



Scenario, implications and prospects of climate change on potato (*Solanum tuberosum*) insect pests: A review

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ABSTRACT

Potato (*Solanum tuberosum* L.) is a cool climate loving crop. Climatically, there is a short window in which potato has been fitted with appreciable use realized even 80 to 90 days old crop. Moreover a few other crops produce comparatively high yields of nutrients per unit area where land is scarce. That's why potatoes are highly important for many marginal families of the country. High production levels and highly perishable sale practices enable farmers to be competitive despite the fact of high input cost, labour problem and forced gluts, still potato is an important cash crop and cultivated mainly as an irrigated winter cash crop. Among the various factors related to insect pests and diseases, potato farmers are increasingly forced to face water stress change, changes in rainfall patterns and its intensity, frost and fog etc. These conditions are generally interpreted to be climate changes. Potato production is highly dependent on climate and weather factors. All climate change projections are based on simulations and therefore involve uncertainties. However, it is clear that climate change will not only affect the cultivation system but also change the pressure of insect pests of potato. Disease free seed production may also be affected due to changes in the life cycles of aphids. Pests such as mite, potato tuber moth and cutworms may become more serious on potato crop. At present most of the potato seed is grown in Northern plains under no or low aphid period in order to keep it virus free but change in climate, in certain regions, aphids/whiteflies will occur in greater numbers, resulting threat particularly to virus free seed production. The precise impact of climate change on insects is somewhat uncertain because some changes may favour insects while other may inhibit the activity of few insects. The best economic strategy for farmers is to use IPM practices to monitor insect occurrence and their buildup on potato crop.

Key words: Climate change, Humidity, Insect pests, Potato, Rainfall, Temperature

In India, insect pest damage varies considerably in different agro-climatic regions across the country especially due to differential impacts of several abiotic factors such as temperature, humidity and precipitation (Sharma *et al.* 2005, 2010). This has major implication for the intensification of yield losses due to potential changes in crop diversity and increased incidence of insect pests in the context of impending climate change. Insect-pests of crop plants are the real candidates most affected by global climate change. Milder winters and warmer nights allow increased winter survival of many potato (*Solanum tuberosum* L.) pests and pathogens. Complex physiological effects exerted by the increasing temperature and CO₂ may affect profoundly, the interactions between crop plants and insect-pests (Caulfield and Bunce 1994, Roth and Lindroth 1995). It has been reported that global climate warming may lead to altitude wise expansion of the geographic range of insect pests (Elphinstone and Toth 2008), increased abundance

of tropical insect species (Cannon 1998, Patterson *et al.* 1999, Bale *et al.* 2002, Diffenbaugh *et al.* 2008), decrease in the relative proportion of temperature sensitive insect population (Petzoldt and Seaman 2010, Sharma *et al.* 2005, 2010), more incidence of insect transmitted viral diseases in plants through range expansion and fast multiplication of insect vectors (Petzoldt and Seaman 2010). Thus, with changing climate condition it is expected that the potato growers have to face new and intense pest problems in the years to come. The climate change lead changes in insect-pest status which will seriously affect agricultural production and the livelihood of farmers in the country where larger portion of work force is directly dependent on climate sensitive sectors such as agriculture (Chahal *et al.* 2008, Deka *et al.* 2008).

The Indian climate has undergone significant changes showing increasing trends in annual temperature with an average of 0.56°C rise over last 100 years (IPCC 2007, Rao *et al.* 2009, IMD 2010). Warming was more pronounced during post monsoon and winter season with increase in number of warmer days in a year (IMD 2010). Even though, there was slight increase in total rainfall received, number of rainy days decreased. The rain fed zone of the country shown significant

