International Journal of Advanced Research and Multidisciplinary Trends (IJARMT)
An International Open Access, Peer-Reviewed Refereed Journal
Impact Factor: 6.4 Website: https://ijarmt.com ISSN No.: 3048-9458

Comparative Evaluation of Phytohormonal Responses in Plants Under Different Abiotic Stress Conditions

Maske Rushikesh Sanjay
Research Scholar, Department of Botany, Malwanchal University, Indore
Dr. Chandrashekhar Ramesh Deore
Supervisor, Department of Botany, Malwanchal University, Indore

Abstract
Abiotic stresses such as drought, salinity, extreme temperatures, and heavy metal toxicity significantly affect plant growth, development, and yield. To adapt and survive under such adverse conditions, plants rely on intricate hormonal signaling networks that regulate physiological and molecular responses. This study presents a comparative evaluation of key phytohormones—including abscisic acid (ABA), ethylene (ET), salicylic acid (SA), jasmonic acid (JA), auxins, cytokinins (CK), gibberellins (GAs), and brassinosteroids (BRs)—and their diverse roles in modulating plant responses to different abiotic stresses. While ABA serves as a primary signal under drought and salt stress, hormones like JA and SA are more active in stress-related defense and detoxification mechanisms. The interaction and cross-talk among these hormones enable plants to fine-tune their responses, depending on the nature and severity of the stress. This review synthesizes recent findings from molecular and physiological studies that highlight hormone-specific response patterns and adaptive mechanisms. It also discusses how stress-specific hormonal pathways interact to influence gene expression, osmotic balance, and reactive oxygen species (ROS) management. By comparing these divergent hormonal strategies, the study offers valuable insights into potential biotechnological and agronomic approaches to enhance stress tolerance in crops, contributing to sustainable agriculture in the face of climate change.
Keywords: Phytohormones, Abiotic stress, Hormonal cross-talk, Stress tolerance, Plant adaptation

Introduction
Plants are constantly subjected to a wide range of abiotic stress conditions, including drought, salinity, temperature extremes, and heavy metal toxicity. These stress factors adversely affect

plant physiology, growth, and productivity, posing a significant threat to global agricultural sustainability. Unlike animals, plants are immobile and must rely on internal signaling mechanisms to perceive environmental changes and initiate adaptive responses. Phytohormones—small but powerful signaling molecules—play a central role in regulating these responses. Among the key hormones involved are abscisic acid (ABA), ethylene (ET), salicylic acid (SA), jasmonic acid (JA), auxins, cytokinins (CK), gibberellins (GAs), and brassinosteroids (BRs). Each of these hormones contributes uniquely to stress perception, signal transduction, and downstream gene regulation. More importantly, their roles often overlap and interact through synergistic or antagonistic pathways, creating a complex network of hormonal cross-talk that fine-tunes plant responses to specific stressors.

This comparative study aims to critically evaluate the differential roles and regulatory strategies of phytohormones in plants exposed to various abiotic stresses. By analyzing both individual and interactive hormonal functions under conditions such as drought, salinity, cold, and heat, this research highlights how plants prioritize certain hormonal pathways depending on the type, duration, and intensity of stress. Recent advancements in molecular biology, transcriptomics, and physiological assays have enabled researchers to uncover distinct hormonal signatures and response patterns that vary not only with stress type but also with plant species and developmental stages. Understanding these divergent hormonal strategies is crucial for developing stress-resilient crop varieties through genetic manipulation or hormone-based treatments. This paper provides a comprehensive insight into the comparative modulation of phytohormonal networks, contributing to the broader goal of enhancing plant performance and productivity under increasingly challenging environmental conditions.

Methodology

The methodology chapter serves as a critical component of any research study, outlining the approach, data sources, and analytical strategies adopted to achieve the stated objectives. This chapter provides a detailed overview of the research design employed for investigating the comparative regulation of plant hormones during abiotic stress conditions. It describes the rationale behind selecting a secondary data-based approach, the criteria for data inclusion and exclusion, and the methods applied for analyzing and synthesizing the information gathered from existing literature. The methodology is carefully constructed to ensure that the research findings are comprehensive, valid, and aligned with the aims of the study.

