THEORETICAL BIOLOGY FORUM

TBF : 80-83 (2022)
Review Article

Climate Change Impact on Pests and Disease Intensityof Rice

Kasthuri Rajamani[1]*, Lydia Chintagunta[2] and G. Bhupal Raj[2]

[1]Professor Jayashankar Telangana State Agricultural University, Hyderabad, Telangana, India.
[2]School of Agriculture, SR University, Warangal, Telangana, India

ABSTRACT

The impact of climate change on pests and diseases has been the subject of intense debate for more than two decades which poses a considerable threat to sustainable food security. Climate parameters such as increased temperatures, rising atmospheric CO2 and changing precipitation patterns result in an expansion of geographic distribution, increased survival during over-wintering, increased number of generations, altered synchrony of host plants, altered interspecific interaction, increased risk of invasive pests, increased incidence of insect-transmitted plant diseases, and reduced effectiveness of biological control measures of pests and diseases. Further, an increased daily maximum temperature of more than 36°C leads to longer flowering periods which declines spikelet sterility to aggravate yield loss. As a result, there is a serious risk of crop economic losses with a challenge to food security for the growing population. As a major driver of pest and disease population dynamics, climate change elements require adaptive management strategies to deal with the changing status of pests and disease outbreaks. Climate Smart Agriculture Practices (CSAP) is a cross-sectoral approach that aims to reduce pests and disease induced crop losses, enhanced ecosystem services, and decline greenhouse gasses emission intensity per unit of food produced to strengthen the resilience of agricultural systems in the face of climate change.

Keywords- Rice, climate change, climate-smart agriculture, food security, pests, and diseases.

ARTICLE HISTORY

Received: 28 July 2022
Revised: 14 September 2022
Accepted: 28 October 2022
Available Online: 15 November 2022

DOI:
https://doi.org/10.61739/TBF.2022.11.2.80

CORRESPONDING AUTHOR:
Kasthuri Rajamani

E-MAIL ID:
kasthuri.agrico114@gmail.com

INTRODUCTION

The change in climate is across the globe, which knocks the temperature shifts, rising sea levels, and precipitation patterns with unpredictable extreme weather conditions. These effects together with anthropogenic drivers caused global warming since the mid-twentieth century and continues to increase beyond 2°C by 2052 [11]. Abundant evidences from various research studies indicate that climate change can have direct negative impacts on crop yields [16], as well as indirect dreadful effects of pests, pathogens, weeds, and other biotic factors [14] which can influence crop growth, development, and yield formation [2,13]. Predictions of climate change on plant health at various spatio temporal scales measured from seasons to centuries, from the genetics to ecosystem level, from farms to entire continents are based on the observed impacts of pests and diseases, extrapolation from expert knowledge and experimental studies and computer models. Further, it is widely acknowledged that climate change is pervasive across the planet, and these needs to be addressed in agriculture, forestry, landscape management, and nature conservation.

Rice is the main ration crop in India, and more than 60% of Indian people depend on rice for their sustenance [6]. According to statistics, from 2015 to 2022, the average annual rice sown area in India increased from 434.99 to 448.23 lakh ha, which accounts for 27.2% of the average rice area globally. The average annual rice yield was 4.17 t ha-1 in India, a share of 23.9% of the annual global rice yield [12]. Rice yield has doubled in all states in India in the last 30 years [10], which may be related to climate change elements such as temperature and solar radiation. By contrast, very high temperatures (> 35 °C) induce heat stress and affect the plant physiological processes which further leads to spikelet sterility, non-viable pollen, and reduced grain quality. On another side, drought reduces plant transpiration rates resulting in leaf rolling and drying, reduction in leaf expansion & plant biomass, immobilization of solutes, and increased heat stress in leaves. Therefore, it is more important than ever to assess scientific reasons for the impact of climate change on rice production and formulate effective coping strategies to provide theoretical support for overcoming rice yield shortages. Many assessments of climate change impacts on crops have focused on potential yields, but pests and pathogens have major effects to determine actual yields. The temperature rises directly affect pest and disease multiplication, survival, spread and population dynamics, pests and disease interaction with the environmentand natural enemies. Under such weather abnormalities, it is very important to monitor pests and diseases' appearance and abundance at a high pace.