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negative trends in annual rainfall (De and Mukhopadhyay 1998, Lal 2003, Rao *et al.* 2009). By the end of this century (2100), the temperature in India is likely to increase by 1-5°C (De and Mukhopadhyay 1998, Lal 2003, IPCC 2007, IMD 2010). According to the estimates of NATCOM (2004), there will be 15-40% increase in rainfall with high degree of variation in its distribution. Apart from this, the country is likely to experience frequently occurring extreme events like heat and cold waves, heavy tropical cyclones, frosts, droughts and floods (NATCOM 2004, IPCC 2007). Being a tropical country, India is more challenged with impacts of looming climate change (Chahal *et al.* 2008). Already, the productivity of Indian agriculture is limited by its high dependency on monsoon rainfall which is most often erratic and inadequate in its distribution (Chand and Raju 2009). The country is experiencing declining trend of agricultural productivity due to fluctuating temperatures (Samra and Singh 2004, Aggarwal 2008, Joshi and Viraktamath 2004), frequently occurring droughts and floods (Samra 2003), problem soils, and increased outbreaks of insect-pests (Joshi and Viraktamath 2004, Srikanth 2007, Dhawan *et al.* 2007) and diseases. Many states like Maharashtra, Andhra Pradesh, Bihar, Chhattisgarh and Uttar Pradesh in the country are experiencing mild to severe drought condition since 2014.

Potato belongs to the crop that grows even in unfavorable conditions like high altitudes to warmer pockets of the country. Moreover a few other crops produce comparatively high yields of nutrients per unit area where land is scarce. That's why potatoes are highly important for many marginal families of the country. High production levels and highly perishable sale practices enable farmers to be competitive despite the fact of high input cost, labour problem and forced gluts, still potato is an important cash crop and cultivated mainly as an irrigated winter cash crop. Among the various factors related to insect pest and diseases, potato farmers are increasingly forced to face water stress change, changes in rainfall patterns and its intensity, frost and fog etc. These conditions are generally interpreted to climate changes. Potato production is highly dependent on climate and weather factors. All climate change projections are based on simulations and therefore involve uncertainties. However, it is clear that climate change will not only affect the cultivation system but also change the pressure of insect pest. At present, most of the potato seed is grown in Northern plains under no or low aphid period in order to keep it virus free but change in climate, in certain regions aphids will occur in greater numbers and different periods, resulting threat particularly to virus free seed production. In this article, It is emphasized that the impacts of climate change on crop production mediated through changes in populations of serious insect-pests need to be given careful attention for planning of adaptation and mitigation strategies for insect pest management.

Insects and environment

Temperature is probably single most important factor which influences distribution, development, survival,

behaviour and its life cycle. Insect life stage, predictions are most often calculated using accumulated degree days from a base temperature and bio fix point. Few researchers believe that effect of temperature on insect largely overwhelms the effects of other environmental factors (Bale *et al.* 2002). It has been estimated that a 2°C temperature increase insects might experiencing one to five additional life cycles per seasons (Yamarusa and Kiritani 1998). Other researchers have found that moisture and CO₂ effects on insects can be potentially important consideration in a global climate change setting (Hamilton 2005, Coviella and Trumble 1999, Hunter 2001).

Effect of rising temperature on insect pests of potato

Climate change resulting in increasing temperature could impact crop insect pests in several ways. One way temperature effect recent trend to decline insect populations especially in tropical regions, while in temperate regions, warmer temperature will result in more types and higher populations of insects.

Increased temperature increase insect pest population

Development strategy of insect species can exert different effects (Bale *et al.* 2002). Temperature can potentially effect insect survival; population size and life cycle beside that also affect insect physiology and development directly or indirectly through the physiology or existence of hosts. Some soil insects which take several days to complete one life cycle like white grub, cut worm, potato tuber moth will tend to moderate temperature or variability over the course of their life history. Some potato crop pests like aphids, white fly, leaf hoppers, mite and thrips are developed more rapidly during periods of time with suitable temperature. Increased temperatures will accelerate the development of these insects on potato crop possibly resulting in more members and generation per year.