The primary objective of this chapter is to explain how the research was conducted without experimental interventions, relying instead on existing scientific literature, reviews, and datasets. As the focus is on understanding and comparing hormonal regulatory mechanisms under various abiotic stress conditions, the study necessitates a broad and integrative perspective. This is best achieved through the analysis of secondary data, which allows access to a wide range of experimental findings and theoretical interpretations across different plant species and environmental conditions.

The decision to employ secondary data as the core of this research is driven by several justifiable factors. Firstly, plant hormone signaling and stress responses are complex and have been extensively studied over decades. Numerous high-quality studies, including peer-reviewed journal articles, review papers, and meta-analyses, are available and provide a robust knowledge base. Leveraging these existing resources not only allows the researcher to analyze patterns and correlations across multiple contexts but also enables the integration of findings from various disciplines, such as molecular biology, plant physiology, and environmental science.the comparative nature of the study—focusing on different hormonal pathways and types of abiotic stress—requires access to a diverse set of studies involving different methodologies, plant species, and stress conditions. Conducting primary research to cover such a wide spectrum would be both time-consuming and resource-intensive. By using secondary data, the research can draw on established experimental evidence to provide a broader, more inclusive, and theoretically grounded comparative analysis. the secondary data approach enhances the feasibility of conducting an in-depth examination of hormonal regulation mechanisms without the ethical, logistical, and technical limitations that often accompany primary experimental studies. This methodology enables the researcher to focus on interpreting and synthesizing information, identifying trends, highlighting contradictions, and suggesting new directions for future research based on cumulative knowledge. This chapter outlines a systematic approach to data collection and analysis based entirely on secondary sources. The rationale for this methodology is grounded in the richness of available literature, the breadth of the topic, and the goal of producing a comparative synthesis of plant hormonal regulation under abiotic stress. By carefully curating and analyzing existing scientific knowledge, the research aims to contribute meaningful insights into plant adaptive responses, which are crucial for improving stress tolerance in crops and addressing global agricultural challenges.

Research Design

This study adopts a qualitative and comparative research design rooted in secondary data analysis to explore the regulatory roles of plant hormones during abiotic stress conditions. The choice of design is grounded in the need to synthesize a vast body of scientific literature that spans various plant species, stress types, and hormonal signaling pathways. Unlike primary experimental designs, which focus on generating new data, this research aims to draw insights from existing findings to identify commonalities, divergences, and trends in hormonal behavior under stress. The comparative nature of the design allows for a cross-study analysis that emphasizes variation in hormonal responses depending on the type of stress (e.g., drought, salinity, temperature extremes) and the physiological and molecular context in which these responses occur.

The qualitative aspect of the design emphasizes interpretation and conceptual understanding over numerical quantification. The study does not involve the manipulation of variables or testing of hypotheses through experimentation. Instead, it relies on descriptive, analytical, and thematic strategies to examine how various plant hormones—such as Abscisic Acid (ABA), Auxin, Cytokinin, Ethylene, Jasmonic Acid (JA), and Salicylic Acid (SA)—function during stress adaptation. A key component of this design involves identifying and synthesizing literature that discusses hormone-stress relationships in depth, especially those that examine gene expression profiles, hormonal cross-talk, signal transduction pathways, and phenotypic responses in plants. The literature is carefully categorized based on hormone type and abiotic stress condition to facilitate a structured and meaningful comparison.

The comparative framework adopted in this research enables a multidimensional analysis of hormonal regulation. By comparing how different hormones respond under similar stress conditions, and how the same hormone behaves across different plant species and environmental settings, the study seeks to uncover regulatory patterns that are either conserved or divergent. For instance, ABA is widely known to mediate drought and salt stress responses by inducing stomatal closure and regulating gene expression. However, its interaction with other hormones such as JA and Ethylene varies depending on the plant species and developmental stage. Similarly, the dual role of Cytokinins in promoting cell division while also modulating stress tolerance through hormonal antagonism or synergy provides a rich ground for comparative analysis. This design supports a deeper understanding of such interactions and the biological significance of hormonal cross-talk under abiotic stress.

