IJABR Vol. 7(1): 56 - 65 (2016)

International Journal of Applied Biological Research 2016

Review Article

CLIMATE CHANGE AND VIRAL DISEASES IN RELATION TO CROP PRODUCTIVITY AND FOOD SECURITY: A REVIEW

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Submitted: April, 2016; Accepted: May, 2016; Published: June, 2016.

ABSTRACT

Food shortage is prevalent in sub-saharan Africa and the situation is worsened by climate change which has become a subject of discourse in the recent years. Climate change is caused by accelerating rise in temperature, carbon dioxide levels and irregularity of rainfall. Apart from its direct impact on crop production and productivity, climate change can aggravate pest damage to crops. It has also been predicted that climate change may lead to geographic expansion of viruses and vector distribution. New viral disease complexes may arise, and plant viruses may follow migrating hosts to infect vegetation in natural plant communities which may induce an epidemic. Climate change may alter the suitability of crops and other plants for certain locations. Global agro-climatic zones are expected to shift as the climate changes and trade patterns will also vary as a result of these changes. Challenges imposed by climate change can be partly mitigated by integrated management systems, especially the development and deployment of well-adapted virus-resistant varieties, using the traditional or transgenic technique and biological control of virus vectors.

KEYWORDS: Climate change, crop productivity, malnutrition, sub-saharan Africa, viral diseases

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INTRODUCTION

Food is one of the basic needs for human existence. However, meeting this need has been a herculean task particularly in sub-saharan Africa where extreme weather linked to climate change is contributing to deaths from malnutrition, poverty and diseases (Gautam and Bhardwaj, 2011). Climate is the average weather pattern of a place over a long period of time (not less than 30 years). It is induced by human activities (Ghini *et al.*, 2008) and has been acknowledged as the greatest challenge to mankind, which causes nearly 400, 000 deaths a year, in addition to over US$ 1.2 trillion losses globally. The impact of climate change has serious consequences on agricultural activities owing to 0.74 °C average annual global increase in temperature in the last 100 years and atmospheric CO_2 concentration increase from 280 ppm in 1750 to 400 ppm in 2013. These changes have negatively impacted on the cultivation and growth of the different crops on the earth (Gautam *et al.*, 2013). Changes in climate are still going unabated and it has been projected that temperature will increase by 3.4 °C and CO_2 concentration to 1250 ppm by the year 2095, as a result of gas emission generated by humans. Climate encompasses abiotic factors such as rainfall, temperature, sunshine, relative humidity and wind. These fundamental components of climate exert obvious impacts on crop production and yield per unit area, individually or through their interactions (Gautam *et al.*, 2013).

Climate change has the tendency to increase frequency of drought, flood, and heat waves (Mittler and Blumwald, 2010) and may reduce growing season in many regions. In addition, it causes extensive salinization as sea levels rise, and a decrease in land suitable for agriculture particularly in central Europe and central Africa. Viral infections can reduce plant growth by suppressing photosynthesis (Técsi *et al.*, 1996) and can make infected plants more attractive to insects by inducing different colours on such plants. In some cases virus-infected plants are better hosts for insects, resulting in increased feeding, whereas in other cases virus-infected plants are poor hosts, and insects leave quickly after probing the plants (Mauck *et al.*, 2012), depending on the compounds produced as a result of viral attack.

There are numerous economically important viruses limiting crop productivity worldover. High incidence and severity of viral infections can drastically reduce crop yield (Picó *et al.*, 1996), resulting in huge economic losses. Increased temperatures and alteration of rainfall patterns have an impact on the persistence and distribution pattern of viruses and host susceptibility (FAO, 2008). Moreover, virus replication, stability, survival, synergism, transmission and perpetuation depend largely on elements of climate, either directly or indirectly (Jones, 2009; Navas-Castillo *et al.*, 2011). Therefore, the impacts of climate change on viral diseases are somewhat complex because of the associated changes in host distribution and phenology. It also encourages dynamics in plant-associated microflora and exerts direct biological effects on pathogens in the face of rapid co-evolution. Combined insect pest and disease attacks in plants could cause up to 20 % losses in potential yield of major food and cash crops worldwide (Thind, 2012). There are also clear evidences that climate change is altering the distribution, incidence and intensity of plant pests and diseases (Herrera *et al.*, 2011).