Migratory insects such as aphids which are an important insect vector of potato may arrive in Northern plains earlier or the area in which they are able to over winter may be expanded. Natural enemy of insects may respond differently to insect host due to change in temperature. Parasitism could be reduced if host populations emerge and pass through vulnerable life stages before emergence of parasitoids. Host may pass through vulnerable life stages more quickly at higher temperature, reducing the chance of parasitism. Temperature may change gender ratio of thrips (Lewis 1997) potentially affecting reproduction rates. Insects that spend important parts of their life histories in the soil may be more gradually affected by the temperature change than those that are above ground simply because soil provides insulation medium that will tend to buffer temperature changes more than air (Bale *et al.* 2002). Lower winter mortality of insects due to warmer winter temperatures could be important in increasing insect population (Harrington *et al.* 2001). Insect species diversing per area tends to decrease with higher latitude (Gastan and willims 1996, Andrew and Hughes 2005), meaning that rising temperatures could result in more

insect species attacking more hosts in temperate climates (Bale *et al.* 2002).

Findings from Peru suggested that global warming is already affecting the distribution of crop insect pests. Scientist from CIP and the partner institutions are of the opinion that current balance of insect populations is almost certain to be upset. In the opinion of Dr Aziz Lagnoai, entomologist from CIP, Lima Peru, climate change will favour invaders over native species. Some insect pests will become more important while others will decline but the net effect will be to increase the pressure of pests on the crop yields. Experience from Canete Valley in Peru revealed that when white flies are few in number, their feeding on crops pose little damage. But if sprayed, they soon developed resistance and multiply. At high population density, white fly can destroy whole crop stand (Singh and Narayana Bhat 2008).

In India, *B. tabaci* was a minor pest till recently. Data on population buildup during the last 28 years revealed that average population of *B. tabaci* was 11 whitefly /100 compound leaves during 1984 which rose to 198.6/100 compound leaves in 2011. During this period, average ambient temperature increased by 1.07°C. This indicates that climate warming may lead to whitefly infestation in Indo-Gangetic plains. Increase in *B. tabaci* population led to outbreak of a new viral disease known as apical leaf curl in potato which has since been identified as a Gemini virus. Gemini Viruses are not reported to infect potato crop world over. Therefore, a new dimension has been added to potato seed production in sub-tropics. The infestation of this virus in some of the varieties, *viz.* Kufri Pukhraj, Kufri Anand, Kufri Sutlej reached almost 100% in seed stocks (Singh and Narayana Bhat 2008). Consequently, altogether new approach was adopted to manage this virus which included discarding of the old stocks and their replacement with disease-free stocks from tissue culture and integrated management of whitefly which included delayed planting, seed treatment and weekly application of insecticides including summer oil (Chandel *et al.* 2010). This disease has since been contained but the danger persists.

Empoasca fabae (leaf hopper) is another pest which has assumed significance in early planted crop in sub-tropical plains of India. Its population during 1984 was 16.6 which rose to 23.8 in 2004. The hopper burn damage also increased from 45 to 68% during this intervening period. Sudden warming up of temperature may also lead to flaring up of the pest. This has happened during 2006-07 in Gujarat. Temperature profile of the region revealed that during crop period right from December to first week of January, ambient temperature was higher and relative humidity was lower than previous years. The increase in temperature was up to 5.8°C during fourth week of December, 2006. This increase in temperature led to faster multiplication of the pest and consequently

very heavy (up to 100%) hopper burn damage (Singh *et al.* 2007).

Similar to hopper damage, mite infestation has also increased in early planted crop. During 1984-85, its damage was 86% which increased to 100% in 2004 (Singh and Narayana Bhat 2008). Results tend to suggest that in sub-tropical plains of India, *Myzus persicae* population is on the rise. During 1984-85, mean aphids population/100 compound leaves were 567 which increased to 728 in 2011-12. On the other hand, population of *Aphis gossypii* has increased three fold during the last 28 years (Bhatnagar 2013). Although *A. gossypii* has low vector efficiency but its appearance right from the emergence of the crop and further maintaining its population throughout the crop season may pose serious problems to seed production in sub-tropical plains.