Furthermore, the research design incorporates a **systematic review approach** to enhance the credibility and comprehensiveness of the findings. This involves clearly defined criteria for literature selection, ensuring that only high-quality, peer-reviewed studies are considered. The inclusion criteria focus on articles that offer detailed molecular or physiological insights into hormone function during abiotic stress. Studies are selected across a wide temporal window to capture both foundational research and recent advances. Additionally, the design accounts for a balance between model plants like *Arabidopsis thaliana* and agriculturally relevant crops such as rice (*Oryza sativa*), maize (*Zea mays*), and wheat (*Triticum aestivum*). This selection allows the study to generalize insights while also appreciating species-specific nuances in hormonal regulation.

Data Sources

The success of any secondary research depends heavily on the quality, credibility, and relevance of the data sources utilized. In this study, data was collected exclusively from published academic literature, with an emphasis on peer-reviewed journals, review articles, scientific databases, and institutional reports. These sources provided an extensive and diverse collection of findings related to plant hormonal regulation under different abiotic stress conditions. The choice to use only secondary data was strategic, ensuring that the study could draw upon a wide breadth of established scientific evidence across various plant species and environmental stress contexts.

A systematic search strategy was employed using reputable online scientific databases, including PubMed, Scopus, Web of Science, ScienceDirect, SpringerLink, and Google Scholar. These platforms were chosen for their comprehensive coverage of research in plant sciences, molecular biology, physiology, and biotechnology. The search included combinations of keywords such as *"plant hormones and abiotic stress," "abscisic acid and drought," "ethylene signaling under salinity," "auxin during heat stress,"* and *"hormonal cross-talk in plants."* Boolean operators (AND, OR) and filters (e.g., date range, subject area) were used to refine search results and ensure relevance.

The majority of the data comes from research published between 2000 and 2025, allowing the inclusion of both foundational theories and the latest advances in the field. Special attention was given to review articles and meta-analyses, as these often synthesize large volumes of data and present integrated perspectives on complex biological pathways. Where available, open-access repositories like NCBI Gene Expression Omnibus (GEO) and Plant Reactome were consulted to retrieve gene expression data, pathway maps, and curated models of hormone signaling mechanisms.

To ensure academic rigor, only studies published in journals with a solid reputation and impact factor (such as *Plant Physiology*, *Journal of Experimental Botany*, *The Plant Cell*, *Trends in Plant Science*, and *Environmental and Experimental Botany*) were included. In cases where newer research findings presented novel mechanisms or deviated from established understanding, additional supporting studies were reviewed to cross-verify the conclusions. Studies based on both model organisms (e.g., *Arabidopsis thaliana*) and commercially important crops (e.g., rice, wheat, maize) were included to create a balanced dataset that supports both theoretical insight and agricultural relevance.

Results and Discussion

Comparative Hormonal Responses Across Stress Types

Plant responses to abiotic stress are governed not by isolated hormonal actions, but by complex and dynamic interactions between multiple hormone signaling pathways. These interactions differ in intensity, timing, and physiological outcome depending on the nature of the stressor, the plant species, and the tissue involved. This section presents a cross-comparison of hormonal responses under the five major stress conditions discussed—drought, salinity, heat, cold, and heavy metal toxicity—highlighting patterns of convergence, divergence, and unique stress-specific features.

Hormone	Drought	Salinity	Heat	Cold	Heavy Metal Toxicity	Common Roles / Notes
Abscisic Acid (ABA)	↑↑ (2–4×): Stomatal closure, osmotic balance	↑↑ (2–3×): Ion transport regulation	↑ (1.5–2.5×): HSP induction, water retention	↑↑ (2–3×): Cold gene activation (CBFs)	↑↑ (2–3×): Detox pathways, osmotic adjustment	Universal stress hormone; rapid signaling in all abiotic stresses