Climatic conditions have a major influence on the survival, propagation and dispersal of plant pathogens. Environmental factors influence each element of epidemics including host, virus and vector. There are many viruses transmitted by insects and activities of these vectors are directly regulated by elements of climate. Since climate exerts significant effect on dispersal of insects, it appears that introduction and distribution of alien insect pests is likely to be aggravated. Favourable climate would favour overwintering insects and ultimately accelerate the spread of viruses by migrating vectors like aphids. For example, in *Musa* sp. the epidemiology of *Banana bunchy top virus* (BBTV) is influenced by environmental factors which affect both disease incidence and behaviour of its aphid vector, *Pentalonia nigronervosa* Coquerel (Raymundo and Pangga, 2011). Additionally, climate change affects the distribution and degree of infestation of insect pests through both direct effects on their life cycle and indirectly on hosts, predators, competitors, and insect pathogens (Warren *et al.*, 2001). Movement of migratory vectors is dependent on air currents and temperatures. Vector biology such as growth and multiplication is generally influenced by temperature, moisture and daylight. All these suggest that insect pests and pathogens that were once minor problems can turn into major constraints and change their range of distribution with climate change (Herrera *et al.* 2011; Karuppaiah and Sujayanad, 2012).

Although crop production still thrives under the prevailing climate change, all climate models predict that there will be more extreme weather conditions in the near future, with more droughts, heavy rainfall and storms in agricultural production regions. Such extreme weather conditions would determine where and when diseases will occur, and definitely reduce crop yield (Gautam *et al.*, 2013). Effective implementation of disease management practices requires knowledge of the various biological features that mediate pathogen transmission (Almeida *et al.*, 2005). An indepth understanding of the potential impacts of climate change would offer opportunities to minimize potential losses from plant diseases (Chakraborty and Datta, 2003). Therefore, this review highlights the impacts of climate change on crop productivity and food security.

EFFECTS ON HOST PLANT, DISEASE INCIDENCE AND SEVERITY

Climate change, even in the absence of pathogen would have a lot of impacts on plants which may bring about changes that will affect their interactions with pathogens (Garrett *et al.*, 2006). For instance, changes in plant architecture may affect microclimate and thus risks of infection (Burdon, 1987). Climate change may trigger increase in plant density which can increase leaf surface wetness and so make infection by foliar pathogens more likely (Huntley *et al.*, 2004). The effect of elevated temperatures on plants can be manifested in various ways. At low temperatures, plant stress may be relieved, whereas during hotter parts of the year, it may increase. When high-temperature stress is aggravated, plant responses may be similar to those induced by water stress. These include symptoms such as wilting, leaf burn, leaf folding and abscission. Others are changes in physiological responses including modification of RNA metabolism and protein synthesis, enzymes, isoenzymes, and plant growth hormones (Christiansen and Lewis, 1982). These changes may result in susceptibility to pathogens and crop loss. For example, the potential effect of temperature on the yield of rice in the Philippines was estimated to decline by 10 % for each 1 °C increase in the minimum temperature during the dry season (Peng *et al.*, 2004). In addition, elevated ozone concentrations can change the structure of leaf surfaces (Peng *et al.*, 2004).

Climate, particularly environmental temperature, frequently plays an important role in disease epidemiology (Daugherty *et al.*, 2009). Plant responses to different stresses are highly complex and are expressed at RNA molecule, cellular, and physiological levels (Atkinson and Urwin, 2012). A change in variability of rainfall and temperature may itself affect yields as well as adversely affect nutritional quality of crops (Porter and Semenov, 2005). Heat and drought stress can cause disproportionate damage to crops compared with either stress individually (Barnabas *et al.*, 2008). Temperature may influence the disease process in virus-infected plants (Matthews, 1981) and its impact on virus can be manifested in different forms.

