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Review Article

Effect of Climate Change on Productivity and Disease Scenario of Potato - A Review

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ABSTRACT

Climate change is the greatest concern of mankind in 21st century. Commercial production of vegetable crops like potato particularly grown under open field conditions is likely to be severely affected by climatic variations. The Indo-Gangetic plain (IGP) is the main potato growing region accounting for almost 85 per cent of the 1.8 mha area under the crop in India, where it is grown as an irrigated crop during the winter season and contributes more than 80 per cent to the total potato production of the country. Potato has very narrow range of temperature requirement for tuber formation. Optimum tuber formation takes place at 20°C. Studies have reported that potato productivity is expected to decline in all potato growing districts of India. In addition to this, potato yield losses due to future warming scenarios from diseases, animal pests and weeds are estimated to be around 40 per cent of attainable production, with diseases alone accounting for 21 per cent among which potato late blight is generally recognized as the most important potato disease. Late blight has been known as weather driven disease which has led to the development of weather-based forecasting models that can assist farmers in scheduling fungicide applications. For different regions of the country significant decline in potato productivity is expected without any special adaptation strategies. Thus, the effects of climate change on potato production can be minimised by using adaptation techniques viz. change in date of planting, breeding short duration and heat tolerant cultivars and cultural management in potato based cropping system. In addition to this, insurance against weather adversities, adoption of agro advisory services and following weather forecast as well as strengthening education, research and development for improving production technology in warmer regions is need of the hour to manage disease incidence and sustain potato productivity in view of changing climatic conditions. In this paper, effect of climate change on potato productivity and its diseases has been reviewed and discussed.

Key words: Adaptation strategies, Climate change, Diseases, Potato, Productivity

Introduction

Climate change refers to long term conspicuous deviation from usual prevalent climate bringing variation in normal temperature, rainfall and atmospheric circulation with abnormal expression in extreme climate such as floods, droughts, extreme temperatures etc. (Ghadekar, 2001). As agricultural production is greatly affected by climate, any change in climate as a result of increasing concentrations of greenhouse gases in the atmosphere, can have serious consequences on agricultural yield potential (Mearns, 2000). In India, agriculture and its allied sectors are largest livelihood provider. Agriculture sector contributes significantly to GDP of our country. A number of crops like wheat, rice, maize, potato etc. are grown by farmers of country. Potato is the world's fourth-

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largest food crop after rice, wheat, and maize and is cultivated in several countries worldwide, including *China*, Iran, and India (Arab *et al.,*2012). This crop can be consumed as a vegetable, and serve as the major food grain dual-purpose crop. Its yield and quality are both dependent on variety and cultural practices as well as environmental condition, including rainfall, temperature, light, and CO_2. India is the second largest producer of potato in the world. India produces about 24 million tonnes of potato from 1.32 million hectares under the crop. The Indo-Gangetic plains (IGP) are the main potato growing region accounting for almost 85 per cent of the 1.8 mha under the crop in India where it is grown as an irrigated crop during the winter season and contributes more than 80 per cent to the total potato production of the country (Pandey and Kang, 2003).The bulk of the produce comes from the states of Uttar Pradesh (UP), West Bengal (WB), Punjab and Bihar contributing 40, 32, 6 and 6 per cent, respectively (Figs. 1 & 2).

For the growth and development crops depend on their genetic constitution and environmental conditions especially soil and climate. Climate is very important factor which influence the nature of plant growth. Every living organism does best under certain interrelated conditions of temperature, moisture and light. Potato requires long days and low temperature for its flowering and is restricted to its temperature requirement

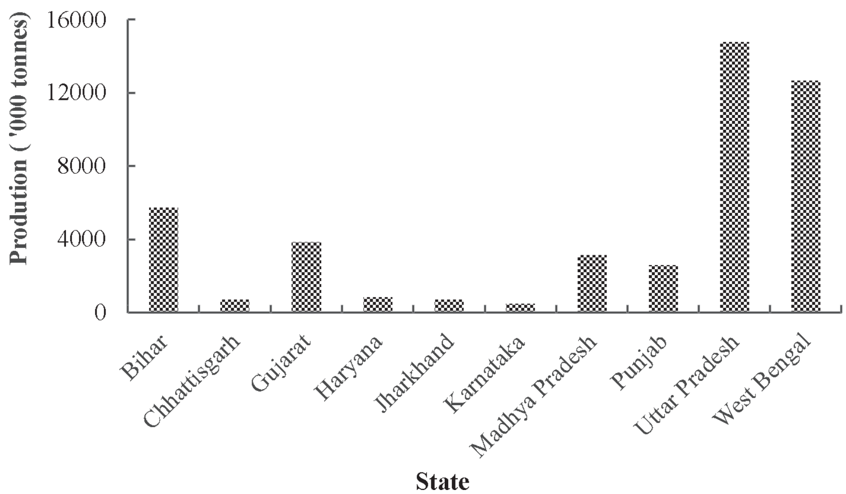

Fig. 1. Potato production in ten major potato producing states of country (Source: www.indiastat.com)