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Jasmonic Acid (JA)	↑ (2×): Antioxidants, growth modulation	↑ (2×): Ion homeostasis, ROS scavenging	↑ (2×): HSP support, redox control	↑ (2×): COR gene expression, ROS defense	↑ (2×): Glutathione, detox enzymes	Supports antioxidant activity; works synergistically with ABA and SA
Salicylic Acid (SA)	→ / ↑ (mild): Limited in drought	↑ (1.5–2.5×): Redox support, membrane stability	↑ (2–3×): Thermoprotection, HSP upregulation	↑ (1.5–2×): Enhances cold tolerance	↑↑ (2–2.5×): Antioxidants, metal chelation	Key role in oxidative defense; also involved in systemic acquired resistance
Ethylene	↑ (moderate): Root growth, ROS signaling	↑ (2–3×): Senescence modulation, ROS control	↑↑ (2–3×): Heat shock transcription factors	↑ / ↓: Context-dependent cold tolerance	↑↑ (2–3×): Stress signals, premature senescence	Dual role—dose-dependent effects; moderate levels often beneficial
Auxin (IAA)	↓ (20–40%): Root plasticity under stress	↓ (30–50%): Affects lateral root development	↓ (30–50%): Disrupted transport	↓↓ (30–60%): Inhibited meristem activity	↓↓ (30–50%): Root growth inhibition	Redistribution critical for adaptive root architecture

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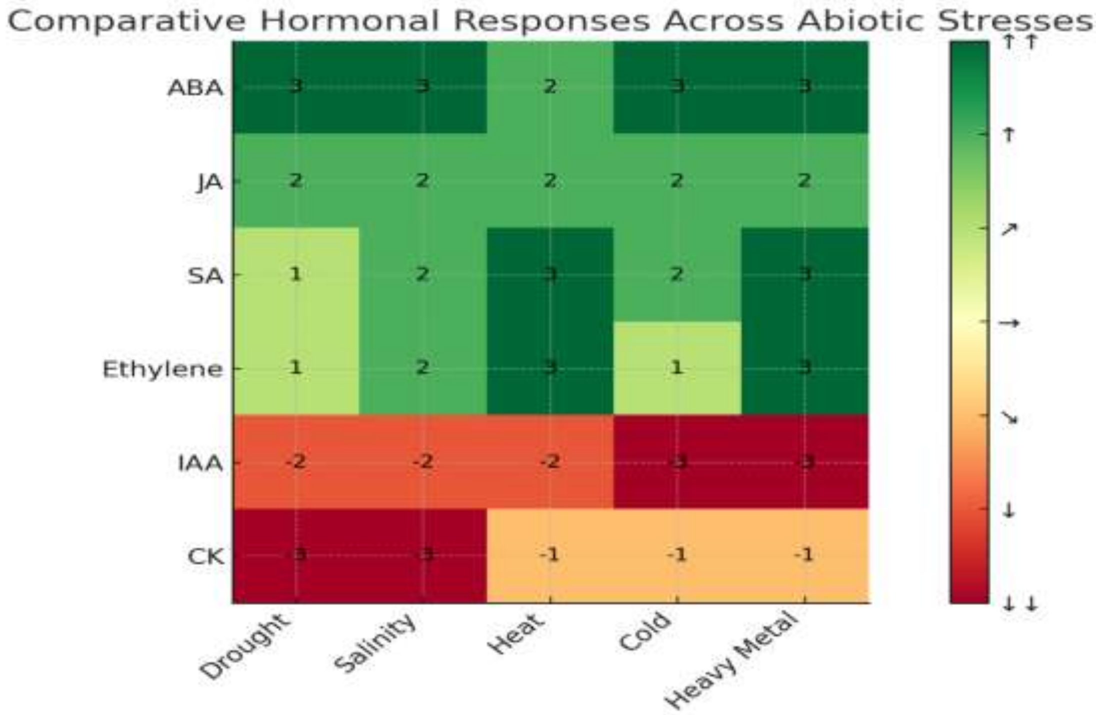
Cytokinin (CK)	↓↓ (30–50%): Suppressed shoot growth	↓↓ (30–50%): Reduced meristem activity	↓: Minimal direct role	↓: Cold-induced senescence modulation	↓: Inhibits heavy metal uptake (indirectly)	Often antagonistic to ABA; downregulated to conserve energy



Here is the heatmap chart visualizing **comparative hormonal responses** across the five major abiotic stress types. Each number represents the intensity of hormonal change:

- **↑↑ (3)** = Strong increase
- **↑ (2)** = Moderate increase
- **↗ (1)** = Slight increase
- **→ (0)** = No significant change
- **↘ (-1)** = Slight decrease
- **↓ (-2)** = Moderate decrease
- **↓↓ (-3)** = Strong decrease

