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Climate Change Impacts on Vegetable Crops: Production, Stress Responses, and Adaptation: Assessing Climate Change Effects on Vegetable Crops: Yield and Stress Responses

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Abstract

Climate change is significantly limiting sustainable vegetable production because these crops are very sensitive to climate. Rising temperatures, changing rainfall patterns, more frequent extreme weather, and higher carbon dioxide levels are disrupting essential processes, reproductive development, and stable yields across various farming regions. Vegetables, known for their short growth cycles, shallow roots, and specific climate requirements, are particularly vulnerable to heat stress, drought, flooding, and salinity. Changes in pests and diseases due to climate also increase production risks by helping pathogens survive, spread, and become more aggressive, while also making traditional management methods less effective. In addition to these physical effects, climate change heightens production uncertainty, raises input costs, and increases economic risks, particularly for small-scale vegetable growers in urban and peri-urban areas. To build resilience in vegetable systems, we need integrated adaptation strategies. These should include improved water and soil management, protected cultivation, pest and disease management that responds to climate change, and breeding for stress-tolerant varieties. Collaborative efforts that link research, technology, and supportive policies are crucial for maintaining vegetable productivity, ensuring nutritional security, and supporting farmers' livelihoods in a changing climate.

Keywords: abiotic; adaptation; climate; stress; sustainability; vegetable.

1. Introduction

Climate change is reshaping farming systems due to rising temperatures, changing rainfall patterns, increasing climate variability, and higher levels of carbon dioxide. These changes pose significant challenges to global food security, particularly for horticultural crops that rely on stable climates for their productivity (Prasad, 2015).

Vegetable crops are particularly vulnerable because they have short growth periods, shallow root systems, and high water needs.

Vegetables are vital for human nutrition since they provide essential vitamins, minerals, dietary fiber, and beneficial compounds, and they also serve as a key income source for small and marginal farmers. However, even slight changes in optimal conditions can negatively impact plant processes and reproduction, leading to unstable yields and poorer market and nutritional quality (Rashid *et al.*, 2020). Increasing instances of heat stress, drought, flooding, salinity, and chilling events have been reported to disrupt the growth and harvest life of many vegetables.

Climate change also increases pest and disease pressures by altering conditions that control pathogen survival and reproduction. The interactions of higher temperatures, carbon dioxide, and host conditions further complicate these relationships, making traditional disease management strategies less effective (Pugliese *et al.*, 2024). Moreover, climate change generates economic stress through rising uncertainty in production, increased input costs, and market instability, which disproportionately affects smallholder and peri-urban vegetable farmers (Degefu and Kifle, 2024). Understanding these interconnected impacts and identifying effective adaptation strategies is crucial for sustaining vegetable production in a changing climate.

2. Climate Change Drivers Affecting Vegetable Crops

Vegetable production is increasingly shaped by interacting climate factors resulting from rising greenhouse gas emissions, land-use changes, and urbanisation. Unlike earlier times with stable seasonal patterns, modern climate change exhibits increased variability, frequent extremes, and exposure to multiple stressors, placing additional pressure on vegetable crops with limited recovery abilities (Prasad and Chakravorty, 2015; Rashid *et al.*, 2020).

Rising temperatures are one of the main factors affecting vegetable productivity. Current warming trends encompass not only higher average temperatures but also more frequent heatwaves, elevated nighttime temperatures, and extended warm periods. These conditions accelerate growth, lead to greater loss of respiratory energy, and shorten the growth period. Reproductive phases are especially sensitive, as even short exposure to high temperatures can harm pollen viability, fertilization, and fruit set, leading to significant yield reductions (Rashid *et al.*, 2020).

Changing rainfall patterns exacerbate climate stress through uneven rainfall, prolonged droughts, and intense downpours. These conditions disrupt soil aeration, nutrient availability, and root function, especially in shallow-rooted vegetable crops that need consistent moisture (Prasad and Chakravorty, 2015). Higher carbon dioxide levels could help photosynthesis, but often provide little advantage in the field due to simultaneous heat, water, and nutrient stresses, while also changing the composition and nutrient content of plant tissue (Pugliese *et al.*, 2024).

The rising frequency of extreme weather events, including heatwaves, floods, unexpected frosts, and storms, creates sudden stress during critical growth periods, often leading to irreversible damage or crop failure. These effects are exacerbated by the declining resilience of agro-ecosystems, rendering recent climate changes more complex and harmful than the gradual shifts observed in earlier decades (Degefu and Kifle, 2024).