Increased temperature decrease insect pest populations

Temperature increases that caused farmer's not to grow host crop specific to potato as insect population would be decreased. Some environmental factors that can impact insect pests and their natural enemies that infect the pests, resulting in increasing attack on insect populations. At higher temperatures, aphids have been shown to be less responsive to the aphid alarm pheromone they release when under attack by natural enemies, resulting more predation (Awmack *et al.* 1997).

Effect of precipitation on insect pest populations

Only few scientific studies have been carried out on the effect of precipitation on insects than temperature. Many insect are sensitive to precipitation and are killed or removed from host plants by heavy rains, this consideration is important when choosing management options for thrips (Reincrs and Petzoldt 2005). Some insects like white grub, termite that over winter in soil, flooding the soil has been used as an effective measure. One would expect the predicted more frequent and intense precipitation, forecasted with climate change to negatively impact on these insects. Fungal pathogens of insects are favoured by high humidity and their incidence would be increased by climate changes that lengthen periods of high humidity and reduce by those that result in drier conditions.

Effect of CO₂ on insect population

In general, CO₂ impact on insects is thought to be indirect impact on insect damage results from changes in the host crop. Some workers have found that rising CO₂ can potentially have important effect on insect pest problems. Recently, free air gas concentration enrichment technology (FACE) was used to create an atmosphere with CO₂ and O₂ concentrations similar to what climate change models predict for the middle of the 21st century. Studies carried out by Bezemer *et al.* (1998) revealed that aphid abundance was enhanced by both the carbon dioxide and temperature. Parasitism rates remained unchanged in elevated carbon

dioxide but showed an increasing trend in conditions of elevated temperature.

Effect on geographic ranges

The geographic distribution and abundance of living species in nature is determined by species specific climate requirements essential for their growth, survival and reproduction. Altered temperature and rainfall regimes with the predictable changes in climate will determine the future distribution, survival and reproduction of the species (NACCAP 2008). With rise in temperature, the insect-pests of potato are expected to extend their geographic range from tropics and subtropics to temperate regions at higher altitudes along with shifts in cultivation areas of their host plants (Hill and Dymock 1989, Parry and Carter 1989, Kuchlein *et al.* 1997, Logan *et al.* 2003, Sharma *et al.* 2005, 2010). This may lead to increased abundance of tropical insect species (Patterson *et al.* 1999, Bale *et al.* 2002, Diffenbaugh *et al.* 2008) and sudden outbreaks of insect-pests can wipe out certain crop species entirely (Kannan and James 2009). Mostly the Polar Regions are constrained from the insect outbreaks due to low temperature and frequently occurring frosts (Volney and Fleming 2000). In future, projected climate warming (Carroll *et al.* 2004) and increased drought incidence (Logan *et al.* 2003) is expected to cause more frequent insect outbreaks in temperate regions also.

Effect on increased overwintering survival

Diapause is a period of suspended developmental activities, the manifestation of which is governed by environmental factors like temperature, humidity and photoperiod. As an adaptive trait, diapause plays vital role in seasonal regulation of insect life cycles because of which the insects have better advantage to survive great deal of environmental adversities. There are two main types of insect diapause; aestivation and hibernation to sustain life under high and low temperature extremes respectively (Chapman 1998). Looking at the past 100 years climate profile of India, warming was more pronounced during winter season and it was the minimum and not the maximum temperature where significant increase was observed (IMD 2010). The temperature in India is expected to increase by 1-5°C within next 100 years (De and Mukhopadhyay 1998, Lal 2003, IPCC 2007, IMD 2010). Thus, insects undergoing a winter diapause are likely to experience the most significant changes in their thermal environment (Bale and Hayward 2010). Accelerated metabolic rates at higher temperatures shorten the duration of insect diapause due to quick depletion of stored nutrient (Hahn and Denlinger 2007). Warming in winter may cause delay in onset and early summer may lead to faster termination of diapause in insects, which can then resume their active growth and development. This gives an important implication that increase in temperature in the range of 1 °C to 5°C would increase insect survival due to low winter mortality, increased population built-up, early infestations and resultant crop damage by insect-pests under global warming

scenario (Harrington *et al.* 2001, Sharma *et al.* 2005, 2010).