Conserved Hormonal Patterns Across Multiple Stresses

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One of the most evident findings from the reviewed literature is the central role of Abscisic Acid (ABA) across nearly all abiotic stress types. Whether in drought, salinity, cold, or even certain cases of heat and metal toxicity, ABA serves as a core signal for activating protective mechanisms. These include stomatal regulation, osmotic adjustment, and the expression of stress-responsive genes. The consistency of ABA induction under water-related stresses (drought and salinity) and cold stress demonstrates its role as a universal coordinator of abiotic stress response. Jasmonic Acid (JA) also emerges as a broadly relevant hormone, involved in oxidative stress regulation, secondary metabolite biosynthesis, and activation of antioxidant enzymes under heat, salinity, and heavy metal stress. Its synergistic interactions with ABA and Salicylic Acid (SA) enhance its function across multiple stress scenarios.

Stress-Specific Dominance of Certain Hormones

While ABA and JA show broad involvement, some hormones exhibit **stress-specific dominance**:

- Salicylic Acid (SA) is particularly prominent in heat and heavy metal stress, where it regulates antioxidant enzyme activity, membrane integrity, and metal detoxification pathways. Its role is less pronounced under drought or salinity, where ABA tends to dominate.
- Ethylene shows dualistic roles in all stress types but is especially sensitive to heat and salinity, where its overproduction may lead to senescence. Under cold stress, ethylene's effect varies by species.
- Auxin consistently shows suppression or misregulation under all stress types, reflecting the plant's adaptive shift from growth promotion to stress survival. However, its role is most extensively disrupted in cold and heavy metal stress, affecting root architecture and nutrient uptake.

Hormonal Crosstalk and Antagonism

Abiotic stress responses often involve hormonal crosstalk, where one hormone modulates or interferes with the action of another. For example:

- ABA and Cytokinin exhibit antagonism under drought and salinity, where ABA suppresses cytokinin signaling to slow down growth and conserve resources.
- JA and SA can act synergistically under heat and metal stress, activating ROS-scavenging enzymes and defense genes.

- Ethylene and ABA interactions are more variable; while ethylene can enhance ABA signaling under mild stress, excessive ethylene often inhibits ABA-mediated benefits, particularly under prolonged stress.

Such interactions underline the importance of hormonal balance, rather than individual hormone levels, in shaping a plant's response.

Intensity, Timing, and Tissue Specificity

Another layer of variation lies in the timing and spatial distribution of hormonal responses. For example, ABA may accumulate in root tissues during early drought, while JA levels rise later in leaf tissues to manage oxidative stress. Similarly, ethylene may act positively in early stress stages but negatively as damage accumulates. This indicates a temporal coordination of hormone signaling where the order and duration of activation determine overall effectiveness. Furthermore, tissue-specificity matters: auxin redistribution in roots, SA activity in leaves, and JA signaling in both roots and reproductive tissues are just a few examples of how location influences hormonal impact.

Species and Genotypic Variability

Comparative studies show that stress-tolerant cultivars or wild genotypes often exhibit faster, stronger, and more integrated hormonal responses, with efficient crosstalk mechanisms. In contrast, sensitive genotypes frequently show delayed responses, overproduction of harmful signals (e.g., ethylene), or failure to coordinate key pathways. This highlights the genetic basis of hormonal regulation, suggesting potential targets for crop improvement via breeding or biotechnology.

In conclusion, while certain hormones like ABA and JA play broad roles across multiple abiotic stresses, others such as SA and ethylene show stress-specific or conditional effects. The most resilient plants are those capable of fine-tuning hormonal networks—both in terms of individual hormone concentrations and their interactive dynamics. Understanding these cross-stress comparisons offers critical insight into how plants prioritize survival over growth and how this balance can be manipulated to improve stress tolerance in agriculture.

Hormonal Crosstalk and Network Integration

Plant hormones rarely act in isolation. Instead, they operate through a highly interconnected signaling network characterized by crosstalk, feedback regulation, and combinatorial control. This network enables plants to interpret complex environmental cues and coordinate an integrated stress response. Under abiotic stress conditions, the hormonal crosstalk becomes particularly important, as it determines the balance between growth regulation, defense activation, and metabolic adaptation. This section explores the major patterns and mechanisms of hormonal interactions, drawing on secondary data from diverse plant systems.