3. Physiological and Developmental Responses of Vegetable Crops

Vegetable crops respond quickly to climate stress because their growth and yields depend heavily on temperature, water availability, and air composition. Changes in soil temperature and moisture disrupt seed germination and early seedling growth by affecting enzyme activity and membrane stability, often resulting in weak crop stands, especially during droughts or waterlogging (Prasad and Chakravorty, 2015).

Heat and moisture stresses limit vegetative growth by impacting photosynthesis and respiration. Higher temperatures increase respiratory losses, while drought causes stomatal closure that hinders carbon absorption, leading to reduced leaf area, faster ageing, and lower biomass (Rashid *et al.,* 2020). The reproductive phase is the most sensitive to climate changes, with high temperatures disrupting pollen viability and fertilization, leading to flower and fruit loss in crops like tomatoes, peppers, and cucurbits.

Extreme moisture levels worsen reproductive failures by disrupting nutrient movement and hormonal balance. Water stress limits carbohydrate supply to developing fruits, while too much moisture hampers root respiration and nutrient uptake, increasing physiological disorders and aging (Prasad and Chakravorty, 2015). Higher carbon dioxide levels can alter the balance of carbon and nitrogen, as well as the profiles of secondary metabolites, often resulting in lower mineral nutrient levels and impacting the quality and resilience of produce (Pugliese *et al.*, 2024; Rashid *et al.*, 2020).

4. Climate Change and Pest–Disease Dynamics

Climate change has significantly changed pest and disease dynamics in vegetable production by altering environmental conditions that affect pathogen survival, reproduction, and spread. Rising temperatures speed up pest metabolism, reduce generation time, and improve their survival rates over winter, resulting in earlier infestations and longer pest pressures (Rashid *et al.*, 2020).

Changes in moisture levels affect disease development by increasing humidity and leaf wetness, which benefit foliar and soil-borne pathogens, while drought weakens plant defences (Prasad and Chakravorty, 2015). Higher atmospheric carbon dioxide levels also change plant tissue and defensive metabolites, making pathogens more aggressive and complicating disease management and prediction (Pugliese *et al.,* 2024).

Climate change has allowed pests and pathogens to expand into new areas, leading to new pest and disease challenges. These changes reduce the effectiveness of chemical controls, disrupt natural pest control agents, and require integrated, climate-adjusted pest and disease management strategies (Juroszek *et al.,* 2020).

5. Adaptation and Mitigation Strategies for Climate-Resilient Vegetable Production

To maintain vegetable production amid climate change, we need integrated strategies that improve resilience while ensuring productivity. Better water and soil management practices, such as precision irrigation, mulching, and adding organic matter, enhance water efficiency and protect crops from temperature and moisture extremes (Porter *et al.,* 2014; Ghosh, 2021).

Protected cultivation systems like polyhouses, net houses, and low tunnels help manage crop microclimates, reducing risks from heat stress, irregular rainfall, and pest pressures. These structures serve as both productivity and risk management tools in high-value vegetable production (Khatri-Chhetri *et al.,* 2017; Mwongera *et al.,* 2017).

Genetic improvements remain crucial for long-term adaptation, with breeding focusing on creating varieties that can tolerate heat, drought, salinity, and combined stresses. Advances in molecular breeding and genomic selection help identify resilient varieties suited for changing climates (Corner-Dolloff *et al.,* 2015; Varshney *et al.,* 2021).

Climate-responsive pest and disease management strategies that combine host resistance, biological control, cultural techniques, and climate-informed forecasts are vital for adapting to shifting pest and pathogen dynamics (Gullino *et al.,* 2018; Juroszek *et al.,* 2020). Mitigation strategies, including better fertilizer use, adopting renewable energy in protected cultivation, and enhancing soil carbon, can help reduce the carbon footprint of intensive vegetable farming while supporting long-term sustainability (Campbell *et al*., 2016; IPCC, 2023).

6. Conclusions

Climate change significantly limits vegetable production by intensifying temperature extremes, increasing rainfall variability, and boosting pest and disease pressures, leading to unstable yields, declining quality, and increased livelihood risks. The growing vulnerability of vegetable crops results from rapid climate changes and weakened agro-ecosystem resilience, both of which exceed the recovery ability of traditional farming methods. To maintain vegetable productivity under these conditions, we need integrated, climate-resilient approaches that improve resource management, develop stress-tolerant crops, and implement climate-responsive pest and disease management while ensuring supportive policies and institutions. Coordinated efforts linking research, technology, extension services, and policy support are crucial for enhancing adaptive capacity and ensuring nutritional access in an increasingly unstable climate.