Thus, the objective of this review was to integrate the advances in pests and diseases towards climate change to express the need for advanced research in this area. Further, this paper will review the impact of predicted climate changes, especially the rise of atmospheric carbon dioxide concentrations and temperatures along with changeable precipitation patterns that influence the biology and ecology of harmful pests and diseases, and invasive species which can be a major problem for crop production. Based on this review, potential solutions for the current issues in crop production will be presented in the form of modified integrated pest and disease management strategies for the production of healthy food in an environmentally friendly way, as well as monitoring advanced techniques and modeling tools to predict pests and diseases.

Interactions among global climatic factors

The impact of pests and diseases on rice production in current conditions are well known, even though there's a need to address the consequences of climate change which were imperfectly understood. Pests and diseases are important yield-reducing factors, as well as early indicators of environmental changes because of their short generation times, high reproductive rates, and efficient dispersal mechanisms. An increase in the concentration of CO_2 and other greenhouse gases has already resulted in an increase in the global average temperature of 0.6–0.7°C over the last century [3], and this average increase has been translated in many regions as shorter and warmer winters [23]. Further, there is widespread evidence that such seasonal shifts have already affected the phenology, abundance, and distribution of many pest and disease species [18]. Additionally, the impact of increased pollutants and CO_2 concentration [5] will be accompanied by the easier introduction of exotic invasive species of plants, pests, and diseases in many regions [4] for further establishment and widespread. There is a consensus that the prediction and management of climate change effects on plant health are complicated by interactions between globalization, shifts in climatic patterns, and increasing number of invasive plants, pests, and pathogens. Assessing the ecological consequences of climate change requires an understanding of biotic interactions, including the evolution of crop pests and diseases, and their hosts at the interface between fields and surrounding remnant semi-natural ecosystems. Free-Air CO_2 Enrichment (FACE) facilities can deliver useful insights into plant protection systems affected by the interactions among climate change factors [5]. Ensuring that landscape management studies incorporate the many insights of global change impacts on plant health to improve sustainability, food security, and to make biodiversity conservation [8]. Although some studies on multiple global change factors may involve plant pathogens under elevated CO_2 and nitrogen fertilization to predict changes in susceptibility of plants against herbivorous pathogens with changing resource availability, and noticed that Phytophthora citricola infected Fagus sylvatica seedlings under elevated CO_2 and low nitrogen supply. In this context, there is a need to include such studies in various plant protection management approaches, including organic agriculture, bio-control mixtures, and agricultural landscapes for natural pest and disease control [26].

Interactions of climatic factors and insect pests

Global climate changes have significant impacts on agriculture, as well as on agricultural insect pests. These climatic factors directly impact pests' reproduction, development, survival, and dispersal activities, while indirectly affecting the relationships between pests, environment, and other insect species such as natural enemies, competitors, vectors, and mutualists [21]. Insect pests are poikilothermic, their body temperature depends on the temperature of the existing environment. Thus, temperature is the most important environmental factor affecting insect behavior, distribution, development, and reproduction. Therefore, drivers of climate change factors significantly affect the population dynamics of insect pests, thus the percentage of crop losses, which threatens food security towards a common global problem in all countries and all regions [7]. Of over 800 rice pests, only 15 20 species cause serious damage due to climate change, and these were divided into four types including leaf-feders such as rice leaf folder (Cnaphalocrocismedinalis); stem-borers like rice stem borer (Chilosuppressalis); grain-suckers as brown plant hopper (Nilaparvatalugens), white back plant-hopper (Sogatellafurcifera), small brown plant-hopper (Laodelphaxstriatellus), southern green stink bug (Nezaraviridula) and root-feeders, such as mole cricket (Neoscapteriscusborellii).

