxicity, including variety of toxins viz., aflatoxins, ochratoxins, fumonisins, trichothecenes, and zearalenone, are secondary metabolites produced by various fungi. *Aspergillus flavus* and produces aflatoxin, *Fusarium verticillioides* produces fumonisin, and produces deoxynivalenol and zearalenone [41, 42]. Among these toxins, aflatoxin is the most important in terms of health risk and high toxicity produced by *A. flavus* and by *A. parasiticus*, which are most prevalent in tropical and subtropical regions where high temperature and drought conditions prevailed. Aflatoxins are highly carcinogenic, produced by *A. flavus* and *A. parasiticus* [43].

Aflatoxins are a group of 20 related fungal metabolites, the major ones are aflatoxin B₁ B₂ G₁ and G₂. Among them AFB₁ is the most potent naturally occurring liver carcinogen [44]. Ingestion of aflatoxins in contaminated food or feed results in aflatoxicosis, while long-term exposure of moderate to low concentration of causes chronic toxicity and immune system disorders [45, 46]. Aflatoxin contributes to significant economic losses in maize which prevents commodities from meeting international standards governing agricultural trade and food safety. High temperatures and low rainfall favors the production of *A. flavus* conidia and their dispersal.

Several studies reported that the high soil temperature and drought stress are positively correlated with aflatoxin contamination and increased incidence of aflatoxigenic strains or species [47–49]. The high temperature coupled with dry weather conditions favors growth, conidia formation and dispersal of fungi *A. flavus*. These factors are contributing to high concentrations of aflatoxins. Therefore these environmental factors has an important role in development of aflatoxin in maize [50–55]. High temperatures and low rainfall also favor production of conidia of *A. flavus* and their dispersal. The most important environmental influences on fumonisin risk are insect damage to grain and moisture stress in maize plants [56, 57].

The Indian subcontinent having land of diversity with diversified climatic condition. If hot humid weather prevailed at the time of critical stage of maize crop like North east, some part of western hills with limited sunshine hours at the maturity of the maize crop are predisposed condition to mycotoxin contamination. Sometimes due to unpredictable weather condition the *rabi* and *kharif* maize crop faces the same situation and ultimately spoiled due to mycotoxin contamination. Extreme dry condition at the time of flowering is also one of the predisposing factors to AFB₁ contamination. In Indian subcontinent there is extreme diversity in soils and climatic condition and maize is grown in a wide range of environments, extending from extreme semi-arid to sub-humid and humid regions. Mold inoculums that occur naturally throughout the environment in all over the world. Although maize is grown mainly in wet, hot climates, it has been said to thrive in cold, hot, dry or wet conditions.

Hence, in future there are more chances of mycotoxin contamination due to rise in temperature and unpredictable rainfall in Indian subcontinent. Maize crop from tropical and/or sub-tropical areas are affected more frequently and severely by aflatoxin contamination, but temperate areas could be of increasing importance due to climate change. In the near future, there is reason to believe that increased climate variability associated with climate change trends may result in higher pre-harvest levels of mycotoxins in Indian subcontinent, posing both economic and health risks for maize crop and food security. The occurrence of aflatoxin in maize is strongly influenced by weather during and after the growing season. Cool, wet growing seasons may delay grain maturity in maize, and result in mold contamination in the field such cobs/grains are prone to develop aflatoxin contamination. Climate change is likely to lead to an increase in hot and dry spells; this implies an expectation of increased risk of aflatoxin contamination. Insect damage of grain and moisture stress in maize favor fumonisin contamination of maize [56, 57]. The optimal conditions for fumonisin production are a temperature close to 30°C and high water activity [34, 58]. It is therefore important to determine impacts of climate change to future food security, in terms of mycotoxin-related economic and health risks. If current climate patterns continue in this century, aflatoxin and fumonisin concentrations in maize will likely increase, more aggressive isolates of *F. graminearum* occur. The overall effect may likely be increased economic and health risks, particularly due to increased aflatoxin concentrations in maize.

7. Critical analysis for future impact

7.1 Effect of CO₂ concentration

The concentration of CO₂ is positively correlate with plant biomass. However the process is regulated by the factors like availability of water and nutrients, competition between weeds, pest and pathogens. When plant is infected with biotrophic fungi such as rust and other foliar diseases, at that time the concentration of

carbohydrates in the host tissues is increased. It is therefore can be assumed that the high concentration of carbohydrates in the host tissue promotes the development of biotrophic fungi such as rust [59]. Hence, there may be chances of increase in severity of Turcicum leaf blight, Polysora rust as well as common rust in the pockets where elevated CO₂ is prevailed.

