Annals of Plant and Soil Research 20(1): 86–98 (2018)

Future of crop diseases and Climate change in Bundelkhand Agro-climatic Zone of Madhya Pradesh: A review

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Received: July, 2017; Revised accepted: December, 2017

ABSTRACT

The shift in the monsoon causes delay in sowing which in turn delays harvesting and in drier conditions the potential yields would be lesser. The incidence of the disease is determined by temperature and the occurrence of wet weather. The pathogens which causing diseases on crops at favorable less temperature and high humidity will be reduced because pathogen could not be built disease on the absence of favorable most condition of areal parts i.e. most of bacterial and some fungal pathogens while high temperature and high humidity diseases i.e. root rots, anthracnose, Fusarium *ear blight in wheat. The viral diseases are mostly disseminated by insect vectors so high temperature and high humidity will be favorable condition for their multiplication of many generation leading to extending the viral diseases. If climate changes bring increased moisture and warmer temperatures to the region, it is likely to exacerbate epidemics and prevalence of leaf fungal pathogens and overwintering population of pathogens.*

Key words: *Climate change, Plant Diseases, Bundelkhand region*

INTRODUCTION

Climate change is a global phenomenon and has varying impacts on each and every one of us. Significant climate shifts have already been observed over the past century (Kothawale *et al.*, 2010.). The 1901 to 2007 period has seen a significant warming trend of 0.51ºC per 100 years in India's annual mean temperature. During the same period, India's maximum and minimum temperatures increased at a rate of 0.71ºC and 0.27ºC per 100 years, respectively. In rural areas of India, over 700 million are directly dependent on climate-sensitive sectors like agriculture, forests, fisheries and natural resources such as water, fodder and biodiversity for their livelihoods (Satapathy, 2011). The studies were carried out keeping in view the estimated losses and to find out the integrated management strategies against emerging crop disease and intervention of new technologies as per the climate change.

Development of diseases in plants

A plant becomes diseased when it is attacked by a pathogen. If at the time of contact of a pathogen with a plant, and for some time afterward, conditions are extreme such as, too cold, too hot, too dry, etc., the pathogen may not be able to attack, or the plant may be able to resist the attack and therefore, despite of tow being in contact host-plant interaction, no disease would develop. Apparently then, a third component, namely a set of environmental conditions within a favourable range, must also occur for disease to development. Each of the three components can display considerable variability; however, as one component changes it affects the degree of disease severity within an individual plant and within a plant population Similarly, the pathogen may be of a more or less virulent race, it may be present in small or extremely large numbers, it may be in a dormant state, or it may require a film of water or a specific vector. Finally, the environment may affect both the growth and the resistance of the host plant and also the rate of growth or multiplication and degree of virulence of the pathogen, as well as its dispersal by wind, water, vector and so on (Singh,1995).

The interactions of three components of disease have often been visualized as a triangle generally referred to as the “disease triangle.” Each side of the triangle represents one of the three components. The length of each side is proportional to the sum total of the characteristics of each component that favour disease. if the plants are susceptible, at a susceptible stage of growth, or planted densely, the host side would be long and the potential amount of disease could be great. Similarly, the more virulent, abundant and active the pathogen, the longer the pathogen side would be and the greater the potential amount of disease. Also, the more favorable the environmental conditions that help the pathogen (e.g., temperature, moisture, and wind) or that reduce host resistance, the longer the environment side would be and the greater the potential amount of disease. If the three components of the disease triangle could be quantified, the area of the triangle would represent the amount of disease in a plant or in a plant population. If any of the three components is zero, there can be no disease. The disease triangle is also represented as a triangle with the words of the three components (host plant, pathogen, environment) placed at the peaks of the triangle rather than along its sides (Agrios, 2005).

Factors governing epidemic

Susceptibility of the host Plants: The ability to combat disease which manifests itself as susceptibility or resistance: e.g., early leaf spot(*Cercospora arachidicola*) and late leaf spot of groundnut (*Phaeoisariopsis personata*) and loose smut of wheat (*Ustilago nuda tritici*)

Aggregation and distribution of susceptible hosts: e.g., late leaf spots of groundnut in Gujarat and Maharashtra States during 1912-1913.

Introduction of new host (s): e.g., Bacterial blight (*Xanthomonas axonopodis pv. malvacearum*) and grey mildew (*Septoacylindrium gossypii*)

Introduction of new collateral or alternate hosts: e.g., Grass hosts (collateral hosts) for *Sclerospora sacchari*, *S. philippinensis* (downy mildews), *Pyricularia oryzae* (rice blast), *Ustilago scitaminea* (sugarcane smut) and blister rust of pine (*Cronartium ribicola*)

Introduction of new pathogen: eg. Late blight of potato caused by *Phytophthora infestans*, Fire blight (*Erwinia amylovora*), Coffee rust (*Hemileia vastatrix*)

Presence of aggressive strain of the pathogen: e.g., *Puccinia graminis tritici* (black rust of wheat)

High birth rate of the pathogen: e.g. Wheat stems rust (*Puccinia graminis tritici*)

Low death rate epiphytotics may also be caused by low death rate: The vegetative propagation (corms, setts, tubers, etc,). Here the buildup of epidemics is comparatively low compared to high birth rate diseases.