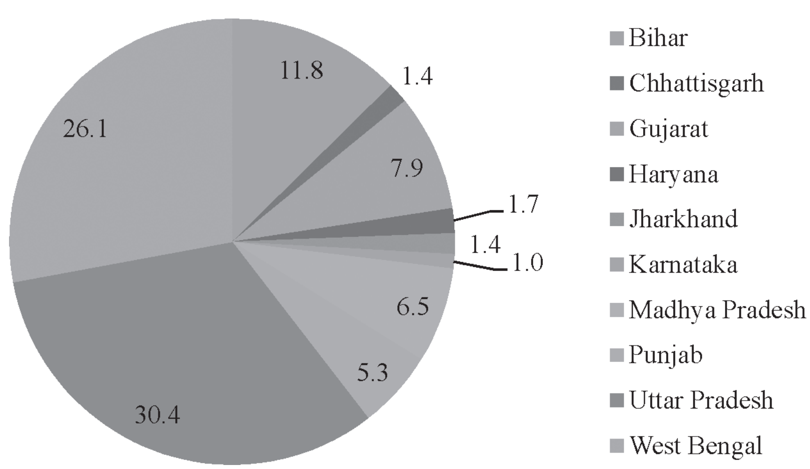

Fig. 2. Per cent contribution of different states in India's total potato production (Source: www.indiastat.com)

for tuber formation. Optimum tuber formation takes place at 20°C. Increase in temperature above 21°C cause sharp reduction in the tuber yield and at 30°C complete inhibition of tuber formation occurs (Shekhawat, 2001). The entire phase from emergence to tuber initiation is photosensitive. Short photoperiods favour early tuber initiation. However, under drought stress conditions tuber initiation and maturity is hastened (Beukema and Van der Zaag, 1990). The radiation use efficiency (RUE) is suppressed under high temperatures (Allen and Scott, 1992). It requires cool night temperature to induce tuberization (Ewing, 1997).Potato is well known for its specific temperature and day length requirement for tuber formation as well as flowering, so it becomes the most vulnerable crop for climate change.

In India, the crop is mainly confined to Indo-gangetic plains where it is grown in mild and cool winters. The autumn/winter planted crop in northern plains of India comprising the states of Uttar Pradesh, West Bengal, Bihar, Punjab and Haryana contributes 84 per cent of total potato production in India.Various studies have projected a 10-40 per cent loss in potato production in India by2080-2100 due to climate change unless farmers adapt to climate change (IPCC, 2007). Its growing duration in the Indo-gangetic plains is projected to decrease due to climate change. Potato growth and development is adversely affected at high temperatures. The effect of climate change on potato production in India has been studied by Singh *et al.* (2009) and they revealed that under the warming scenarios, potato productivity is expected to decline in all potato growing states of India. Its growth is not possible below 2°C and above 30°C.Maximum, optimum and minimum temperatures for net photosynthesis of potato have been reported as 0-7°C, 16-25°C and 40°C, respectively.

In addition to this climatic variations have a significant effect on disease incidence in potato. IPCC (2007) projected that plant diseases are one of the important factors which have a direct impact on global agricultural productivity and climate change is expected to further aggravate the situation. Plant diseases are estimated to cause yield reduction of about 20 per cent in the principal food and cash crops worldwide. Although, effective management of pests and diseases has played a key role in doubling food production during the last 40 years, but pathogens still claim 10-16 per cent of the global harvest (Chakraborty and Newton 2011). In Asia, 14.2 per cent of the potential production costing about US$ 43.8 billion is lost due to diseases (Oerke *et al.,*1994).

Although, climate models predict a gradual rise in CO_2 concentration and temperature all over the world, but they are not precise in predicting future changes in local weather conditions such as rain, temperature, sunshine and wind in combination with locally adapted plant varieties, cropping systems and soil conditions. No doubt, currently we are able to secure food supplies under these varying conditions. However, all climate models predict more extreme weather conditions, with more droughts, heavy rainfall and storms in agricultural production regions which can have adverse impact on disease incidence and may impose severe risks of crop failure. Thus, 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. As potato is the major food crop at global scale, thus evaluating the effect of climate change on its productivity and disease incidence scenarios is the need of hour, so that viable adaptation strategies can be explored to sustain its productivity under changing climatic conditions. Keeping this in view, the effect of climate change on potato productivity and disease incidence as well as various strategies have been reviewed and discussed in this paper.

Climate change and potato productivity

The crop productivity is subjected to a number of stresses and potential yields are seldom achieved under stress. During last century, the mean global temperature has increased by 0.85°C and is predicted to increase further by 1.6-5.8°C by the end of 21st century (IPCC, 2014). Climate change is predicted to cause an increase in

Table 1. Projected changes in climate of India (2070-2099)

Region	Season/Months			
	Jan-March	April-June	July-Sept	Oct-Dec
Change in temperature (°C)				
Northeast	4.95	4.11	2.88	4.05
Northwest	4.53	4.25	2.96	4.16
Southeast	4.16	3.21	2.53	3.29
Southwest	3.74	3.07	2.52	3.04
Change in precipitation (%)				
Northeast	-9.3	20.3	21.0	7.5
Northwest	7.2	7.3	27.2	57.0
Southeast	-32.9	29.7	10.9	0.7
Southwest	22.3	32.3	8.8	8.5