7.2 Effect of temperature

Changes in temperature may favors the development of dormant pathogens, warmer mean air temperatures in India in early springs especially during winter, favors post flowering stalk rots in winter maize. However, warmer and drier summers may hinder spread of most fungal pathogens, and finally slow down or completely inhibit disease progress of foliar diseases like Turcicum leaf blight, Maydis leaf blight, banded leaf and sheath blight and downy mildews etc., resulting in the regional distribution patterns of these diseases is going to be modified and foliar diseases started to infect *rabi*/winter maize due to warming effect. Pathogens also have the capacity to adopt warmer conditions [14, 15] and temperature/humidity dependent on disease resistance of crop cultivars may be altered in the future [16, 17]. Therefore TLB prevalent cooler and temperate region, but now common in tropical in wither maize. Stalk rot diseases are anticipated to increase in hot and dry areas in summer crops as well as in winter crops of Bihar, Rajasthan, Andhra Pradesh and Karnataka due to rise in temperature in early springs at the time of flowering. Increasing trend in cultivation of *rabi*/winter maize in various states as a result host is available throughout the year round in major maize growing areas leads to multiplication of inoculum of soil borne disease which is an important factor for increasing the extent of crop losses. Therefore, the total number of diseases may not change dramatically, but there might be some changes in relocation and diversification of maize diseases in future range in India [60] also considered stalk rots of maize, particularly related to sweet corn under temperate climatic conditions. The importance of *Fusarium*/*Gibberella* stalk rots may increase in sweet corn, whereas the future importance of *Pythium* stalk rot might decrease.

7.3 Impact on ear/cob rots

Ear rots is associated with mycotoxin contamination with negative human and animal health consequences truly an alarming issue. The potential risk may be expected to increase in a future climate change scenario. If, temperature, drought, and insect injury in subtropical and tropical regions would increase, an increase the incidence of *Aspergillus flavus* and *F. verticillioides* may occur, consequently mycotoxin contamination will increase. If hot humid weather prevailed at the time of critical silking stage of maize crop in North east, some part of Western hills with limited sunshine hours at the maturity of the maize crop are suitable condition to mycotoxin contamination. Extreme dry condition at the time of flowering is also one of the predisposing factors to AFB₁ contamination. Although maize is grown mainly in wet, hot climates, it has been said to thrive in cold, hot, dry or wet conditions. Hence, in future there are more chances of mycotoxin contamination due to rise in temperature and unpredictable rainfall in Indian subcontinent.

8. Suggestions for new management strategies

In present climate changing scenario, the choice of crop management practices should be based on the prevailing situation. It is therefore important that

weather-based disease monitoring, inoculums monitoring, should be done time to time. There is an urgent need to develop maize disease forecast module.

8.1 Rescheduling of crop planting

The changes in global climate changes have direct impact on temperature and rainfall pattern may result in shrinking of crop growing seasons with extreme problems of diversification and relocation of maize diseases. Therefore, the rescheduling crop planting dates as per suitability to maize crop in changing environment scenario is needed urgently. Maize disease management strategies needs to be changed in accordance with the projected changes in disease incidence and extent of crop losses in view of the changing climate.

8.2 Sensitization of farmers/stakeholders

In view of the impacts of future climate change on sustainability and productivity of maize, there is an urgent need to sensitize the stakeholders, farmers/growers, extension workers, about the diversification of major diseases at zonal and regional level and management strategies to cope with the situation. Sensitization of farmers, stakeholders, industries and exporters about the importance of mycotoxin/aflatoxin and their management strategies is also needed. This can be achieved through organization of awareness campaigns, training and capacity-building programmes, development of learning material and support guides for different risk scenarios.

8.3 Breeding climate-resilient varieties

In order to minimize the impacts of climate and other environmental changes, it will be crucial to breed new varieties for improved resistance to abiotic and biotic stresses such as resistant to cold and heat stress, as well as for drought and water log condition. Considering erratic monsoon late onset and/or shorter duration of winter, there is chance of delaying and shortening the growing seasons for certain *rabi*/cold season crops.

8.4 Screening of pesticides with novel mode of actions

There is a need of screening of nano-pesticides ingredient against important maize diseases. The application of zinc oxide nano particles against disease powdery mildews has antifungal activity [61, 62]. The salicylic acid is associated with plant defense responses which enhance plant vigor and abiotic stress tolerance, independent of their insecticidal action [63–67]. This gives an insight into investigating role of insecticides in enhancing stress tolerance in plants.

9. Conclusion

As the climate continues to warm in response to further greenhouse gas emissions, high temperature extremes will become hotter and cold extremes will become less cold. The amount of future global warming is closely related to cumulative CO₂ emissions that weakens our ecosystems and may support pest and disease dispersal and incidence. It has impact on plant physiology and structure, as a result vulnerability of plants towards pests and diseases may increased. Degrading ecosystems and water scarcity can affect food security and livelihoods and contribute to

economic crises, forced migration and conflicts, pest and disease risks also. Indian subcontinent, being tropical area, is more challenged with impacts of impending changes. Dealing with the climate change which is a tedious task due to its complexity, unpredictability, uncertainty and differential impacts over time period and places. However impact of climate change on crop production mediated through changes in populations of insect-pests need to be given careful attention for planning and devising adaptation and mitigation strategies for future pest management programmes. There is a need to combine both durable multiple-disease and multiple-insect resistance, using gene transfer and genome editing technology would greatly help against the pathogens and insect pests where no native resistances are available in elite breeding materials. Also steps to be taken to increase our adaptive capacity urgently so that the support to adaptation research, developing regionally differentiated contingency plans for temperature and rainfall related risks and also seasonal weather forecasts and their applications for reducing risks can be taken care. Evolvement of new land use systems, including heat and drought tolerant varieties, adapted to climatic variability and climate change. By implementing international standards for phytosanitary measures, may help countries to prevent the introduction and spread of harmful pests and to preserve biodiversity. Preserving biodiversity may helps to improve plant resilience and mitigate the impact of climate change on plant health.

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