Easy and rapid dispersal of the pathogen: Like wind, water, insects, mites and nematode

Adaptability of the pathogen: Pathogens have the capacity to adapt to adverse conditions

Effects of climate change on fungal pathogens

Elevated CO_2: The enhancement and reduction in disease severity under elevated CO_2 has been reported e.g., development of rusts, mildews, leaf spots and blights. Survival of saprophytes will be increased higher winter temperature could increase pathogen survival on over-wintering crop residues and increase the amount of initial inoculation available for subsequent infection. For example, reduction in the rate of primary penetration of *Erysiphe graminis* on barley and a lengthening of latent period in *Maravalia cryptostegiae* (rubervine rust) has been observed under elevated CO_2. The second important effect is an increase in the fecundity of pathogens under elevated CO_2. Following penetration, established colonies of *Erysiphe graminis* grew faster and sporulation per unit area of infected tissue was increased several-fold under elevated CO_2.

Elevated temperature: Temperature change might lead to appearance of different races of the pathogens hitherto not active but might cause sudden epidemic. Change in temperature will directly influence infection, reproduction, dispersal, and survival between seasons and other critical stages in the life cycle of a pathogen.

Elevated levels of atmospheric pollutants (ozone and nitrous oxide): Most air pollutants indirectly influence diseases through their effect on host. Ozone induces reactions similar to those normally elicited by viral and other pathogens. Of the 49 bacterial and fungal pathogens examined, exposure to elevated ozone concentration enhanced disease in 25, did not affect 10 and reduced 14. Plants appear to be less sensitive to nitrous oxide, however, higher concentrations can cause water-soaked lesions, which soon turn brown. Ozone and nitrous oxide injury on plants in turn may add new problem to pathologists in diagnosis.

Acid rain: Most studies on the effect of acid rain were done with simulated acid rain since it is not easy to establish experiments under field conditions. In first year of experiment no effect of acid rain has been observed on any of four pathosystems: alfalfa leaf spot, peanut leaf spot (PLS), potato late blight (PLB), and soybean brown spot. In the second year, PLS severity decreased with increasing acidity and the dose response was linear, PLB severity showed a curvilinear response to acid rain.

Elevated ultraviolet: Some strains of *Septoria tritici* are more sensitive to UV-B than others and *S. nodorum*, as a species, is more sensitive than *S. tritici*. UV-B radiation can modify the relative composition of phylloplane organisms, such as pink and white yeast. Continued exposure to enhanced UV-B radiation lowers the level of antifungal compounds in foliar parts. UV-B has been shown to reduce tolerance of rice to blast (*Pyricularia grisea*) and although higher UV-B reduced plant biomass and leaf area; there was no increase in blast severity.

Effects of climate change on viral pathogens

Most plant viruses are transmitted by vectors and majority by insects. Particularly aphids are expected to react strongly to environmental changes because of their short generation time, low developmental threshold temperatures and ability to survive mild winters without winter storms. An increase in the number of insect vectors will inevitably lead to a higher risk for viral infection of plants. The aphid transmissible complex of barley yellow dwarf viruses in cereals and potato virus Y in potato are amenable to show potential effects on the prevalence of infection because of climate change. In mild winters, high intensity of aphid movement during spring and a high frequency of PVY-infected potatoes have been reported. The severity of viral diseases is determined in large part by the amount of inoculums and the time of infection. The amount of virus inoculum is influenced by winter survival of its hosts. For some viruses, higher temperatures also cause more severe symptoms development. Aphids are expected to have increased survival with milder winter temperatures, and higher spring and summer temperatures will increase their development and reproductive rates and lead to more severe disease. Milder winters are also expected to increase survival of alternate weed hosts of viruses. Increases in frequency and intensity of summer storms with high winds, rain, and hail will increase wounding of plants and result in increased transmission of viruses by mechanical means. Therefore, with predicted changes in climate, viral diseases of plants are expected to increase in importance.

Effects of climate change on bacterial pathogens

Milder and shorter winters are expected to have little effect on soil-borne bacterial pathogens; however, survival of host or debris-borne and vector-borne primary inoculum is expected to increase. Soil-borne, bacterial plant pathogens, such as *Agrobacterium tumefaciens*, may build up their populations in host plants and could be released into the soil where they can survive as primary inoculum in the next season. Host or debris-borne bacteria survive on and in host tissues. On perennial hosts, bacteria, such as *Erwinia amylovora* on apple, overwinter on infected host tissue, and primary inoculum is spread from host to host in the next season. On annual hosts, bacteria such as *Pseudomonas syringae* pv. *phaseolicola* may survive in host debris in soil or on the soil surface. Vector-borne bacterial pathogens, such as *Erwinia stewartii*, survive in insect vectors, and these vectors act as the source of primary inoculum in the next season.

Bacterial pathogens, such as *Pseudomonas syringae* pv. *tomato* and *Xanthomonas campestris* pv. *vesicatoria*, arise from infected seed and possibly also survive in debris, soil, and weeds. Bacteria are spread to their host plants mainly by water, usually in the form of rain splash, and insects. In humid, wet conditions, infected plant tissues can exude masses of bacteria that are spread from host to host by rain splash and insects. Therefore, the warmer drier summers expected with climate change should limit bacterial diseases. However, bacteria often enter hosts through wounds and the expected increase in frequency and intensity of summer storms with high winds, rain, and hail will increase wounding of plants and provide moisture for the spread of bacteria.