Source: Kavikumar (2010)

average air temperature, increases in atmospheric CO_2 concentration, and significant changes in rainfall pattern (Houghton *et al.,* 2001). The present challenges like global climate change, water and soil pollution, decreasing water availability, urbanization etc. add up to the situation. Climate change projections to 2100 AD for India indicate an overall increase in temperature by 2-4°C with no substantial change in precipitation (Kavikumar, 2010) (Table 1). Kingra *et al.* (2017) reported a decrease in rainfall and increase in temperature from north-east to south-west Punjab during both the *kharif* and *rabi* seasons. No significant temporal variation was observed in maximum temperature and rainfall during both the seasons, but a significant increase in minimum temperature over the years was observed in different zones of Punjab. On an average, minimum temperature is increasing at 0.05°C per year during both the seasons.Climatic changes will influence the severity of environmental stress imposed on vegetable crops. The response of plants to environmental stresses depends on the plant developmental stage and the length and severity of the stress (Bray, 2002). Plants may respond similarly to avoid one or more stresses through morphological or biochemical mechanisms (Capiati *et al.,* 2006). However the environmental interactions may make the stress response of plants more complex or influence the degree of impact of climate change.

Effect of temperature

Vegetable production is threatened by increasing soil salinity particularly in irrigated croplands which provide 40 per cent of the world's food. Luck *et al.* (2010) expected 16 per cent decline in tuber yield of potato by 2050 for West Bengal if any special strategies are not adapted. However, they suggested planting of potato crop at optimal time of mid-November in order to minimize the yield losses up to 8 per cent. Increase in temperature favours the potato cultivation by prolonging the crop growing season in high altitudes and temperate regions of the world like Europe, Russia and, Himalayan and other mountain regions in India and frost prone states like Haryana and Punjab (Table 1) whereas, it disfavours the potato production by shortening the growing period in subtropical plains such as West Bengal and Bihar during winter season (Singh *et al.,* 2010).

In potato high harvest index (HI) of 0.8 was recorded at 15°C night temperatures of and zero at 28°C in North Indian parts viz. Punjab, Haryana, Uttar Pradesh, Bihar and Northern hills. A moderate HI of 0.4-0.6 is recorded at 20°C night temperatures in Central Indian states like Gujarat, Chhattisgarh, some parts of Maharashtra and West Bengal indicating temperature stress limiting the partitioning of photosynthates to the tubers. However, a low HI of 0.2 was recorded at more than 20°C night temperatures in South India

(Pandey *et al.,* 2009; Singh *et al.,* 2010). Potato tubers with high starch content are favoured by the processing industry. At low temperatures starch is converted into the sugar, which causes browning due to charring of sugar while chips making thereby reduces their preference by the processing industry. This ultimately results in increased post harvest losses more than the present level, which is figured at 40-50 per cent. This is most common problem in areas where night temperatures fall below optimum during winter season (Singh *et al.,* 2010). Thus, potato productivity is expected to decline in all potato growing districts of India (Table 2). However, these effects can be minimised by using some adaptation techniques.

Effect of CO_2

Climate change is projected to reduce potato yields approximately by 2.5, 6 and 11 per cent in the IGP region by 2020 (2010-2039), 2050 (2040-2069) and 2080 (2070-2099) respectively (Kumar *et al.,* 2015). Singh *et al.,* (2013) revealed that elevated CO_2 (550 ppm) produced a beneficial effect in tuber yield (+11.1%) up to a temperature increase of +1°C but when the temperature increment reached a threshold of +3°C even the elevated CO_2 caused a reduction of 13.7 per cent in tuber yield. Fleisher *et al.* (2016) pointed out that temperature is more important source of uncertainty in potato crop models than CO_2 and water.In northern states like Punjab and Western Uttar Pradesh, which currently have the lowest average minimum temperatures, are not expecting increase in temperature, and some authors expect increase in rainfall as a result, potato production may be benefitted in those regions. Nonetheless, in Punjab, in addition to the monsoon, farmers also utilize groundwater sources for irrigation and there is evidence of overexploiting this resource and further depletion of groundwater may reduce the benefits of the increase rainfall (Baweja *et al.,* 2017).

Table 2. Impact of climate change on tuber productivity in major potato growing states of India without adaptations under optimal management (2020:1ºC,393 ppm; 2050:3ºC, 543 ppm)

States	Change(per cent) from current productivity	
	Future Climate (Year)	
	2020	2050
Uttar Pradesh (UP)	-1.61	-9.08
West Bengal (WB)	-4.86	-16.11
Bihar	-3.01	-11.50
Punjab & Haryana	-7.31	-3.66
Madhya Pradesh (MP)	-6.64	-20.63
Gujarat	-16.75	-55.10
Maharashtra	-8.82	-35.29
Karnataka	-18.68	-45.73

Source: Singh *et al.* (2009)

Effect of moisture (Rainfall/drought)

Potato is mostly grown in north India during winters usually receiving few scattered rains. Under future scenarios the global warming is projected to be more pronounced over land areas in south east Asia with maximum temperature increase over northern India. The winter and post-monsoon seasons are likely to be more affected by warming. Therefore, potato in addition to direct effects on growth and yield, may also be subjected to some indirect effects of warming. These are increasing drought due to reduction in precipitation and unpredictable extreme events of erratic unseasonal rains, frost, floods etc.