7. References

Campbell, B. M., Thornton, P., Zougmore, R., van Asten, P., & Lipper, L. (2016). Sustainable intensification: What is its role in climate smart agriculture? *Current Opinion in Environmental Sustainability,* 8, 39–43.

Challinor, A. J., Watson, J., Lobell, D. B., Howden, S. M., Smith, D. R., & Chhetri, N. (2018). A meta-analysis of crop yield under climate change and adaptation. *Nature Climate Change,* 4, 287–291.

Corner-Dolloff, C., Loboguerrero, A. M., Lizarazo, M., Nowak, A., Howland, F., Andrieu, N., & Thornton, P. K. (2015). *Climate-smart agriculture: What is it? Why is it needed?* CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Degefu, M. A., & Kifle, F. (2024). Impacts of climate variability on vegetable production of urban farmers: Nexus of climate-smart agricultural technologies. *Climate Services, 33*, 100430.

Food and Agriculture Organization of the United Nations (FAO) (2017). *Climate-smart agriculture sourcebook*. FAO.

Ghosh, A. (2021). Climate smart agriculture: An approach for sustainable agricultural development. *Indian Journal of Agricultural Sciences, 91*(1), 1–9.

Gregory, P. J., Johnson, S. N., Newton, A. C., & Ingram, J. S. I. (2009). Integrating pests and pathogens into the climate change/food security debate. *Journal of Experimental Botany, 60*(10), 2827–2838.

Gullino, M. L., Pugliese, M., Gilardi, G., & Garibaldi, A. (2018). Effect of increased CO_2 and temperature on plant diseases: A review. *Journal of Plant Pathology, 100*, 391–404.

Hansen, J. W., Mason, S. J., Sun, L., & Tall, A. (2019). Review of seasonal climate forecasting for agriculture in sub-Saharan Africa. *Experimental Agriculture, 47*(2), 205–240.

Intergovernmental Panel on Climate Change (IPCC). (2023). *Climate Change: Synthesis Report*. IPCC.

Juroszek, P., von Tiedemann, A., & Kleinhenz, B. (2020). Climate change and plant disease management. *Plant Pathology, 69*(4), 569–581.

Khatri-Chhetri, A., Aggarwal, P. K., Joshi, P. K., & Vyas, S. (2017). Farmers' prioritization of climate-smart agriculture technologies. *Agricultural Systems, 151*, 184–191.

Lobell, D. B., Tebaldi, C., & Mastrandrea, M. D. (2022). Climate change impacts on global crop yields. *Nature Reviews Earth & Environment, 3*, 230–245.

Mwongera, C., Shikuku, K. M., Twyman, J., Läderach, P., Ampaire, E., Van Asten, P., & Thornton, P. K. (2017). Climate-smart agriculture rapid appraisal (CSA-RA): A tool for prioritizing context-specific climate-smart agriculture technologies. *Agricultural Systems, 151*, 192–203.

Porter, J. R., Xie, L., Challinor, A. J., Cochrane, K., Howden, S. M., Iqbal, M. M., Lobell, D. B., & Travasso, M. I. (2014). Food security and food production systems. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. IPCC.

Porter, J. R., Howden, S. M., & Smith, P. (2019). Considering agriculture in climate change mitigation. *Philosophical Transactions of the Royal Society B, 374*(1769), 20180287.

Prasad, B. V. G., & Chakravorty, S. (2015). Effects of climate change on vegetable cultivation – A review. *Nature Environment and Pollution Technology, 14*(4), 923–929.

Pugliese, M., Gilardi, G., Garibaldi, A., & Gullino, M. L. (2024). The impact of climate change on vegetable crop diseases and their management: The value of phytotron studies. *Phytopathology, 114*(5), 843–854.

Rashid, M., Hussain, K., Malik, A. A., Narayan, S., Nazir, G., Hussain, S. M., Maqbool, S., Farwah, S., Hussain, T., & Ayoub, I. (2020). Impact of climate change on vegetable crops and its mitigation. *International Journal of Current Microbiology and Applied Sciences, 9*(Special Issue 11), 2429–2445.

Varshney, R. K., Bohra, A., Yu, J., Graner, A., Zhang, Q., & Sorrells, M. E. (2021). Designing future crops: Genomics-assisted breeding comes of age. *Trends in Plant Science, 26*(6), 631–649