Impact of climate change on disease management

New dimensions of climate change may add extra uncertainty in management strategies for diseases caused by different pathogens. Delayed planting to avoid a pathogen may become less reliable. There may be problems with applications of biocontrol agents in the field because of the vulnerability of biocontrol agent populations to environmental variations and environmental extremes If appropriate temperature and moisture are not consistently available, biocontrol agent populations may reach densities that are too small to have important effects, and may not recover as rapidly as pathogen populations when congenial conditions reoccur. The classic disease triangle recognizes the role of physical environment in plant disease as no virulent pathogen can induce disease on a highly susceptible host if weather conditions are not favourable. Weather influences all stages of host and pathogen life cycles as well as the development of disease. Relationships between weather and disease are routinely used for forecasting and managing epidemics, and disease severity over a number of years can fluctuate according to climatic variation. The interrelated climate, land, water, vegetation and human activity determine the ever changing environment on earth. Increased emissions of CO_2 and other radioactively active gases from industrial and agricultural development are changing the atmospheric composition. There is a strong interactive link between the large-scale clearing of forests in the humid tropics for logging and intensive agriculture, which alters global carbon balance and climate, Global change, including a changing climate, is one of the most critical issues facing our future today as terrestrial and aquatic ecosystems which sustain life on Earth are being increasingly accepted by it. While the global population continues to rise, productive land resource, necessary for food production, shrinks. Uncertainties of climate change only magnify the challenge of increasing agricultural production to feed the expanding population

Bundelkhand Profile

Bundelkhand region comprising seven districts of Uttar Pradesh and six districts of Madhya Pradesh is one of the most backward regions of the country. Agriculture is the main source of livelihood of this region. The region being largely rain fed is perturbed with variable precipitation trends. Drought conditions are frequent to the region..However, due to large area of waste land, the percentage of land used for cultivation falls drastically, to around 50%.

Climate facts: The Bundelkhand region is marked by extremes of temperatures, reaching the mid to upper 40s centigrade during the summer months and dropping as low as 1 degree celsius in winter. It is a hot and semi-humid region. Minimum temperature varies from around 6-12^{0}C. Maximum temperature varies from 38-40^{0}C. Generally hottest days are in May and coldest days in December or January. The lowest temperature recorded is 0.6^{0}C.The rainfall distribution pattern is irregular, with approximately 90% of all rainfall in the region caused by the monsoon, falling from June to October. Average rainfall per year is 800-900 mm but most is lost due to runoff. July and August are the months of maximum rainfall, while November and April are the driest months of the year.

Land: Land use pattern in UP Bundelkhand and MP Bundelkhand districts is not significantly different from the rest of UP and MP, respectively. Around 7% of cultivable land in UP Bundelkhand and around 5% of cultivable land in MP Bundelkhand lies fallow in any year.

Water: Main rivers of Bundelkhand are Ken and Betwa, however, most rivers are dry or almost dry in summer. The lower courses of the rivers, towards the Yamuna, are in fertile alluvial plains, where the rivers cause much erosion and create ravines. Almost all the dams and reservoirs in Bundelkhand is built at the points where the upland meets the lowland; at these points, the rivers are narrow and the strata are hard.

Flora and Fauna: Babul (*Acacia nilotica*), Khair (*Acacia* *catechu*), Palas (*Butea monosperma*), Ber (*Zizyphus varieties*), Tendu (*Diospyros melanoxylon*), Mahua (*Madhuca Indica*), Semal (*Salmalia malabarica*) , Kardhai

(*Anogeissus pendula*), Salai (*Boswellia serrata*), Seesham (*Dalbergia sissoo*), Dhau (*Anogeissus latifolia*),Karaundha (*Carissa spinarum*) shrub and occasionally, Teak.Tendu and bamboo are found in small patches across Bundelkhand's rivers, including animal species known locally as Rahu, Bhadur, Mrigal, Tingar, Singahi, Mangur, Awda, Baam, Sooja, Sinni and Mahasir.

Distribution of operational holdings in Bundelkhand the marginal holdings accounted for 40% of all holdings .The percentage of small(20%) and semi medium (15%) holdings of 1-2 hectares and 2-4 hectares. The percentage of medium (24%) holdings is 4 to 10 hectares. The large holding farmers more than 10 hectares are only 1%.

Climate change trend in Bundelkhand: The average surface daily maximum temperatures, in the period 2030s is projected to rise by 1.8-2.0°C throughout Madhya Pradesh and the daily minimum temperature is projected to rise between 2.0-2.4°C during the same period. The eastern half of the state is expected to experience more warming than the western half. According to the MP-SAPCC, trends of average monsoon rainfall data from 1961 to 2002 indicate an inter-annual variability of average monsoon rain fall in the 41 year period. The rain fall trend shows a declining trend of rainfall for Madhya Pradesh.

The Bundelkhand region of the state given its fragile geophysical condition is significantly sensitive to climate change. (Hedger and Vaideeswaran, 2010).The average daily surface temperatures, in the period 2030s is projected to rise by 1.8-2.0°C throughout Madhya Pradesh and the daily minimum temperature is projected to rise between 2.0-2.4°C during the same period. The eastern half of the state is expected to experience more warming than the western half. According to the MP-SAPCC, trends of average monsoon rainfall data from 1961 to 2002 indicate an inter-annual variability of average monsoon rain fall in the 41 year period. The rain fall trend shows a declining trend of rainfall for Madhya Pradesh.