In this climate change scenario, grain-suckers especially Nilaparvata lugens received the most attention due to changes occur in their physiology, which further influenced distribution and population dynamics to alter up to the pest management level. When the temperatures exceed 34°C, old nymphs of Nilaparvata lugens die and have not emerged, but with the increased CO_2, honeydew excretion and fecundity of pests exhibited a negative effect on rice yield. Further analysis on impacts of climate change [29] on over wintering boundary for Nilaparvata lugens in China, and predicted that the pest would move about 50 km between 2010 to 2039 northward, and pesticide efficacy also decreased under elevated CO_2. Many researchers have proved that insect pests are varied in their genetic variability and due to that reason some may tolerate high temperatures [28]. For instance, brown plant-hoppers tolerate heat stress for first and third-instar nymphs LT_{50} of the temperate region is 57.2 to 144.6 hours, and only 23.4 to 22.8 hours for the tropical region [9]. Similar results were also observed in the mirid bug (Cyrtorhinuslividipennis Reuter), a predator of brown plant-hopper which has 30 times higher LT_{50}, compared to the tropical regions [30], and these results showed that these insects may adapt high temperatures due to environmental change for further evolution. Overall, few investigations revealed that interspecific interactions co-existing between rice plant hoppers (i.e., Nilaparvatalugens and Sogatellafurcifera), and viruses transmitted through small brown plant-hoppers.

At such changing climatic conditions, scientists gave much attention to other rice pests at individual and population levels including physiological responses with acclimation to thermal stress, behavioral adaptation, occurrence and distribution, and population dynamics. Due to the thermal tolerance of rice leaf folders (Cnaphalocrocis medinalis), they enlarged after two or three generations, and laid eggs on the lower surfaces of rice leaves as a consequence of thermo regulation behavior. By 2031–2050, the pest population and abundance will be increased with an increase in winter temperature compared to 1981–2000 [24]. Further, herbivorous insects are affected by dry climates, which may provide suitable environmental conditions for their growth and development because of decrease in secondary metabolite production which provide a defense function. For example, when plants lose their moisture through the process of transpiration, water columns in the xylem break apart and cavitate andplants undergo stress by drought and become more susceptible to insect attack.

Interactions of climatic factors and diseases

The importance of environment in the development of plant diseases has been known for over two thousand years. Since 2000, increase in CO_2 concentration is greater than that of previous decades and a similar trend has been for the concentration of methane (CH_4), nitrous oxide (N_2O), and other greenhouse gases [15]. Due to an increase in the concentration of these greenhouse gases in the atmosphere from natural and anthropogenic sources, the global average surface temperature has increased by 0.76°C and could increase from 2.4 to 6.4°C from 2090 to 2099 relative to 1980 to 1999.

Among the fungal diseases of rice, blast (caused by Magnaporthe oryzae), brown spot (caused by Bipolaris oryzae), sheath blight (caused by Rhizoctonia solani), and bakanae disease (caused by Fusarium fujikuroi) are considered as dominant diseases of rice which decrease its yield and quality. Elevated levels of both ozone and CO_2 can affect the expression of resistance more directly on pathogen growth, such as the potential risks for infection of leaf blast and epidemics of sheath blight will increase in the future if CO_2 concentrations keep rising [25 & 1]. The consequence of climate change is a poleward shift of agro climatic zones causing fluctuation in the geographical distribution of host pathogens [22]. Therefore, new diseases may become prevalent in northern areas, causing considerable losses in agricultural production [27].