Effect on increase in number of generations

Now, it is very well understood that the temperature being the one of the most important regulating factor for insects (Yamamura and Kiritani 1998, Bale *et al.* 2002, Petzold and Seaman 2010), global increase in temperature within certain favourable range may accelerate the rates of development, reproduction and survival in tropical and subtropical insects. Consequently, insects will be capable of completing more number of generations per year and ultimately it will result in more crop damage (Yamamura and Kiritani 1998, Petzold and Seaman 2010).

Effect on insect pest population dynamics and outbreaks

Climate change resultant abiotic environment like temperature, elevated CO₂ and depleted soil moisture etc. will significantly affect the diversity and distribution of insect-pests through geographic range expansion, increased overwintering survival and more number of generations in a year, thereby increasing the extent of crop losses. It may result in disturbing ecological balance because of unpredictable changes in the population of insect-pests along with their existing and potential natural enemies (Rao *et al.* 2006). Changes in climatic variables have led to increased frequency and intensity of outbreaks of insect-pests. Outbreak of whitefly on cotton in Punjab state during 2015-16 resulted in 30-50% yield losses. Whitefly is an important vector of potato crop and Punjab is one of the important states of potato seed production.

Effect on host plant resistance

Host plant resistance is one of the environment friendly options for managing insect-pests of potato wherein the plant can experience less damage caused by insect-pests through various mechanisms like preference and non-preference, antibiosis and tolerance (Painter 1968). However, expression of the host plant resistance is greatly influenced by environmental factors like temperature, humidity, sunlight, soil moisture, air pollution, etc. Under stressful condition, plant becomes more susceptible to attack by insect-pests because of weakening of defense system resulting in pest outbreaks and more crop damage (Rhoades 1985). With global temperature rise and increased water stress, tropical countries like India may face the problem of severe yield loss in sorghum due to breakdown of resistance against midge and spotted stem borer (Sharma *et al.* 2005).

Effect on changing insect pest scenario and its socio-economic impacts

Effect on changing insect pest scenario and resultant crop losses will have serious environmental, social and economic impacts on farmers whose livelihoods depend directly on the agriculture income.

New and intense insect pest problems in ecosystem

The farmers have to face new and intense insect pest

problems due to spread of these pests in to new areas along with shift in crop cultivation areas of host crops (Elphinstone and Toth 2008, Petzoldt and Seaman 2010). Therefore, insect management strategies will be changed in relation with the changes in pest incidence and extent of crop losses due to changing climate. In India, *B. tabaci* was a minor pest of potato till 2001. Data on population buildup during the last 28 years revealed that average population of *B. tabaci* was 11 whitefly /100 leaves during 1984 which rose to 198.6/100 leaves in 2011.

Effectiveness of pest management strategies

Various effective cultural practices used in insect pest management like rotation of crops, change in planting dates, crop sequence, trap crops, barrier crops etc. will be less or not effective with change in climatic condition because of shrinking of crop growing seasons, colonization of crops by early insect arrival and or increased winter survival (Sharma *et al.* 2005, Petzoldt and Seaman 2010). Certain pesticides like pyrethroids, organophosphates, carbamates and biopesticides in particular being highly thermo-unstable degrade faster at higher temperatures. Altered temperature regimes may render many of these products to be less or no effective in pest control, necessitating frequent insecticide applications for effective control (Musser and Shelton 2005). This may intensify the pest problems due to the increased chances of resistance development in insects. Ultimately it will add to increased cost of crop protection to the farmers and in turn environmental cost (Musser and Shelton 2005, NACCAP 2008, Petzoldt and Seaman 2010). The forecasting models of aphid/whitefly arrival/ infestations based on earlier climate profiles need to be further revised in accordance with location specific changes in climate in order to provide precise forecast of the insect pest incidence in ecosystem. This will further reduced the aphid free period for breeder seed production especially in north-western India.