Trends of climate variability climate data from 1980 to 2005 period has indicated an increase in the mean maximum temperature in Bundelkhand region by 0.28ºC as compared to the baseline period of 1960-1990. Analysis of the simulated data generated by PRECIS Regional Climatic Model predicts that the temperature throughout the year is likely to be higher, in the range of 13.2 to 3.5ºC by mid century. The major precipitation season is expected to shift by one month (from July to August). The shift in the monsoon causes delay in sowing which in turn delays harvesting and in drier conditions the potential yields would be lesser. The climate science data developed by IITM revealed the climatic change exposure of Bundelkhand region 14 by the end of the century. The data was developed using the PRECIS model run over three time slices (2020s, 2050s and 2080s) using 1970s as base period.

The annual average surface temperatures are projected to rise by 1-2ºC, up to 3ºC and up to 5ºC towards 2020s, 2050s and 2080s, respectively, especially in the northern part of Bundelkhand. Projected rise in lowest minimum temperature is more as compared to rise in maximum temperature. In near future there may not be such change in seasonal monsoon rainfall, however the rainfall may increase by 5-10% towards 2050s and upto 20% towards 2080s with respect to base. July rainfall is likely to decrease but other months show an increase in rainfall by the end of the century. The number of cyclonic disturbances may decrease in future but the systems may be more intense with increase in associated rainfall by 10-15 mm. Moreover, the number of rainy days may decrease, but may be more intense in the future.

According to the report on drought mitigation strategies for UP and MP Bundelkhand by the Inter-ministerial Central Team, the region experienced a major drought in every 16 years during the 18th and 19th centuries, which increased by three times during the period 1968 to 1992 (Samra, 2008). Historically, the region was thickly forested but is now characterized by bare hilly terrain with sparse vegetation.

There were several manifestations of drought like, late arrival of rains, early withdrawal, long break in between, lack of sufficient water in reservoirs and drying up of wells leading to crop failure and even un- sowing of crops which ultimately curtailed livelihoods and led to some out-migration during 2000-2010 period. During the 2002-03 drought, all the 6 districts of MP Bundelkhand and 3 districts of UP (Banda, Hamirpur & Jalaun) were affected.

The most recent and continued period of poor rainfall recorded in Bundelkhand was during 2004-10, when below average and erratic rain was reported in most part of the region in all the years. Drought is the combined effect of meteorological (reduced rainfall) and hydrological (reduced available water supply) factors. In the UP part of Bundelkhand, drought became evident in 2004-05 with a 25% short fall in monsoon rains. The rainfall deficit increased further to 43% in 2006-07 and 56% in 2007-08, leading to severe (metrological) drought conditions. Bundelkhand drought in Mahoba, Jhansi and Chitrakut districts. Except Tikamgarh and Datia districts, drought in the Bundelkhand region of MP commenced from 2006- 07.

Agriculture: Traditionally, gram and wheat were the main rabi (post-monsoon) crops in most parts of Bundelkhand and jowar and bajra were the main kharif (monsoon) crops. A variety of coarse cereals like mandwa (ragi), kodon (*Paspanum scrobiculatum*), sawan (common millet), kakun (Italian millet) and kutki (Little millet) were also grown in the kharif season in some areas (Table I).

Table 1: Season wise major crops grown in Bundelkhand

Season (Period)	Crop group	Crops which are growing in Bundelkhan zone of MP and UP of India
Kharif (July to September)	Cereals	Sorghum, Maize ,Paddy, Pear millets and Small millets
	Pulses	Black gram, Green gram, Pigeonpea
	Oilseeds	Sesame, Soybean. Ground nut
	Spices	Ginger ,Turmeric
	Vegetables	Potato, Tomato, Brinjal, Chilli, Colocasia
	Fruits	Mahua, Ber, Citrus, Mango, Gauva, Aonla
Rabi (October to March)	Cereals	Wheat, Barley, Maize
	Pulses	Chickpea
	Oilseeds	Mustard, Linseed
	Spices	Coriander, Garlic, Onion
	Vegetables	Tomato, Brinjal, Potato Chilli, Colocasia
	Fruits	Papaya
Zaid (March to June)	Cereals	Maize
	Pulses	Green gram
	Oilseeds	Not specified
	Spices	Not specified
	Vegetables	Cucurbits
	Fruits	Not specified

Maize is seen only in Lalitpur, and sorghum accounts for a significant area under cultivation only in Hamirpur, Banda and Chitrakoot. Barley and bajra have become minor crops and cultivation of coarse cereals is seen only in patches in hilly areas inhabited by tribal groups. Rice is cultivated only in Banda, Chitrakoot, Panna and Damoh. Cotton has virtually disappeared from the region due to paucity of assured water and sugarcane is grown only in parts of Datia, Jalaun and Tikamgarh districts (Table 2).