Changes in temperature and precipitation regimes of climate change may alter the growth stage, development rate, the pathogenicity of infectious agents, and the physiology and resistance of the host plant. Temperature is one of the most important factors affecting the occurrence of bacterial diseases such as Razoctonia solanacearum, Acidovoraxavenae, and Burkholderiaglumea could proliferate in areas where temperature-dependent diseases have not been previously observed [20]. As the temperature increases, the duration of winter and the rate of growth and reproduction of pathogens may be modified, as the same incidence of vector-borne diseases will be altered. The relation between elevated temperature and viral pathogens in the molecular study revealed that when temperature increases may affect two types of antiviral resistance mechanisms in plants; gene-silencing based on ribonucleic acid (RNA) interference (RNAi) resistance based on protein-protein recognition and RNAi defend plants against viruses using small interfering RNA (siRNA) to target and destroy viral RNA. The RNA silencing increases with increasing temperature, and it is manifested in the appearance of less symptomatic newly developed leaves because warmer temperatures on host-pathogen interactions increased the pathogen development rate, transmission, and generations per year. The increase in over wintering of pathogens which changes the host susceptibility to infections aggravate the RNA-stimulated resistance. During the dry season, rice crop yield declined by 10% for each 1oC increase in the minimum temperature in the Philippines. Furthermore, severe and unpredictable consequences would occur if populations of pathogens and hosts separated geographically due to climate constraints. 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 to provide new opportunities for pathogen hybridization .

Interaction with Climate Smart Agriculture Practices (CSAP)

Climate Smart Agriculture Practices (CSAP) include farm-level to national-level approaches to seek holistic mitigation and compatible adaptation solutions to overcome multiple challenges raised by climate change parameters. CSAP is designed to become a key component of Climate Smart Agriculture (CSA) and will contribute to three main objectives of CSA aims to tackle: adapting and building resilience to climate change; reducing and/or removing greenhouse gas emissions, and sustainably increasing agricultural productivity and incomes. Integration and convergence between CSAP and existing CSA practices are multiple because farm-level CSAP not only considers biotic factors but also abiotic factors and crop husbandry practices. Certain CSA practices such as site-specific nutrient management, integrated soil fertility management, conservation agriculture, breeding for climate-resilient crops, and crop diversification strategies are most relevant for the success of CSAP. Specific attention was also given to aligning CSAP with CSA approaches aiming to increase gender responsiveness of the intervention, because women produce more than half of the food grown world wide, which accounts for 20–30% of less yield compared to males due to less access to agricultural information and input availability sources among the factors. An assessment of climate-smart push–pull technology in East Africa shows that women were more willing to upscale the technologies which seemed to favor women's preference for the success of CSAP [19]. Inter-linking the activities among extension, research, and the public/private sectors to provide data and resourcesto improve diagnosis of emerging pests and diseases and to formulate policies and research agendas to reduce response time to these pest and disease outbreaks. The extension services need strong linkages with diagnostic teams to diagnose and suggest appropriate recommendations, and this will be essential for pests and disease spread in response to climate change.

CONCLUSION

Food and Agriculture Organisation (FAO) estimates that global food production need to increase by 60% by mid-century to cater the needs of growing world population and their changing diets. However, climate change is already having impacts on agriculture, including biology, distribution, and outbreak potential of pests and diseases across all lands and landscapes. Additionally, it is expected that there will be an overall increase in the number of pests and disease outbreaks involving a broader range of insect pests and diseases, and expand their geographic distribution towards northward. Invasive pest species will establish more readily in new areas and emerge more insect-transmitted plant diseases. Another negative consequence of climate change is the reduced effectiveness of biological control agents and natural enemies which could be a major problem in future pest and disease management programs. At the same time, agriculture is also a major climate change driver, since it remains the world's second-largest emitter of GHG [17]. Bringing down the impact of pests and diseases is more important to ensure global food security, reducing the application of pesticides, and decreasing GHG emissions intensity per unit of food produced. This necessitates the immediate implementation of adaptation strategies at farm and landscape level to decrease the vulnerabilities of individual farmers for their agricultural economies to overcome the adverse impact of climate change. Further, it also requires mitigation strategies to reduce global climate change for sustainable food production and to maintain livelihoods. In this context, the approach of CSAP seeks to support farmers, extension workers, scientists, and public and private sector stakeholders to act in coordination to reorient pest and disease management approaches to evolve climate change-induced pests and disease threats more effectively.

REFERENCES

[1.] Alam, M.S., Maina, A.W., Feng, Y., Wu, L.B. and Frei, M. (2022). Interactive effects of tropospheric ozone and blast disease (Magnaportheoryzae) on different rice genotypes. Environ Sci Pollut Res 29, 48893–48907. https://doi.org/10.1007/s11356-022-19282-z.