Hormone Pair	Type of Interaction	Stress Conditions Involved	Functional Outcome	Examples / Notes
ABA + JA	Synergistic	Drought, Salinity, Heat, Heavy Metals	Enhances antioxidant activity, stomatal regulation, stress gene expression	Joint activation of *RD29*, *HSPs*, and detox enzymes like SOD, CAT
ABA + SA	Synergistic	Cold, Salinity, Heavy Metals	Boosts ROS scavenging, stabilizes membranes, improves osmotic balance	Improves survival under oxidative and osmotic stress
ABA + CK (Cytokinin)	Antagonistic	Drought, Salinity, Heat	ABA suppresses growth-promoting effects of CK during stress to conserve energy	CK downregulation aids in ABA-mediated stress tolerance
ABA + Ethylene	Context-dependent	Drought, Heat, Cold	Ethylene can antagonize or enhance ABA, depending on concentration and timing	High ethylene can inhibit ABA-induced stomatal closure
JA + SA	Synergistic or context-specific	Heat, Heavy Metals, Cold	Combined ROS detoxification, activation of	Enhances HSP expression and glutathione activity

			defense-related transcription factors	
JA + Ethylene	Synergistic	Heat, Heavy Metals	Co-activation of stress-responsive genes and antioxidant mechanisms	JA-Ethylene coregulates *PDF1.2*, a stress marker gene
SA + Ethylene	Antagonistic or balancing	Heat, Cold	Ethylene may counteract SA-mediated responses; balance determines outcome	Seen in thermotolerance studies in tomato and *Arabidopsis*
IAA + ABA	Antagonistic (mostly)	Drought, Cold, Heavy Metals	ABA inhibits auxin transport and signaling to limit growth	Root meristem shrinkage observed under cold and drought
IAA + Ethylene	Synergistic (root-focused)	Drought, Salinity, Heavy Metals	Modulates root elongation and architecture	Ethylene enhances auxin redistribution via PIN proteins
CK + Ethylene	Antagonistic	Drought, Heat	Ethylene-induced senescence countered by cytokinin; balance affects leaf longevity	CK delays leaf yellowing caused by ethylene under stress

ABA as a Central Regulatory Hub

Abscisic Acid (ABA) serves as the primary hormonal hub in most abiotic stress responses, especially under drought, salinity, and cold stress. ABA not only initiates protective pathways—such as stomatal closure, osmotic adjustment, and stress gene activation—but also interacts dynamically with other hormones.

- ABA and Cytokinin exhibit a well-documented antagonistic relationship. Under stress, ABA downregulates cytokinin signaling to halt cell division and reduce shoot growth, while cytokinin counters ABA to promote growth under non-stress conditions.
- ABA and Ethylene interactions are more nuanced. Ethylene can enhance or inhibit ABA responses depending on concentration and developmental context. In some cases, ethylene promotes ABA-induced stomatal closure; in others, it disrupts ABA signaling, especially when overproduced under prolonged stress.
- ABA and Jasmonic Acid (JA) frequently function in synergistic coordination, particularly in regulating antioxidant activity, transcriptional reprogramming, and stress-responsive gene expression.

The coordination between ABA and these hormones ensures that survival takes priority over growth during severe environmental stress.

Conclusion

The comparative evaluation of phytohormonal responses under various abiotic stress conditions reveals the remarkable adaptability and complexity of plant hormonal signaling networks. Each phytohormone—whether abscisic acid, ethylene, jasmonic acid, salicylic acid, auxins, cytokinins, gibberellins, or brassinosteroids—plays a distinctive yet interconnected role in shaping plant responses to specific environmental challenges such as drought, salinity, temperature extremes, and heavy metal toxicity. Abscisic acid emerges as a central regulator under water-deficit and salinity stress, triggering stomatal closure, osmotic adjustment, and gene activation. Ethylene, JA, and SA contribute significantly to stress signaling and cellular defense, while auxins, cytokinins, and gibberellins often adjust growth processes and developmental plasticity during stress. The ability of these hormones to function in synergy or antagonism allows plants to modulate their physiological and molecular responses with high precision. This hormonal cross-talk ensures that energy and resources are allocated optimally, prioritizing survival over growth when necessary. The integration of recent molecular, transcriptomic, and physiological findings enhances our understanding of how these hormonal responses differ depending on stress type, duration, and plant species. These insights are crucial for designing innovative strategies to improve crop resilience, whether through genetic engineering of hormone-related genes, exogenous hormone treatments, or breeding programs targeting hormone sensitivity. Ultimately, understanding the divergent yet coordinated hormonal mechanisms provides a foundation for developing climate-resilient crops and sustaining agricultural productivity in an era of increasing environmental stress.