Table 2: District wise main crops grown in Bundelkhand

District	Main crops (% of total cropped area under cultivation)
Jhansi	other pulses (47.37%), wheat (27%), gram (14.25%), groundnut (4.65%)
Lalitpur	other pulses (43.99%), wheat (25.51%), gram (12.89%), maize (7.49%)
Jalaun	other pulses (37.40%), wheat (29.89%), gram (15.93%)
Hamirpur	other pulses (29.48%), gram (28%), wheat (23.32%), jowar (9.68%)
Mahoba	other pulses (38.69%), gram (24.9%), wheat (22.48%)
Banda	wheat (32.48%), gram (26.57%), other pulses (11.64%), rice (14.40%), jowar (8.07%)
Chitrakoot	wheat (29.40%), gram (25.27%), other pulses (8.93%), jowar (11.32%), rice (7.17%), tur/ahar (5.49%), bajra (5.02%)

Several minor crops are grown in particular areas across Bundelkhand. Pan is grown in parts of Lalitpur and Mahoba district; the Mahoba pan is famous and commands a premium. Peppermint is grown in parts of Jalaun district, where several peppermint oil extraction units have also been set up. Medicinal plants like ashvagandha, white museli and chakori are grown by a few farmers in many districts. Fruits like amla, ber and guava are grown in a few pockets. Mangoes are grown near Banda town.

In Newari block of Tikamgarh, which is close to Jhansi town, vegetables and spices are grown on a large but unsustainable scale. Newari has one of the lowest water tables in the region though the Betwa flows through the block (Table 3).

Table: 3 District-wise main crops in Bundelkhand, Madhya Pradesh

District	Main crops in (% of total cropped area under cultivation)
Datia	Wheat (32.20%), other pulses (26.56%), gram (16.07%), sesame (5.36%)
Chhatarpur	Wheat (27.78%), gram (20.04%), other pulses (17.52%), sesame (8.20%), soybean (4.55%)
Tikamgarh	Wheat (25.48%), other pulses (19.13%), gram (8.0%), soybean (7.65%), sesame (5.92%), groundnut (4.77%), fodder crops (5.2%), rapeseed and mustard (4.59%)
Panna	Gram (32.86%), wheat (23.78%), rice (20.40%), other pulses (11.67%)
Damoh	Gram (41.82%), wheat (23.04%), rice (13.52%), soybean (11.36%), other pulses (7.49%)
Sagar	Gram (28.36%), soybean (23.75%), wheat (23.04%), other pulses (14.75%)

Source: *District-wise Land Use Statistics, Ministry of Agriculture, Government of India, May 2008. Percentages derived from absolute figures. Total cropped area includes area cropped more than once (gross cropped area)*

Effect of climate change on major crop diseases in Bundelkhand

(A) Cereals

The major wheat diseases were leaf rust (*Puccinia recondita*), stem/black rust (*P. graminis f. sp. tritici*), yellow rust (*P. striiformis*), stinking smut (*Tilletia cories*), Karnal bunt (*T. indica*), loose smut (*Ustilago tritici*), flag smut (*Urocystis agropyri*), ergot (*Claviceps purpurea*), bacterial leaf blight (*Pseudomonas atrofaciens*) and barley yellow dwarf viral found in the Bundelkhand. But now these diseases disappeared from last 10-years due to increased in day temperature and less humidity. While in other hand new improved/resistant varieties growing area are increasing, The rusts and smuts and bacterial diseases decreasing due to unfavorable climate but high temperature and less humidity diseases might be raised such as barley yellow dwarf viral, ear blight (Fusarium ear blight) because increased in temperature leading to favorable condition for multiplication of insect vectors and high temperature favorable diseases such Fusarium ear blight and root rot of wheat. Fusarium ear blight is a serious disease affecting. The incidence of the disease is determined by temperature and the occurrence of wet weather at the flowering or anthesis of the wheat crops." During severe epidemics, wheat crop losses can be as much as sixty per cent., the Fusarium pathogen produces toxic chemicals known as mycotoxins. The levels of mycotoxins present in the grain may render it unsuitable for either human or animal consumption. Climate change will increase the risk of serious ear blight epidemics on winter wheat in Central China by the middle of this century 2020-2050. (Zhang *et al.*, 2014). More than 34 °C directly inhibited *Puccinia* species. (Asseng *et al.*, 2011)

. The downy mildew (*Sclerospora sorghai*), ergot (*Sphacelia sorghai*), grain smut (*Sphacelotheca sorghai*), head smut (*Sphacelotheca reliana*), bacterial leaf stripe (*Pseudomonas sorghicola*) and maize dwarf mosaic virus. The smuts diseases will be decreased due to increasing introduction of hybrids, improved/ resistant varieties and increasing in temperature and less rain fall will also helped in decreasing humidity while viral diseases will be increased. The smuts diseases, bacterial diseases will be reduced because these fungus required high humidity and low temperature for their development but high temperature and low humidity required diseases such as maize downy mildew (*Sclerospora maydis*) dry root rot (*Rhizoctonia bataticola, Fusarium, Aspergillus* and *Pythium*) might be leading to increased (Lance,2015).

Table 4: Major diseases of cereal crops on exiting cropping system in Bundelkhand