According to Wang *et al.* (2009), a higher growth temperature may either increase or decrease disease resistance, thus revealing a differential impact of the same temperature on different plant-pathogen systems. Expression of resistance to infection is based on the understanding that viral infection in a host plant activates a defence mechanism related to post-transcriptional gene silencing (PTGS) which results in degradation of viral RNA and slows down or limits virus accumulation and systemic infection. This process is facilitated by double-stranded RNA (dsRNA), synthesized by replicative intermediates of single-stranded RNA (ssRNA) viruses. It could also result from genomic or defective viral ssRNAs with extensive secondary structure, which is cleaved by Dicer-like enzymes to produce 21–24 nucleotide (nt) fragments called small interfering RNAs (siRNAs) (Baulcombe, 2004). Thus virus accumulation at high temperature could be attributable to slow virus replication due to loss of replicase activity, or from increased RNA breakdown due to temperature (Vela´zquez *et al.*, 2010).

The sensitivity of resistance genes to different temperatures has been reported for many viral resistance genes. For example, in tobacco (*Nicotianatabacum* L.) the *Tm*-1 gene suppressed symptoms elicited by *Tobacco mosaic virus* (TMV) strain 0, when plants were grown at constant temperatures from 20 to 35 °C; high temperatures greatly reduced virus multiplication (Fraser and Loughlin, 1982). On the other hand, TMV-1 induced more severe symptoms at higher temperatures. Tomato plants coded with *Tm*-2 or *Tm*-2^2 gene for TMV resistance were symptomless at normal temperatures when inoculated with strain 0, whereas severe systemic necrosis occurred at elevated temperatures (Pelham, 1972). Similar effects of high temperature on resistance to TMV have also been reported in transgenic tobacco exhibiting the coat protein of TMV (Nejidat and Beachy, 1989). In temperature sensitive resistance systems, the breaking or change in the resistance of cultivars is often accompanied by inability of such cultivars to limit virus spread. However, it is possible that the hypersensitive response that limits viral movement at normal temperatures is affected at high temperatures. It has been observed in soybean (*Glycinemax* [L.] Merr.)that systemic necrosis changed to systemic mosaic at temperatures above 28 °C (Tu and Buzzell, 1987). However, Carnegie e*t al.* (2010) reported the greatest incidence of *Potato mop-top virus* (PMTV) on plants grown at low (16 °C) temperature and absence of symptoms at elevated (24 °C) temperature.

In another study, Ochoa *et al.* (1996) documented that symptoms caused by *Tospovirus* in Chrysanthemum reached the highest expression when the mean temperature was 27 °C. High-temperature regime (daytime, 29 ± 2 °C; night-time, 24 ± 3 °C) resulted in an increase in both incidence and rate of the symptoms expression on *Physalisixocarpa* and *Daturastramonium*, when compared with low temperatures (daytime, 23 ± 1 °C; night-time, 18 ± 2 °C) (Llamas-Llamas *et al.*, 1998). Therefore, both low and high temperatures may affect disease resistance in plants, which in turn impact negatively on virus pathogenicity with grave consequences on crop productivity (Navas-Castillo *et al.*, 2011). Similarly, moisture can impact both host plants and virus in various ways. For instance, drought stress has been observed to influence the incidence and severity of *Maize dwarf mosaic* and *Beet yellows viruses* (Olsen *et al.*, 1990; Clover *et al.,* 1999). Conversely, high incidence of *Potato mop-top virus* has been attributed to excessive rainfall (Cooper and Harrison, 1973).