Effect on sustainability of food security

In the coming century, the greatest challenge for humanity is to many folds increase the food production to meet the ever growing population especially in South Asia by sustainable use of shrinking natural resource base (Deka *et al.* 2008). The climate change is likely to affect the extent of entomophilies pollination by disrupting the synchrony between plant-pollinator life cycles (Kudo *et al.* 2004), with an estimated risk of reduction in world food production by one-third (Klein *et al.* 2007). This has major implication for food and nutritional security (FAO 2008). This may have direct bearing on the livelihood of the rural poor as their survival is directly linked to outcomes from food production systems. However, potato is a vegetatively prorogated crop and it will address future food security and poverty alleviation.

Effect on adaptation strategies in potato production due to changing pest scenario

It is likely that farmers will experience extensive

impacts on insect management strategies with change in climate. It is assumed that insects will expand their geographic ranges and increase reproduction rates. This means that it is likely that farmers will have more types and higher number of insects to manage. Based on current comparison of pesticides used by southern states as compared to northern states of the country, insecticides and their applications have significant economic costs for growers and environmental cost for society. Additionally, some classes of pesticides like pyrethroids and spinosad have been shown to be less effective in controlling insects at higher temperatures (Musser and Shelton 2005). It is predicted that additional generations of important insect pests of potato specifically in temperate climate as a result of increased temperatures required more insecticide application to maintain population below economic threshold levels. One of the ways to avoid insecticide resistance is to apply insecticide with a particular mode of action less frequently (Shelton *et al.* 2001). With more insecticide applications required the probability of applying a given mode of action insecticide more times in a season will increase, thus increasing the probability of more and more members of insects developing resistance to insecticides specially sucking insects of potato.

A number of cultural practices that can be used by Indian farmers could be affected by change in climate. Although it is not clear whether these practices would be helped, hindered or not affected by the anticipated changes. Using crop rotation as an insect management strategy could be less effective with earlier insect arrival or increased over wintering of insects. However, this can be balanced by change in the earliness of crop planting time, development and harvest. Row covers used for insect exclusion might have to be removed earlier to prevent crop damage by excessive temperatures under the covers would the targeted early insects is also complete their damaging periods earlier or be ready to attack when the row covers were removed.

Climate change is a slow and gradual process that will give enough opportunity to Indian farmers to adopt them. It is not very well understood, how these changes will affect potato crop, insect, disease, natural enemies and their complex relationship among them. It is likely that new insect pests of potato will become stabilized in narrower areas and to be able attack on plants in new regions. It is likely that plants in some regions will be attacked more frequently by certain pests. A few pests may be less likely to attack on crop as changes occur. It is likely that we will not know the actual impact of the climate change on pests until they occur. Clearly, it will be important for farmers to be aware of crop pest trends in their regions and flexible in choosing both their management methods and in the crop they grow. It is important that the potato farmers closely monitor the occurrence of insect pests in their fields and keep records of their incidence frequency and cost of managing pests over time will be a better position to make decisions about whether it remains economical to continue to grow potato crop with appropriate pest management techniques. It is

important that farmers may use integrated pest management practices more precisely such as monitoring of insect vectors, forecasting, keeping records of insect pest incidence and choosing economically and environmentally sound control measures will be most likely to be successful in dealing with the effects of climate change.