Crop	Major diseases	Pathogen	Favorable climatic condition for development of disease
A. Cereals			
Wheat	Leaf /brown Rust	*Puccinia recondita*	Urediospores develop rapidly when free moisture is available and temperatures are near 20C. Successive generations of urediospores can be produced every 10-14 days if conditions are favorable. As plants mature or when environmental conditions are not favorable, masses of black teliospores may become evident
	Stem /black Rust	*P. graminis f. sp. tritici*	Urediospores develop rapidly when free moisture is available and temperatures are near 20C. Successive generations of urediospores can be produced every 10-14 days if conditions are favorable. As plants mature or when environmental conditions are not favorable, masses of black teliospores may become evident
	Yellow Rust	*P. striiformis*	Urediospores develop rapidly when free moisture is available and temperatures are near 20C. Successive generations of urediospores can be produced every 10-14 days if conditions are favorable. As plants mature or when environmental conditions are not favorable, masses of black teliospores may become evident
	Stinking Smut	*Tilletia caries*	Spores lying dormant in the soil or on seed germinate and infect emerging seedlings. Infection is favored by cool temperatures during germination.
	Karnal Bunt	*T. indica*	Seed- or soil-borne, floral infecting disease. Teliospores on or near the soil surface. The degree of disease establishment and development depends on environmental conditions from spike emergence through grain filling.
	Loose Smut	*Ustilago tritici*	Infection and disease development are favored by cool, humid conditions, which prolong the flowering period of the host plant.
	Flag Smut	*Urocystis agropyri*	Infection is favored by low soil moisture and cool soil temperatures.
	Powdery mildew	*Erysiphe graminis f. sp. tritici*	The development of powdery mildew is favored by cool (15-22 ^{0}C), cloudy, and humid (75-100% relative humidity) conditions.
	Ergot	*Claviceps purpurea*	High humidity or irrigation, as well as warmer temperatures (20 to 25 ^{0}C) favor infection and disease development.
	Bacterial Leaf Blight	*Pseudomonas atrofaciens*	Rainy or humid weather favors the production of exudates and spores. An ergot body develops in each infected floret; these fungal structures can survive in the soil from one season to the next, and under dry conditions they can remain viable for many years. Sclerotia require cold temperatures before they can germinate.
	Barley Yellow Dwarf	BYD-Virus	Temperatures of approximately 20 ^{0}C are favorable for disease development and symptoms appear approximately 14 days after infection.
Sorghum	Downy mildew	*Sclerospora sorghi*	Maximum sporulation takes place at 100 per cent relative humidity. Optimum temperature for sporulation is 21-23˚C during night. Light drizzling accompanied by cool weather is highly favorable.
	Ergot	*Sphacelia sorghai*	A period of high rainfall and high humidity during flowering season. Cool night temperature and cloudy weather aggravate the disease.
	Grain smut	*Sphacelotheca sorghai*	Spore germination temp. 20-30˚C
	Head smut	*Sphacelotheca reliana*	Dry (25˚C) and cool soil temp. favorable while most and warm soil reduced the disease, sandy soil less favorable
	Bacterial leaf stripe	*Pseudomonas sorghicola*	This disease is most commonly found in the spring since it is dispersed by rain and wind. As the growing season approaches summer, the disease usually becomes insignificant in severity.
	Maize dwarf mosaic	Maize dwarf mosaic virus	Average to warm temperatures
Maize	Downy mildew	*Sclerospora maydis*	Sporangia favorable high humidity and moderate temp. The optimum temp. of germination of conidia is 25˚C
Paddy	Bacterial blight	*Xanthomonas oryzae*	The disease favors temperatures at 25−34°C, with relative humidity above 70%.
	Blast	*Pyricularia oryzae*	Low soil moisture, frequent and prolonged periods of rain shower, and cool temperature in the daytime. In upland rice, large day-night temperature differences that cause dew formation on leaves and overall cooler temperatures favor the development of the disease.
	Brown spot	*Helminthosoprium oryzae*	High relative humidity (86−100%) and temperature between 16 and 36°C. It is common in un-flooded and nutrient-deficient soil, or in soils that accumulate toxic substances

The major diseases are bacterial blight (*Xanthomonas oryzae*), blast (*Pyricularia oryzae)* and brown spot *(Helminthosporium oryzae*). A report of surveys in hundreds of farmers' fields over the last 10 years show that rice diseases are strongly influenced by climate change. Water shortages, irregular rainfall patterns, and related water stresses increase the intensity of some diseases, including brown spot and blast. On the other hand, reductions of diseases such as sheath blight (IRRI, 2015) (Table 4).

Pulses

The major pulse diseases in Bundelkhand are anthracnose (*Collectrotrichum lindemuthianum*), dry root rot (*Rhizoctonia bataticola*), Alternaria leaf spot (*Alternaria alternata*), Wilts (*Fusarium* spp.), phytophthora blight (*Phytophthora cajani*), MYMV and leaf crinkle. Stem rot (*Sclerotium rolfsii*) resistance in groundnut is temperature-dependent (Pande *et al.* 1994). Dry root rot (*Rhizoctonia bataticola*) in chickpea and charcoal rot (*Macrophomina phaseolina*) increased many folds due to high temperature and prolonged moisture stress. (Sharma *et al.* 2010). Prolonged moisture may create a new scenario of potential diseases in such as anthracnose, collar rot, wet root rot, and stunt diseases in chickpea; Phytophthora blight and Alternaria blight in pigeonpea, leaf spots and rusts in groundnut indicated that outbreak of Phytophthora blight of pigeonpea (*Phythophthora drechsleri* f. sp. *cajani*) in last 5 years may be attributed to high intermittent rain (>350 mm in 6–7 days) in July–August (Pande and Sharma 2009). The high temperature tolerant fungal and MYMV disease will be increased because favorable condition for increased the vectors will be occurred in future (Table 5).