Potato is extremely sensitive to drought particularly at tuber initiation which leads to substantial loss in tuber yield. Optimal water supply is essential for potato, because of its shallow root system. The potato plant generally roots rather shallowly by about 40 to 50 cm. Dry matter partitioning to root, shoot, leaf and stem as a function of development stage (OS) and the root: shoot ratio is affected by drought stress. Drought, while reducing dry matter production increases the root: shoot ratio indicating a shift in the balance of growth in favour of roots. Roots of plants grown in drought conditions also tend to be trimmer. Both responses enable drought facing plants to exploit the available soil moisture more effectively (Vos, 1995).

Effect of frost

Potato is highly sensitive to frost and severe damage may occur when temperature drops below 0°C (Hijmans *et al.,* 2003).Complete loss of foliage is reported if minimum temperatures are below 2°C for 2-3 consecutive nights. More than 4-5 hours duration of temperature below 1°C may result in foliage loss of 50 per cent in even one night exposure. However, yield losses depend on crop growth stage at occurrence of frost. Frosting late in the season from 80-90 days after planting (DAP) results in yield loss of 10-15 per cent, while that at 50-60 DAP may cause yield loss of 30-50 per cent. In Punjab, frost has been observed as a most disastrous extreme weather event for potato growth, development and yield. The results of the surveys revealed that delay in planting beyond third week of October resulted in exposure of the crop to ground frost later in the season which caused substantial loss in tuber yield. This could be avoided if the crop was planted in time (Arora *et al.,* 2010).

Pradel *et al.,* (2019) concluded that keeping productivity at current rates will pose a tremendous challenge for policy-makers, breeders, extension agents and farmers alike and will require continuous investment into genetic improvement and similar efforts in the promotion and dissemination of released varieties. Even if India becomes highly resilient to climate change, producing food at current rates will not suffice with the growing population. Thus, strategies to produce more food will require more attention in the future which will depend upon using resources more efficiently and reducing negative environmental and social implications.

Climate change and potato diseases

Plant diseases are one of the important factors which have direct impact on global agricultural productivity and climate change will further aggravate the situation. Plant diseases are estimated to cause yield reduction of almost 20 per cent in the principal food and cash crops worldwide (Thind, 2012).The potato is prone to more than hundred diseases caused by bacteria, fungi, viruses and mycoplasmas. However, *Phytophthora infestans, Alternaria solani, Rhizoctonia solani, Sclerotium rolfsii, Streptomyces* spp., *Ralstonia solanacearum*, and several virus pathogens have been observed responsible for degeneration and deterioration of potato crop as well as yield losses to crop (Shekhawat *et al*., 1993). Different pathogens prevail in different regions depending on the geographical limits of any area (Table 3). Changes in temperature and precipitation regimes due to climate change may alter the growth stage, development rate and pathogenicity of infectious agents, and the physiology and resistance of the host plant (Chakarborty and Datta, 2003). A change in temperature could directly affect the spread of infectious diseases and their survival between seasons (Table 4). Major climate change factors likely to influence plant disease severity and spread include elevated CO_2, heavy and unseasonal rains, higher humidity, drought, cyclones and hurricanes, and elevated temperature (Luck *et al.,* 2011).

Late Blight of Potato

Potato late blight is an important disease caused by the *Phytophthora infestans* (Mont.) De Bary. Late blight is well-known for its role in the Irish potato famine and its current threat to potato production globally. Potato yield losses from diseases, animal pests and weeds were estimated to be around 40 per cent of attainable production, with diseases alone accounting for 21 per cent (Oerke, 2006), out of which potato late blight is generally recognized as the most important potato disease. Late blight has been known as weather driven disease which has led to the development of weather-based forecasting models that assist farmers in scheduling fungicide applications. Andrade-Piedra *et al.* (2005) using a meta modelling approach demonstrated that late blight was very sensitive to changes in temperature and relative humidity, which could be critical factors in determining the role that late blight might play in a potato system's robustness against climate change (Hijmans *et al.,* 2000).

Late blight scenario in India would also change drastically with climate change. Currently,

