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A Comprehensive Review on Plant Stress Hormones: Roles, Mechanisms, and Applications

Rajkumar Yadav and Avshesh Kumar

Department of Botany, T.D.P.G.College, Jaunpur Affliated to VBSP University,Jaunpur

Abstract

Plant stress hormones are central to the modulation of responses to biotic and abiotic stresses. This review synthesizes recent advances in our understanding of major plant hormones—abscisic acid (ABA), jasmonates (JAs), salicylic acid (SA), ethylene (ET), and others—in mediating stress responses. We discuss the signaling pathways, crosstalk among hormones, and the practical implications of manipulating these pathways to enhance stress tolerance in crops. Finally, we outline future research directions for integrating hormone signaling into sustainable agricultural practices.

Keywords: abiotic, understanding, integrating, hormones—abscisic, salicylic

1.Introduction

Plants are constantly exposed to a range of stress factors, including drought, salinity, extreme temperatures, and pathogen attack. To cope with these challenges, they have evolved complex hormonal networks that enable them to perceive stress signals and trigger appropriate responses. Among the critical regulators are stress hormones such as ABA, JAs, SA, and ET (Zhu, 2016; Cutler et al., 2010). Understanding these hormonal responses is essential for developing strategies to improve plant resilience and productivity.

Table 1 summarizes the major plant hormones involved in stress responses, their primary functions, and the types of stresses they mediate.

Table 1. Major Plant Stress Hormones and Their Roles

Hormone	Primary Function	Stress Type Managed	Key References
ABA	**Stomatal closure, drought response, osmotic balance**	**Drought, salinity**	**Zhu (2016), Park et al. (2009)**
Jasmonates (JA)	**Defense against herbivores, wounding response**	**Biotic stress, cold**	**Wasternack & Hause (2013)**
Salicylic Acid (SA)	**Pathogen defense, systemic acquired resistance**	**Biotic stress**	**Vlot et al. (2009)**
Ethylene (ET)	**Stress adaptation, fruit ripening, senescence**	**Multiple stresses**	**Dubois et al. (2018)**

2.Abscisic Acid (ABA) and Drought/Salinity Stress

ABA is widely recognized as the primary hormone mediating responses to water-deficit stress and salinity (Finkelstein, 2013; Hauser & Waadt, 2018). Under stress conditions, ABA levels increase, leading to stomatal closure, induction of stress-responsive genes, and activation of protective mechanisms.

Figure 1 illustrates the ABA signaling pathway in response to drought stress, highlighting key receptors (PYR/PYL/RCAR), phosphatases, and downstream transcription factors.

Figure 1. ABA Signaling Pathway in Response to Drought Stress

(A graphical representation showing how ABA activates stress response genes, leading to stomatal closure.)

3. Jasmonates (JAs) and Salicylic Acid (SA) in Biotic and Abiotic Stress

Jasmonates and salicylic acid are pivotal in plant defense against pathogens and herbivores (Wasternack & Hause, 2013; Vlot et al., 2009). JA is generally associated with responses to necrotrophic pathogens and insect herbivory, while SA is linked to defense against biotrophic pathogens (Pieterse et al., 2012).

Figure 2 shows the antagonistic crosstalk between JA and SA signaling, demonstrating how they fine-tune defense responses based on pathogen type.

Figure 2. Crosstalk Between Jasmonate and Salicylic Acid Pathways

(A schematic diagram showing the interplay between JA and SA, with examples of upregulated and downregulated defense genes.)

4. Ethylene: A Multifunctional Stress Modulator

Table 2 presents a comparative analysis of ethylene's role under different stress conditions, highlighting its interaction with other hormones.

1.2 Objective of the Research

The objective of this research is to explore how AI as well as ML techniques can be leveraged to improve the performance of EPS and SG, addressing the challenges outlined above. Specifically, this study aims to achieve the following objectives:

Table 2. Ethylene's Role in Stress Responses

Stress Type	Ethylene Function	Interaction with Other Hormones	Key References
Drought	Induces leaf senescence	Antagonistic to ABA	Nakashima et al. (2014)
Pathogen Attack	Activates defense genes	Synergistic with SA	Dubois et al. (2018)
Salt Stress	Modifies root growth	Works with ABA & JA	Fujita et al. (2006)

5. Crosstalk and Integration of Hormonal Pathways

A major theme in plant stress physiology is the extensive crosstalk between different hormone signaling pathways. These interactions enable plants to integrate multiple environmental cues and mount coordinated responses (Pieterse et al., 2012).

Figure 3 depicts a network diagram of key hormone interactions in response to stress, showcasing positive and negative regulatory relationships.

Figure 3. Hormonal Crosstalk in Stress Response

(A visual model illustrating how ABA, JA, SA, and ET interact in response to drought, pathogens, and temperature extremes.)

6. Applications in Agriculture and Crop Stress Management

Understanding the hormonal regulation of stress responses has significant implications for agriculture. Manipulation of hormone biosynthesis and signaling pathways has been employed to develop transgenic crops with enhanced tolerance to drought, salinity, and pathogen attack (Zhu, 2016).

Table 3 lists biotechnological advancements that leverage hormonal pathways for improved stress tolerance in crop

Table 3. Biotechnological Applications of Stress Hormones in Crops

Target Hormone	Genetic Modification	Resulting Crop Improvement	Reference
ABA	Overexpression of PYR1	Drought resistance	Cutler et al. (2010)
JA	Activation of MYC2	Enhanced pest resistance	Wasternack & Hause (2013)
SA	Increased NPR1 expression	Improved disease resistance	Vlot et al. (2009)

7. Future Perspective

Future research should aim to dissect the dynamic and context-dependent nature of hormone signaling networks under combined stress conditions. Advances in genome editing and systems biology provide exciting opportunities to unravel the complexity of hormone interactions and develop crops with tailored stress responses (Pieterse et al., 2012).

8. Conclusions

Plant stress hormones are integral to the regulation of defense and adaptation mechanisms. While ABA, JA, SA, and ethylene have been extensively studied, the intricate crosstalk between these and other hormones presents a complex landscape for future research. An improved understanding of these networks will facilitate the development of innovative strategies for enhancing plant resilience and agricultural sustainability.

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