[2.] Bebber D P. (2015). Range-expanding pests and pathogens in a warming world. Annual Review of Phytopathology, 653(1): 335-356.

[3.] Benvenuti, S. (2009). Potenzialeimpattodeicambiamenticlim aticinell'evoluzionefloristica di fitocenosispontanee in agroecosistemimediterranei. RivistaItaliana di Agronomia, S1, 45–67.

[4.] Chytrý, M., Wild, J., Pyšek, P., Jarošík, V., Dendoncker, N., Reginster, I., Pino, J., Maskell, L.C., Vilà, M., Pergl, J., Kühn, I., Spangenberg, J.H. and Settele, J. (2012), Projecting trends in plant invasions in Europe under different scenarios of future land-use change. Global Ecology and Biogeography, 21: 75-87. https://doi.org/10.1111/j.1466-8238.2010.00573.x.

[5.] Eastburn, D. M., Mc Elrone, A. J. and Bilgin, D. D. (2011). Influence of atmospheric and climatic change on plant–pathogen interactions. Plant Pathology, 60, 54–69.doi:10.1111/j.1365-3059.2010.02402.x.

[6.] Eliazer Nelson, A.R.L., Ravichandran, K and Antony, U. The impact of the Green Revolution on indigenous crops of India. J. Ethn. Food 6, 8 (2019). https://doi.org/10.1186/s42779-019-0011-9.

[7.] FAO. (2020). Climate Related Transboundary Pests and Diseases. Available online: http://www.fao.org/3/a-ai785e.pdf (accessed on 19 December 2020).

[8.] Geyer, J., Kiefer, I., Kreft, S., Chavez, V., Salafsky, N and Jeltsch, F (2011). Classification of climate-change-induced stresses on biological diversity. Conservation Biology, 25, 708–715. doi:10.1111/j.1523-1739.2011.01676.x.

[9.] Horgan, F.G., Arida, A., Ardestani, G. and Almazan, M.L.P. (.2021) Elevated temperatures diminish the effects of a highly resistant rice variety on the brown planthopper. Sci Rep 11, 262 . https://doi.org/10.1038/s41598-020-80704-4.

[10.] IPCC (2013) Working Group I Contribution to the IPCC Fifth Assessment Report on Climate Change 2013: The Physical Science Basis, Summary for Policymakers. www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf.

[11.] IPCC (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II Contribution to the IPCC Sixth Assessment Report. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

[12.] International Production Assessment Division, USDA Foreign Agricultural Service, US Department of Agriculture, September, 2022.

[13.] Juroszek P, Von Tiedemann A (2013). Plant pathogens, insect pests and weeds in a changing global climate: a review of approaches, challenges, research gaps, key studies and concepts. Journal of Agricultural Science, 151(2): 163 188.

[14.] Kobayashi T, Ishiguro K, Nakajima T, Kim H Y, Okada M, Kobayashi K. (2006). Effects of elevated atmospheric CO2 concentration on the infection of rice blast and sheath blight. Phytopathology, 6(4): 425-431.

[15.] Latif, S.N.A., Chiong, M.S., Rajoo, S., Takada, A., Chun, Y.-Y., Tahara, K. and Ikegami, Y. (2021). The Trend and Status of Energy Resources and Greenhouse Gas Emissions in the Malaysia Power Generation Mix. Energies, 14, 2200. https:// doi.org/10.3390/en14082200.

[16.] Luo Y, Tebeest D O, Teng P S and Fabellar N G. (1995). Simulation studies on risk analysis of rice leaf blast epidemics associated with global climate change in several Asian countries. Journal of Biogeography, 22(4/5): 673-678.

[17.] Lynch, J., Cain, M., Frame, D. and Pierrehumbert, R. (2021). Agriculture's Contribution to Climate Change and Role in Mitigation Is Distinct From Predominantly Fossil CO2-Emitting Sectors. Frontiers in Sustainable Food Systems. Ma C S, Ma G, Pincebourde S. Survive a warming climate: insect responses to extreme high temperatures. Annual Review of Entomology, 2021, 66(1): 163-184.https://doi.org/10.3389/fsufs.2020.518039.