Table 3. Distribution of potato diseases among different states of India

Sr. No.	Name	Causal Organism	States	Reference
		Fungal Diseases of Potato		
1	Late Blight of potato	*Phytophthorainfestans*	Punjab, Haryana, Uttar Pradesh, Maharashtra Bihar, West Bengal, Karnataka	Mohan and Thind, 1999 Bhat *et al.,* 2010
2	Early Blight of potato	*Alternaria solani*	Uttar Pradesh, Madhya Pradesh, Andhra Pradesh and Maharashtra	Singh and Gupta, 1953
3	Wart Disease	*Synchytriumendobioticum*	West Bengal, Darjeeling hills	Singh, 1998
4	Black scurf / Canker	*Rhizoctonia solani*	Himachal Pradesh, Uttar Pradesh, Uttrakhand, Sikkim, Assam, Maharashtra, Madhya Pradesh	Verma *et al.,* 1990, Khurana *et al.,* 1998 and Bains *et al.,* 2002
5	Charcoal rot	*Macrophominaphaseolina*	Uttar Pradesh, Himachal Pradesh, Uttrakhand	Rao and Mukerji, 1972
6	Dry rot	*Fusarium species*	Madhya Pradesh, Haryana	Sagar *et al.,* 2011
7	Wet rot	*Sclerotiumrolfsii*	Uttar Pradesh, Maharashtra, Madhya Pradesh,Himachal Pradesh, Uttrakhand	Madhavi and Bhattiprolu, 2011 Banyal *et al.,* 2008
		Bacterial diseases of potato		
8	Common Scab	*Streptomyces scabies*	Khasi Hills (Meghalaya), West Bengal, Himachal Pradesh	Paharia and Pushkarnath, 1963
9	Bacterial Wilt	*Rolastonia solanacearum*	Trivendrum, Assam,Orissa, Karnataka, West Bengal, Uttar Pradesh,Punjab,Haryana, M.P., Chhattisgarh	Anonymous, 1981
		Viral diseases		
10	Mosaic disease	Potato virus X	Himachal Pradesh,Karnataka,West Bengal, Uttar Pradesh,Punjab,Haryana, M.P., Chhattisgarh, Bihar, Sikkim, Maharashtra	Khurana, 2004
		Potato virus Y	M.P., U.P., Punjab, Bihar	Khurana, 2004

late blight is not a serious problem in autumn in the state of Punjab, Haryana and parts of Uttar Pradesh, primarily due to sub-optimal temperature regimes during December-January. However, disease outbreaks are expected to become more intense with increase in ambient temperature coupled with high relative humidity. Such scenarios were witnessed during 1997-98 and 2006-07, when average crop losses in this region were over 40 per cent. Increase in ambient relative humidity would have a far greater impact of late blight outbreaks in the country. Here, the crop is grown totally under irrigated conditions. Luck *et al.* (2012) assessed the influence of climate change on potato production and potato late blight was assessed using two climatically distinct potato growing regions each in India's West Bengal (Nadia and Hooghly) and Bangladesh (Bogra and Munshiganj). Regional climate projections to the year 2050 were obtained for each location using IPCC climate scenario A1B for West Bengal and Bangladesh. Two regional forecasting models indicated an increasing trend (+0.2 to +0.6°C) for maximum and minimum temperatures by 2050. An increasing trend in rainfall was expected for 2050 but no difference in solar radiation was

Table 4. Climatic requirement of different diseases of potato

Sr. No.	Name	Causal organism	Optimum climatic requirement	Reference
		Fungal Diseases of Potato		
1	Late Blight of potato	*Phytophthorainfestans*	Range:10-27°C RH> 90% Range:14-27°C Night temperatures: 10-16°C with light rain, fog or heavy dew Day temperature: 16-13 °C with high relative humidity	Zwankhuizen and Zadoks, 2002; Luck *et al.,* 2012 Kirk *et al.,* 2013
2	Early Blight of potato	*Alternaria solani*	Range:10-35°C RH> 90% Range:13.5-24°C Rainy weather with RH>90%	Rotem 1974; Johnson *et al.,* 2015
3	Wart Disease	*Synchytriumendobioticum*	Soil Moisture: 100% Infection is favoured when temperatures are between 14 and 24°C	Singh 2000
4	Black scurf / Canker	*Rhizoctoniasolani*	Soil temperature: 16-23 °C Soil: Dry Air temperature: 18-28°C	Lui 2001; Frohning 2013
5	Charcoal rot	*Macrophominaphaseolina*	Ambient temperature: 30°C or above	Somani 2007
6	Powdery Scab	*Spongosporasubterranea*	16–17°C and that the minimum and maximum temperatures were <11°C and 22–25°C respectively	Kole 1954
7	Dry rot	*Fusarium species*	Range: 25-35°C RH: 90-98%	Theron and Holz 1990
		Bacterial diseases of potato		
8	Common Scab	*Streptomyces scabies*	Optimal soil temperature :19-24°C With low moisture level	Healy and Lambart 1991
9	Wet rot	*Sclerotiumrolfsii*	Range: 4-37°C Cool to moderate maximum daily temperatures (29°C) and moisture from rain, fog, dew, or high relative humidity.	Duarte *et al.,* 2004 Workneh and Yang 2000
		Viral diseases		
10	Mosaic disease	Virus	Temperatures of 16 to 20° Cwith cloudy weather	Sutic *et al.,* 1999

predicted compared to 1981-2010 data. The impact of climate change on potato production in the study areas in India and Bangladesh showed yield decline of 23-32 per cent by 2050. To assess the effect of climate change on Potato Late Blight, nine published models were tested for accuracy against ten years of West Bengal disease incidence records. The best model was only 25 per cent accurate in predicting Late Blight outbreaks for that time period and, therefore, an alternative approach was developed by adapting the Jhulsacast model and applying fog-based rules. When climate change projections were incorporated, this modified model showed that the onset of Late Blight is likely to be earlier in the growing season for 2031-2040 but severity is likely to be 5-7 per cent less than 1981-2010 records in the intensive potato growing areas of West Bengal. However, in northern Bangladesh, disease severity is predicted to increase by up to

12 per cent, and reduce by 7 per cent in central Bangladesh.

