Journal of Research in Biology
An International Scientific Research Journal

ISSN No: Print: 2231 –6280; Online: 2231- 6299

Comprehensive Review

Molecular Mechanisms of Plant Adaptation to Abiotic Stress Under Changing Climates

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ABSTRACT:

Abiotic stresses, including drought, salinity, extreme temperatures, flooding, and nutrient deficiency, represent the most formidable constraints to global agricultural productivity, collectively accounting for more than 50% of yield losses in major crop species worldwide. The accelerating pace of climate change is predicted to intensify the frequency, severity, and co-occurrence of these stressors, posing unprecedented challenges to food security for a rapidly growing global population. Plants, as sessile organisms, have evolved an extraordinarily sophisticated and multilayered repertoire of molecular mechanisms to perceive, transduce, and respond to adverse environmental signals. These mechanisms span the entire spectrum of biological organization, from membrane-localized receptor kinases and second messenger cascades, through transcriptional reprogramming orchestrated by diverse families of transcription factors, to post-translational modifications, epigenetic remodeling, and non-coding RNA-mediated regulation. This review provides a comprehensive and integrative synthesis of the current understanding of the molecular mechanisms underpinning plant adaptation to abiotic stress in the context of changing climates. This review systematically examine stress perception and signal transduction, the roles of phytohormones particularly abscisic acid (ABA), jasmonic acid (JA), ethylene, and melatonin the functions of major transcription factor families including NAC, WRKY, AP2/ERF, bHLH, MYB, and HSF, the significance of post-translational modifications such as ubiquitination and SUMOylation, the emerging roles of epigenetic memory and stress priming, and the contributions of omics technologies and genome editing to crop improvement. Special attention is given to quantitative and statistical dimensions of these processes, as well as to the mathematical frameworks that describe stress response dynamics. The review concludes by identifying key knowledge gaps and future research priorities for engineering climate-resilient crops.

Keywords:
Abiotic stress, Climate change, Signal transduction, Transcription factors, Epigenetics, ABA signaling, Stress tolerance, Crop improvement

Article Citation:
Kores J J . Molecular Mechanisms of Plant Adaptation to Abiotic Stress Under Changing Climates. **Journal of Research in Biology (2025) 15(2): 1-24**

Web Address:
http://jresearchbiology.com/documents/RA0875.pdf

Dates:
Received: 18 Jan. 2025 **Accepted:** 19 March 2025 **Published:** 15 April 2025