[18.] Matyssek, R., Wieser, G., Calfapietra, C., de Vries, W., Dizengremel, P. and Ernst, D. (2012). Forests under climate change and air pollution: gaps in understanding and future directions for research. Environmental Pollution, 160, 57–65. doi:10.1016/j.envpol.2011.07.007.

[19.] Murage, Alice & Midega, Charles &Pittchar, J. & Pickett, John and Khan, Zeyaur. (2015). Determinants of adoption of climate-smart push-pull technology for enhanced food security through integrated pest management in eastern Africa. Food Security. 7. 10.1007/s12571-015-0454-9.

[20.] Pickson, R.B., He, G. and Boateng, E. (2022). Impacts of climate change on rice production: evidence from 30 Chinese provinces. Environ Dev Sustain 24, 3907–3925 . https://doi.org/10.1007/s10668-021-01594-8.

[21.] Prakash, A., Rao, J., Mukherjee, A.K., Berliner, J., Pokhare, S.S., Adak, T., Munda, S. and Shashank, P.R. (2014). Climate Change: Impact on Crop Pests; Applied Zoologists Research Association (AZRA), Central Rice Research Institute: Odisha, India; ISBN 81-900947-2-7.

[22.] Prasad P., S.C. Bhardwaj., R.K. Thakur., S. Adhikari., O.P. Gangwar., C. Lata and S. Kumar. 2021. Prospects of climate change effects on crop diseases with particular reference to wheat. Journal of Cereal Research 13(2): 118-135. http://doi.org/10.25174/2582-2675/2021/112817.

[23.] Quarles, W. (2007). Global warming means more pests. The IPM Practitioner, 29(9/10), 1–8.

[24.] Schneider, L., Rebetez, M. and Rasmann. S. (2022).The effect of climate change on invasive crop pests across biomes. CurrOpin Insect Sci, 50, Article 100895, 10.1016/j.cois.2022.100895.

[25.] Senthil-Nathan, S. (2021). Effects of elevated CO2 on resistant and susceptible rice cultivar and its primary host, brown planthopper (BPH), Nilaparvatalugens (Stål). Sci Rep 11, 8905. https://doi.org/10.1038/s41598-021-87992-4.

[26.] Steingröver, E. G., Geertsema, W. and van Wingerden, W. K. R. E. (2010). Designing agricultural landscapes for natural pest control: a transdisciplinary approach in the HoekscheWaard (The Netherlands). Landscape Ecology, 25, 825–838. doi:10.1007/s10980-010-9489-7.

[27.] Valeria Trivellone, Eric P. Hoberg, Walter A. Boeger and Daniel R. Brooks. (2022). Food security and emerging infectious disease: risk assessment and risk management, Royal Society Open Science, 10.1098/rsos.211687, 9, 2.

[28.] Vailla, S., Muthusamy, S., Konijeti, C., Shanker, C. and Vattikuti, J. L. (2019). Effects of elevated carbon dioxide and temperature on rice brown planthopper, Nilaparvatalugens (Stål) populations in India. Curr. Sci. 116, 988.

[29.] Xi, C., Ahmad, S., Yu, J., Zhang, J., Chen, Y., Zhang, G., Zhu, H., Ge, L., Yu, X. and Shu, Z. (2022). Seed Coating with Triflumezopyrim Induces the Rice Plant's Defense and Inhibits the Brown Planthopper's Feeding Behavior. Agronomy 2022, 12, 1202. https://doi.org/10.3390/agronomy12051202.

[30.] Yueliang,B., Quais, M., Zhou, W. and Zahu, Z.R. (2021). Consequences of elevated temperature on the biology, predation, and competitiveness of two mirid predators in the rice ecosystem, Journal of Pest Science (2021). DOI: 10.1007/s10340-021-01414-y.