Early blight of potato

Early blight caused by *Alternaria solani* is influenced by temperature and relative humidity. High temperature and relative humidity favour its outbreak. Such situation mostly exists in plateau and sub-mountainous regions, although, it is known to infect potato crop throughout Indo-Gangetic plains as well as high hills. The disease is most favoured by temperature ranging from 25 to 30°C with an optimum of 26°C (Dutt, 1979) prevailing temperatures in the foothills and plateau are already high. Further warming may not lead to any substantial effect on the disease. However, altered precipitation, especially above normal, may favour the disease development in nitch areas.

Soil borne diseases

A large number of soil borne pathogens attack potato crop. Some of the important ones include, *Synchytrium endobioticum* causing wart, *Spongospora subterranea* causing powdery scab, *Rhizoctonia solani* (black scurf and canker), *Streptomyces scabies* (common scab), *Sclerotium rolfsii* (sclerotium wilt), *Macrophomina phaseolina* (charcoal rot), *Rolastonia solanacearum* (bacterial wilt) and *Fusarium spp*. (wilt and dry rots). Some of them viz. *S. endobioticum* and *S. subterranea* are favoured by low temperature and high soil moisture whereas remaining ones are favoured by moderate to high temperature and low soil moisture. Consequently, the effect of climate change would also vary from pathogen to pathogen. Although, wart spores can cause infection in the range of 10 to 28°C with an optimum of 21°C but there is hardly any infection beyond 23°C. Therefore, warmer climates are likely to reduce wart infestation. Similarly, reduced precipitation will also lower down wart infestation as it requires 100 per cent soil moisture for infection to occur. Powdery scab infestation is also likely to be reduced with increase in temperature and reduction in rainfall as a consequence of global warming. Since optimum temperature for powdery scab is 12°C, and moisture requirement is 100 per cent, the global warming may either lead to elimination of this disease or it will be pushed to higher altitudes making high hills free of powdery scab. Diseases like *sclerotium* wilt, charcoal rot and bacterial wilt are favoured by high temperature and moisture. *Sclerotium* wilt in India is restricted to plateau regions (M.P., Karnataka, Maharashtra). Optimum temperature requirement for this disease is 30-35°C. With the increase in temperature due to global warming, the disease may enter into other areas like mid hills, and in long run, it may also become prevalent in eastern Indo-gangetic plains. Similarly, bacterial wilt may also advance to higher altitudes in hilly regions due to global warming.

Charcoal rot is currently endemic in eastern U.P., Bihar and M.P. The global warming is likely to increase the severity of this disease in these regions. It is also likely to expand to other parts of North Central plains as well. Black scurf and common scab are favoured by moderate temperatures (15-21°C and 20-22°C, respectively) and are likely to remain insulated from global warming in near future. By the end of the century, when ambient temperatures are likely to increase by 1.4 to 5.8°C, the severity of these two diseases may decrease substantially. Virus diseases are bane to potato production world over, but more so in subtropics and tropics. The rate of multiplication of most of the potato viruses gets increased with the increase in temperatures. This is the reason why viral diseases are not so damaging in the temperate world. But, global warming may change the entire scenario of potato viruses in temperate world. Hilly regions are considered best for potato seed production but it may not be the case after 2-3 decades. Sup-tropical plains, where majority of the potatoes are grown, represent a different scenario. Although, global warming may not affect potato viruses directly, but may have a serious repercussion through the altered biology of insect vectors. The increase in temperature will enhance vector population thereby increasing the number of insecticide sprays for keeping the vector population in check (Singh and Bhat, 2008).

Climate change is predicted to have a direct impact on the occurrence and severity of diseases in crops, which will have a serious impact on our food security. Climate change will lead to rise in temperature and carbon dioxide levels and will also have a varied effect on moisture. In many cases, temperature increases are predicted to lead to the geographic expansion of pathogen and vector distributions, bringing pathogens into contact with more potential hosts and providing new opportunities for pathogen hybridization (Baker *et al.,* 2000; Braiser, 2001). Pathogen evolution rates are determined by the number of generations of pathogen reproduction per time interval, along with other characteristics such as heritability of traits. Temperature governs the rate of reproduction for many pathogens. Longer seasons that result from higher temperatures will allow more time for pathogen evolution. Pathogen evolution may also be more rapid when large pathogen populations are present, so increased overwintering and over summering rates will contribute as well. Climate change may also inûuence whether pathogen populations reproduce sexually or asexually; in some cases, altered temperatures may favour overwintering of sexual propagules, thus increasing the evolutionary potential of a population.