EFFECTS ON INSECT VECTORS

Plant-infecting viruses operate in intimate association with their hosts and vectors (Malmstrom *et al.*, 2011). Climate change may expose insects to different photoperiod in addition to increased temperatures. This in turn affects both host plant and insect-vector populations, thereby affecting the spread of plant viruses (Jones, 2009). Changes in abiotic factors will affect insect performance not only directly, but also indirectly by influencing their food quality and natural enemies (Berggren *et al.*, 2009). Climate change can mediate primary infection of the host and spread of the virus within the host and transmission of the pathogen to new hosts by the vector. Also, it may modify the phenology and physiology of the host, which may affect its susceptibility to virus as well as the ability of the virus to infect. Subsequently, alteration of host physiology can facilitate the attractiveness of the host to vectors and spread of the virus. Disruption of the geographic range of virus vectors can aggravate density, migration and activities of the vectors.

Elevated temperature may aggravate multiplication and movement of airborne virus vectors such as winged aphids (Raymundo and Bajet, 2000). This is based on the fact that increased temperatures are usually related to increased fitness, higher survival rates, and shorter development times (Bale *et al.*, 2002). In contrast, it has been projected that as future temperature rises due to climate change, bunchy top disease spread will be slower in certain tropical areas as the aphid vector will reproduce less and the bunchy top virus will be transmitted less efficiently (Anhalt and Almeida, 2008). Recently, a study has shown that larval development could be shortened in a warmer climate and thereby decreasing the risk of predation which may increase the risk for insect outbreaks (Kollberg *et al.*, 2013). Although increased CO_2 levels have little direct impact on insect predators, they can affect the third trophic level indirectly by altering the density and composition of populations of prey insects available to predators (Jones, 2009). Wind also influences virus spread through its impact on air borne vectors.

Although winged aphids do not fly when wind speed is high, they may be transported over long distances by strong wind (Parry, 2013). Disruption of the populations and long-distance movement of insect vectors have been implicated in the emergence of some economically important viral diseases such as tomato yellow leaf curl disease, African cassava mosaic disease, *Ipomovirus* diseases of cucurbits, tomato chlorosis caused by *Criniviruses*, and the torrado-like diseases of tomato (Navas-Castillo *et al.*, 2011). Elevated temperatures speed up biochemical reactions particularly catabolism and anabolism that require energy, thereby increasing activity, growth, development, and reproduction. Unfortunately, rapid metabolism is detrimental in some ways because it requires higher food consumption rates to maintain a positive energy balance. This phenomenon can decrease survival as temperature increases, particularly for non-feeding free-living stages such as eggs, cysts and larvae (King and Monis, 2007). For instance, the survival of *Cryptosporidiumparvum* cysts was retarded with prolonged exposure to warm temperatures because increased metabolism drained the energy reserves in cysts (Fayer *et al.*, 1998).

COPING STRATEGIES AND CONCLUSION

Changing disease scenario due to climate change underscores the need for sound agricultural practices and use of ecofriendly methods in disease management in order to achieve sustainable crop production (Boonekamp, 2012). As a result of changing climate and shift in seasons, choice of crop management practices based on prevailing situation is essential. Therefore, there is need to adopt novel approaches to counter the resurgence of viral diseases under changed climatic scenario. Cultivation of resistant varieties is one of the best strategies for mitigating the negative effects of climate change on agricultural crops. To achieve this, molecular biology which offers an exciting array of opportunities to augment traditional plant breeding and to transfer novel genes from alien species through genetic engineering (Bennetzen, 1995) could be exploited. Adoption of plant protection pesticides is an option against virus vectors. More importantly is the application of decision support tools such as integrated pest management (Gautam and Bhardwaj, 2011). Applications of botanical pesticides and plant-derived soil amendments such as neem oil and neem cake and karanja seed extract would also help to mitigate climate change effects as they reduce nitrous oxide emission by nitrification inhibitors such as nitrapyrin and dicyandiamide (Pathak , 2010). In view of the increasing harmful consequences of climate change, there is need for better collaboration both within and across countries. Additional research is needed to increase the resilience of agricultural systems to climate change and its deleterious impacts in order to prioritize risks and improve the reliability of predictions. This includes more dialogue in the scientific community and among trade policy practitioners on how to deal with issues relating to climate and food insecurity (Sutherst, 2008).

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