Table 5: Major diseases of pulses crops on exiting cropping system in Bundelkhand

B. Pulses			
Crop	Major diseases	Pathogen	Favorable climatic condition for development of disease
Black/ green gram	Anthracnose	*Colletotrichum lindemuthianum*	High relative humidity (Above 90 per cent), Low temperature (15-20°C) Cool rainy days.
	Dry root rot	*Rhizoctonia bataticola*	Day temperature of 30˚C. Prolonged dry season followed by irrigation.
	Yellow mosaic	MYMV	Transmitted by whitefly, *Bemisia tabaci* is favourable conditions are high temperature
	Leaf crinkle disease	Urdbean leaf crinkle virus	Transmitted by whitefly, *Bemisia tabaci* is favourable conditions are high temperature
Pigeonpea	Alternaria blight	*Alternaria alternata*	High humidity and warm temperatures; plants grown in nitrogen and potassium deficient soils are more susceptible
	Wilt	*Fusarium udum*	Wilt can be developed at a wide range of temp. 17-29°C and tolerate at pH 4.6-9.0
	Phytophthora blight	*Phytophthora cajani*	High humidity and a high temp. ranges of 28-32°C
Chickpea	Wilt	*Fusarium oxysporum f. sp. ciceris*	High temperatures and warm moist soils. The optimum temperature for growth of fungus is between 25-30°C, and the optimum soil temperature for root infection is 30°C.

Oilseeds

The major oilseeds crop are covering 80% area are soybean and mustard followed by sesame, ground nut and linseed. The oilseeds crop fungal diseases are MYMV, leaf crinkle, leaf spots white rust, wilt and phyllody in Bundelkhand. Oil seed rape pathogens such as *Alternaria brassicae*, *Sclerotinia sclerotiorum*, and *Verticillium longisporum* are predicted to be favored by average warmer temperatures (Siebold and Tiedemann, 2012). The viral vectors will increase and high temperature fourable diseases causing pathogen will be emerged in coming time on oilseeds crops in Bundelkhand (Table 6).

Table 6: Major diseases of oilseeds crops on exiting cropping system in Bundelkhand

C. Oilseeds			
Crop	Major diseases	Pathogen	Favorable climatic condition for development of disease
Sesame	Phyllody	*Phytoplasma*	Transmitted by the vector leaf hopper(*Orosius albicinctus) and insect is favored by high temperature*
Soybean	Yellow mosaic	MYMV	Transmitted by whitefly, *Bemisia tabaci* is favourable conditions are high temperature
	Leaf crinkle	Black gram leaf crinkle virus	Transmitted by whitefly, *Bemisia tabaci* is favourable conditions are high temperature
Ground nut	Leaf spot	*Cercospora spp.*	Average temperature is 27 ºC during the growing season and the rainfalls varied from 116 mm to 156 mm per month.
Linseed	Wilt	*Fusarium oxysporum f. sp. lini*	Optimum temperature for infection is 24 ºC
Mustard	Powdery mildew	*Erysiphe cruciferarum*	High temperature (15-28 ºC) coupled with low humidity (<60% humidity) and low or no rainfall with wind favors disease development
	White rust	*Albugo candida*	Moist (more than 70% relative humidity) coupled with warm weather (12-25 °C) and intermittent rains favors disease development.
	Alternaria spot	*Alternaria brassicae*	Moist (more than 70% relative humidity) coupled with warm weather (12-25 °C) and intermittent rains favors disease development

Spices

The major spices crops of Bundelkhand are ginger, turmeric, coriander, onion and garlic. The major diseases are soft rot (*Pythium spp*., *Ralstonia solanacearum*), powdery mildew (*Erysiphe polygoni*) and purple blotch (*Alternaria porri*). Under low-temperature and high-moisture conditions in the soil, *P. ultimum* and P. irregular are the most damaging species to cotton seed and seedlings, *P. aphanidermatum* is favored by higher soil moisture content and warmer temperatures typically for the tropics. Transmission of *Pythium* spices is normally associated with movement of infested soil or contaminated plant material. (Bayer Crop Science, 2015). *Ralstonia solanacearum* causing bacterial wilt is able to survive even in colder environments for about 3 years (Messiha, 2006) and it is severe in temperature ranges of 24°C - 35 °C with optimum of 27°C (Johnson 2003; Lemay *et al.* 2003). Alternaria sporulates best at about 26.6°C, when abundant moisture (as provided by rain, mist, fog, dew, irrigation) is present. Infections are most prevalent on poorly nourished or otherwise stressed plant (Table 7).

Table 7: Major diseases of spices crops on exiting cropping system in Bundelkhand

D. Spices			
Crop	Major diseases	Pathogen	Favorable climatic condition for development of disease
Ginger	Soft rot	*Pythium spp Ralstonia solanacearum*	Cool and moist conditions due to rain
Turmeric	Soft rot	*Pythium spp Ralstonia solanacearum*	Cool and moist conditions due to rain
Coriander	Powdery mildew	*Erysiphe polygoni*	High temperature (15-28 ºC) coupled with low humidity (<60% humidity) and low or no rainfall with wind favors disease development
Onion	Purple blotch	*Alternaria porri*	favourable conditions of temperature 28-30ºC and 80-90% relative humidity
Garlic	Purple blotch	*Alternaria porri*	favourable conditions of temperature 28-30ºC and 80-90% relative humidity