Analysis of the last 30 years historical weather data from different locations of Punjab has indicated that significant changes have occurred in the weather causing early warming in February. In potato, economic production is often impossible without the application of pesticides. Late blight of potato is considered to be the most economically important disease of potato worldwide. The disease can destroy potato crop within a few weeks. Estimates of losses to late blight in developing countries vary between US$ 3 and US$ 10 billion each year, and about US$ 750 million is spent on pesticides alone. In the temperate Indian hills which occupy about 20 per cent of the acreage, a severe epiphytotic (epidemic) of late blight recurs every year resulting in 40–85 per cent yield loss. The disease now appears earlier in the northern part (November) and later in the eastern part (February) and within altered temperature range, i.e. 14-27.5^{o}C than at 10-25^{o}C recorded in earlier years (Luck *et al.,* 2012). In effective disease management strategy in potato, pesticide usage may increase if changing crop physiology interferes with the uptake and translocation of pesticides or changes in other climatic factors (e.g. more frequent rainfall, washing away residues of contact pesticides) indicate that there is a need for more frequent applications. Faster crop development at increased temperature could also increase the need for application of pesticides. The range of many pathogens is limited by climatic requirements for infection and development. However many studies have indicated their geographical expansion in view of climate change and warming scenarios (Chakarborty *et al.,* 2002; Evans *et al.,* 2007).

The concentration of CO_2 in the atmosphere has reached about 410 ppm at present, which exceeds the natural range of values of the past 650,000 years. Increase in CO_2 levels may encourage the production of plant biomass. However, productivity is regulated by the availability of water and nutrients, competition against weeds and damage by pests and diseases. Thus, an increase in biomass can modify the microclimate and affect the risk of infection. In general, increased plant density will tend to increase leaf surface wetness duration and regulate temperature, and thus causing infection by foliar pathogens more likely (Yanez-Lopez *et al.,* 2012). Some workers suggest that elevated CO_2 concentration and climate change may accelerate plant pathogen evolution, which can affect virulence. Under elevated CO_2 conditions, potential dual mechanism of reduced stomatal opening and altered leaf chemistry results in reduced disease incidence and severity in many plant pathosystems where the pathogen targets the stomata (Mcelrone *et al.,* 2005).

Similarly, moisture can impact both host plants and pathogens in various ways. Some pathogens such as apple scab, late blight and several vegetable root pathogens are more likely to infect plants with increased moisture content because forecast models for these diseases are based on leaf wetness, relative humidity and precipitation measurements. Other pathogens like the powdery mildew species tend to thrive under conditions with lower (but not low) moisture (Coakley *et al.,* 1999). Condition of drought is also expected to lead to increased frequency of tree pathogens due to indirect effects on host physiology (Desprez *et al.,* 2006). More frequent and extreme precipitation events that are predicted by some climate change models could result in longer periods with favourable pathogen environments. Host crops with canopy size limited by lack of moisture might no longer be so limited and may produce canopies that hold moisture in the form of leaf wetness or high-canopy relative humidity for longer periods, thus increasing the risk from pathogen infection (Coakley *et al.,* 1999).

Adaptation to climate change - need of hour

Changing crop productivity and disease scenario in potato due to climate change has highlighted the need for better agricultural practices and use of eco-friendly methods in yield and disease management for sustainable crop production (Boonekamp, 2012). In the changing climate and shift in seasons, choice of crop management practices based on the prevailing situation is important. In such scenarios, weather-based disease monitoring, inoculum monitoring and rapid diagnostics would play a significant role. There is a need to adopt novel approaches to counter the adverse climatic conditions and resurgence of diseases under changed climatic scenario (Fig.3). Different adaptation strategies are discussed as following:

Improved cultivars

It is an important strategy to adapt to the negative implications associated with climate change. In India, Pradel *et al.,* (2019) analyzed the extent to which the potato sector is resilient to climate change. State-level climate change projections were compared with adoption of high resistant and tolerant potato varieties to major abiotic and biotic stresses. Release and adoption data was collected in 2016 in six expert elicitation workshops conducted with 130 experts from the potato value chain in Bihar, Gujarat, Karnataka, Punjab, Uttar Pradesh, and West Bengal. They observed that from 81 releases, 45 improved varieties are adopted in India and that in each state high resistant and tolerant varieties are cultivated providing some degree of varietal resilience. Early maturity has been the most important and heat tolerance is the least important trait. Punjab has the most balanced resilience in comparison to other states. High drought tolerance, late blight resistance, and early maturity are found in adopted varieties. Despite the heat tolerant index being very low, the state is predicted to become warmer, which will favour potato production. Heat tolerance is thus of less importance. Similarly, due to expected increases in (extreme) rainfall, droughts are unlikely to become an issue for potato production in Punjab. Under changing climatic scenario of Punjab, late blight can remain as an issue with acurrent late blight resistance index (LBI) of 0.57.One of the important climate change adaptation strategy is to breed drought and salinity tolerant cultivars. Exotic cultivars like Rutt and Haig are reported

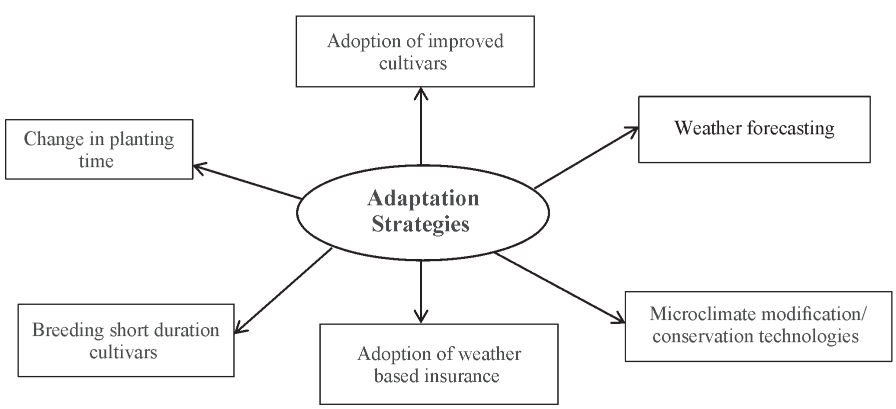

Fig. 3. Different adaptation strategies for sustainable potato production

Table 5. Effect of adaptation through change of planting date on potato production in India