References

1. Devireddy, A. R., Zandalinas, S. I., Fichman, Y., & Mittler, R. (2021). Integration of reactive oxygen species and hormone signaling during abiotic stress. *The Plant Journal*, *105*(2), 459-476.
2. Fahad, S., Nie, L., Chen, Y., Wu, C., Xiong, D., Saud, S., ... & Huang, J. (2014). Crop plant hormones and environmental stress. *Sustainable Agriculture Reviews: Volume 15*, 371-400.
3. Franco, J. A., Bañón, S., Vicente, M. J., Miralles, J., & Martínez-Sánchez, J. J. (2011). Root development in horticultural plants grown under abiotic stress conditions–a review. *The Journal of Horticultural Science and Biotechnology*, *86*(6), 543-556.
4. Ghosh, D., Gupta, A., & Mohapatra, S. (2019). Dynamics of endogenous hormone regulation in plants by phytohormone secreting rhizobacteria under water-stress. *Symbiosis*, *77*(3), 265-278.
5. González-Stewart, D., & Herrera-Alamillo, M. Á. (2025). Influencia de factores de transcripción de la superfamilia APETALA2/factor de respuesta a etileno en respuesta al estrés abiótico en plantas. Mexican Journal of Biotechnology.
6. Goura, K., Legrifi, I., Kallali, N. S., Taoussi, M., & Kenfaoui, J. (2025). Beyond survival: The role of secondary metabolites in plant defense mechanisms. Journal of Crop Science.
7. Gregory, B. D. (2025). Coordinated regulation of RNA metabolism and silencing by ABA signaling in plant abiotic stress responses. Molecular Plant, 18(5), 785–798. https://doi.org/10.1016/j.molp.2025.04.007
8. Haak, D. C., Fukao, T., Grene, R., Hua, Z., Ivanov, R., Perrella, G., & Li, S. (2017). Multilevel regulation of abiotic stress responses in plants. *Frontiers in plant science*, *8*, 1564.
9. Hana, W., Sukirno, S., Aziz, P., Sri, K., & Kumala, D. (2025). Effects of salicylic acid on growth, photosynthesis pigment, proline and endogenous hormones content of black rice grown under salt stress. AGROBIOS Journal, 19(2), 45–54.

10. Jan, R., Asaf, S., Numan, M., Lubna, & Kim, K. M. (2021). Plant secondary metabolite biosynthesis and transcriptional regulation in response to biotic and abiotic stress conditions. Agronomy, 11(5), 968.
11. Karimian, A., Bahramnejad, B., & Siosemardeh, A. (2025). Boosting drought resilience: The role of endophytic Bacillus safensis in enhancing melatonin production in chickpea cultivars. BMC Plant Biology.
12. Kaur, R., Bhardwaj, R., Sharma, R., Kapoor, D., Kohli, S., Kumar, V., & Kaur, P. (2016). Hormonal regulation of drought stress in plants. *Water Stress and Crop Plants: A Sustainable Approach*, *2*, 582-599.
13. Khan, N., Bano, A., Ali, S., & Babar, M. A. (2020). Crosstalk amongst phytohormones from planta and PGPR under biotic and abiotic stresses. *Plant Growth Regulation*, *90*(2), 189-203.
14. KIM, J. M., To, T. K., Nishioka, T., & Seki, M. (2010). Chromatin regulation functions in plant abiotic stress responses. *Plant, Cell & Environment*, *33*(4), 604-611.
15. Kizis, D., Lumbreras, V., & Pagès, M. (2001). Role of AP2/EREBP transcription factors in gene regulation during abiotic stress. *FEBS letters*, *498*(2-3), 187-189.
16. Kohli, A., Sreenivasulu, N., Lakshmanan, P., & Kumar, P. P. (2013). The phytohormone crosstalk paradigm takes center stage in understanding how plants respond to abiotic stresses. *Plant cell reports*, *32*(7), 945-957.