Vegetables

The major vegetables of Bundelkhand are tomato, potato, chilli, brinjal, colocasia and cucurbites which are affected with early blight (*Alternaira alternata*), late blight (*Phytophthora infestans*), phomopsis (*Phomopsis vexans*), powdery mildew (*Erysiphe cichoracearum*) and leaf curl virus. A combination of hot (>25°C), dry weather and periods of leaf wetness favour Alternaria spp. (Syngenta (2015**).** The requirement for high relative humidity, a proxy for leaf surface wetness, is common for many foliar pathogens (Caubel *et al.,* 2012). As temperatures increase from 8-22 degrees C to 23-26 degrees for a susceptible, more hours of leaf wetness (hours above RH 90%) are required to late blight (Grünwald *et al.* 2000). Powdery mildew develops quickly under favorable conditions. Infection can take place as low as 50% RH. Dryness is favorable for colonization, sporulation, and dispersal. Rain and free moisture on the plant surface are unfavorable. However, disease development occurs in the presence or absence of dew. Mean temperature of 20-26°C is favorable; infection can occur at 10-32°C. Powdery mildew development is arrested when daytime temperatures are at least 37.0°C (Margaret Tuttle McGrath, 2011). The viral diseases are spread by insects and insects are more multiplied at high humidity and high temperature. Therefore, in change climatic conditions the viral infection will be increased while aerial fungal diseases will be low in incidence as compared to root pathogens (Table 8).

Table 8: Major diseases of vegetable crops on exiting cropping system in Bundelkhand

E. Vegetables			
Crop	Major diseases	Pathogen	Favorable climatic condition for development of disease
Potato	Early blight	*Alternaria alternata*	Warm and humid environmental conditions are conducive to infection. In the presence of free moisture and at an optimum of 28-30°C
	Late blight	*Phytophthora infestans*	Favorable conditions for the disease (10-12°C and RH > 80%)
Tomato	Leaf curl virus	Potato leaf curl virus	Favorable environmental conditions for leaf roll include high temperatures, drought, and prolonged periods of wet soil
Brinjal	Phomopsis blight	Phomopsis vexans	High humidity and a high temp. ranges of 28-32°C
Chilli	Leaf curl virus	Chilli leaf curl virus	Favorable environmental conditions for leaf roll include high temperatures, drought, and prolonged periods of wet soil
Colocasia	Phytophthora blight	*Phytophthora colocasai*	High humidity and a high temp. ranges of 28-32°C
Cucurbits	Powdery mildew	*Erysiphe cichoracearum*	High temperature (15-28ºC) coupled with low humidity (<60% humidity) and low or no rainfall with wind favors disease development

Fruits

The major fruit crops are citrus, mango, guava and papaya in this zone. The major diseases of fruit crops are Canker (*X. axonopodis* pv. *citri*), wilt-complex (*Fusarium* spp.), anthracnose (*Collectrotrichum* spp.) and leaf curl virus. In citrus canker, wind-driven rain is the main dispersal agent and wind @ 8 m/s (18 mph) aids in the penetration of bacteria through the stomata pores (Drawing of the disease cycle) or wounds made by thorns, insects (leaf miner), and blowing sand. (Gottwald, 2000). Higher rainfall during July-September with maximum (31.3 to 33.5°C) and minimum temperature (23 to 25°C) and humidity of 76%. They further found that generally two-four months are required for the complete wilting of plants after infestation of fungi (Gupta, 2010). Anthracnose (*C. gloeosporioides)* was significantly inhibited by the increase of temperature. The leaf curl virus affect crop yield due to change in temperature and precipitation patterns, resulting in the shift of some insect/pest from small population to large population. (Farooq *et al.,* 2014) (Table 8).

Table 9: Major diseases of cereal crops on exiting cropping system in Bundelkhand

F. Fruits			
Crop	Major diseases	Pathogen	Favorable climatic condition for development of disease
Citrus	Canker	*X. axonopodis* pv. *citri*	The maximum and optimum temperature ranges for growth are to 39°C and 28 to 30°C.
Mango	Anthracanose	*Collectrotrichum* spp.	High temperature and high humidity
Gauva	Wilt	Wilt-complex	Optimum temperature for infection is 24˚C
Papaya	Leaf curl virus	Leaf curl virus	Favorable environmental conditions for leaf roll include high temperatures, drought

CONCLUSION

Climate factors that affect growth, spread, and survival of crop diseases include temperature, precipitation, humidity, dew, radiation, wind speed, circulation patterns, and the occurrence of extreme events. Higher temperature and humidity and greater precipitation result in the spread of plant diseases, as wet vegetation promotes the germination of spores and the proliferation of fungi and bacteria. Insects are particularly sensitive to temperature because they are cold-blooded. In general, higher temperatures increase rate of development with less time between generations. Warmer winters will increase survival and possibly increased insect populations in the subsequent growing season. If climate changes bring increased moisture and warmer temperatures to the region, it is likely to exacerbate epidemics and prevalence of leaf fungal pathogens and overwintering population of pests.

The incidence of the disease is determined by temperature and the occurrence of wet weather. The pathogens which causing diseases on crops at favorable less temperature and temperature and high humidity will be reduced because pathogen could not be built disease on the absence of favorable most condition of areal parts i.e. most of bacterial and some fungal pathogens while high temperature and high humidity diseases i.e. root rots, anthracnose, Fusarium ear blight in wheat. The viral diseases are mostly disseminated by insect vectors so high temperature and high humidity will be favorable condition for their multiplication of much generation leading to extending the viral diseases.

Acknowledgments

The KVKs scientists of Bundelkhan zone is acknowledge to providing valuable information need for studies and various NGOs, sates agricultural, horticultural, forest and other district department for providing primary data and reports.

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