Location: Indo-Gangetic Plains	Date of Planting	Change (per cent) in yield		
		Current	2020	2050
Jalandhar (Punjab)	-5	-5.6	6.7	-3.4
	Optimum (Nov 1st)	0.0	7.3	3.7
	+5	15.1*	18.1	13.8
	+10	19.4*	21.7	18.9
Burdwan(West Bengal)	-5	-1.4	-7.5	-19.8
	Optimum (Mid Nov)	0.0	-3.9	-7.7
	+5	-8.6	-9.4	-15.5
	+10	-15.0	-19.6	-24.1

Source: Singh *et al.* (2009)

to initiate tubers at continuous exposure to as high temperature as 30°C. Mining for biodiversity to heat tolerance is on priority.

Weather forecasting

Weather forecasting can be very useful in minimizing risks of climatic adversities. Any variability in the weather during the crop season, such as delay in the monsoon, excessive rains, flood, droughts, spells of too-high or too-low temperatures (frost) would affect the crop growth and finally the quality and quantity of the yield. The losses in crop can be reduced by adopting proper crop management by timely and accurate weather forecasts. Weather forecast also provides guidelines for selection of crops best suited to the anticipated climatic conditions. The objective of the weather forecasting is to advice the farmers on the actual and expected weather and its impact on the various day-to-day farming operations i. e. sowing, weeding, time of pesticides spray, irrigation scheduling, fertilizer application etc. and overall crop management. Weather forecast helps to increase agriculture production, reduce losses, risks, reduce costs of inputs, improve quality of yield, increase efficiency in the use of water, labour and energy and reduce pollution with judicious use of agricultural chemicals. (Vashisth *et al.,* 2013)

Change in planting time

Change in date of planting is one of the important adaptation techniques. Singh *et al.,* (2009) reported that by changing date of planting from optimum sowing time of November 1st can improve the potato yield under Punjab conditions (Table 5). However, delay in sowing is not recommended because of chances of frost during winter season. Frost is extreme weather condition which decreases potato yield significantly under Punjab conditions. Change in planting time has been observed as the single most important adaptation option which may lead to yield gains approximately by 6 per cent by 2020 and its combination with improved variety or additional nitrogen may be required to adapt to climate change leading to positive gains of 8 and 5 per cent by 2020 and 2050, respectively. However, in 2080 adoption of all the three adaptation strategies may be needed for positive gains. (Kumar *et al.,* 2015).

Microclimate modification

There are number of techniques which can be used to modify microclimate and save crop from harsh weather effects. For example, mulching can raise the content of organic matter in the soil. This, in turn, increases the soil water holding capacity, thus reducing runoff and erosion and making more water available to plants. Sustain-able water use can also be achieved through improved irrigation systems, one example of which is drip-irrigation. Such systems need not be expensive. In some developing countries such as, for example, India, low-cost micro-irrigation systems are produced locally and at a relatively moderate price. Conservation tillage and on farm crop residue management. Singh and Ahmad (2008) concluded that mulching had significant influence on potato growth and yield. Emergence, plant height and number of stems improved with black polythene mulching at Leh (Ladakh). Maximum tuber yield (35.2 t ha^{-1}) was recorded with black polythene mulching followed by white polythene.

Weather based insurance

Insurance against adverse weather is required for the cash crop of potato with high cost of cultivation.Effective crop insurance schemes should be evolved to help farmers in reducing the risk of crop failure due to these events. Both formal and informal, as well as private and public, insurance programs need to be put in place to help reduce income losses as a result of climate-related impacts. However, information is needed to frame out policies that encourage effective insurance opportunities.

Conclusions

Climate change is likely to have significant effects on potato productivity and disease incidence, which can be more severe in the tropical regions like India. Although, increase in CO_2 concentration can lead to improvement in potato productivity at increase in temperature by 1°C, but its benefit can be negated when warming increases beyond 3°C. Similarly, changes in temperature and precipitation can significantly affect spread of diseases and survival of pathogens leading to significant reductions in food production and threatening food security. More frequent and extreme precipitation events in future may result in longer periods with favourable environments for pathogens. Under such conditions, adopting some adaptation techniques to maintain potato productivity and manage disease incidence is the need of hour. Change in planting time, adoption of frost tolerant varieties and weather based crop insurance in climate sensitive regions can act as effective approaches to face this global challenge. Modification of microclimate to make it unfavourable for pathogens and favourable for crop growth is another option to sustain productivity and check disease incidence. In addition to this, timely availability of accurate weather forecast and agro-advisory can be of great benefit in saving crops from damages of adverse weather conditions and managing diseases by scheduling spray applications.

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