Conditions are more favourable for the proliferation of insect pests in warmer climate, whereas, warmer winter temperatures may also allow larvae to over winter in areas where they are now limited by cold, thus causing greater infestation during the following crop season. Altered wind patterns may change the spread of air borne insects like thrips and aphids. The possible increases in insect pests infestation may bring about greater use of insecticide to manage them, a situation that will require the further development and application of integrated pests management techniques. Some insect pests that are currently present at low levels or that are not considered a threat at this time, may become more prevalent.

Sensitization of stakeholders about climate change

Considering the impacts of future climate change on sustainability and productivity of potato, especially in the developing countries like India, there is an urgent need to sensitize the farmers, extension workers and other stakeholders involved in supply chain management of food crops about the climate change and associated changes in incidence of pests and diseases of major crops in their regions and adaptation strategies to cope with the situation. This can be achieved through awareness campaigns, training and capacity-building programmes, development of learning material and support guides for different risk scenarios of pest.

Farmers' participatory research for adaptability of climate change

The decision making ability and adaptive capacity of farmers can be enhanced through the integration of a farmers' participatory and multidisciplinary research approach involving research and developmental organizations and farmers as equal partners. This will help to improve the channels of communication between researchers and farmers for dissemination of knowledge and information regarding the current advances in the provision of weather and climate information, weather based agro-advisory services for facilitating operational decisions at farm level. A decision support system (DSS) involving mechanisms for collection and dissemination of information on insect-pest data under diverse environmental conditions for improved assessments well in advance needs to be developed.

Resource conservation technologies

Conservation of natural resources can be promoted by giving incentives to the farmers those who are adopting environmental conserving pest management activities such as organic farming, bio-control, integrated pest management, natural and habitat conservation for important insect

pollinators, etc. Strategies for adaptation and coping could benefit from combining scientific and indigenous technical knowledge (ITK), especially in developing countries like India where technology is least developed. ITK is helpful to adapt the adverse effects of changing climate.

Future challenges

In order to counter the changes in climate in addition to above strategies, we have to decide the future line of research for combating the pest problems under climate change.

Genetic base and breeding of climate-resilient potato varieties

In order to minimize the impacts of climate, we have to breed new potato varieties for improved resistance/tolerance to biotic and abiotic stresses. Considering late onset and/ or shorter duration of winter, there is chance of delaying and shortening the growing seasons for certain Rabi/ cold season crops, which is a main potato growing season in the country. Hence we should concentrate on breeding varieties suitable for late or early planting and those can sustain adverse climatic conditions and pest and disease incidences as per the cropping system of different agro-climatic zones of India.

Change of crop calendars

Increase in temperature and rainfall patterns will be result in shrinking or increasing of crop growing seasons with severe problems of early or late insect infestations. As such certain effective cultural practices like crop rotation and planting dates will be less or not effective in controlling crop pests with changed climate. Hence, there is need to change the crop calendars according to the changing crop environment of different agro-climatic zones of India.

Use of local satellites-GIS based risk mapping

Geographic Information System (GIS) based technology help in outlining the insect pest outbreaks in different agro-climatic zones, hence could be best utilized in pest prone areas. In what ways, climatic changes will affect development, incidence, and population dynamics of insect pests can be studied through GIS by predicting and mapping trends of potential changes in geographical distribution (Sharma *et al.* 2010) and delineation of agro-ecological hotspots and future areas of pest risk (Yadav *et al.* 2010).

Evaluation and novel mode of action of pesticides

Insecticides resistance management studies on sucking pests especially aphids, whiteflies and hoppers has been gaining momentum. It has been reported that the application of neonicotinoid insecticides for controlling sucking pests induces salicylic acid, associated plant defense responses which enhance plant vigour and abiotic stress tolerance, independent of their insecticidal action (Gonias *et al.* 2003, Thielert 2006, Horii *et al.* 2007, Chiriboga *et al.* 2009, Ford *et al.* 2010). Such more compounds needs to be identified

for use in future crop pest management programme of potato crop under change of climate scenario.

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