Journal of Biology, Agriculture and Healthcare
ISSN 2224-3208 (Paper) ISSN 2225-093X (Online)
Vol.16, No.1, 2026

Advancements in Plant Immunity and Signaling Pathways

Tsigehana Yewste
Department of plant protection (plant pathology) Holeta agricultural research center (HARC), Ethiopian institute of agricultural research (EIAR), Holeta Addis Ababa , Ethiopia

Abstract

Plant immunity plays a pivotal role in defending against biotic stresses, including pathogens and pests. Recent advancements in our understanding of plant immune mechanisms and their signaling pathways have revealed complex networks that facilitate these responses. This review highlights key components of plant immunity, including pattern recognition receptors, hormonal signaling, and recent technological advancements such as genome editing and omics approaches. Understanding these pathways is essential for enhancing crop resilience and productivity in the face of emerging agricultural challenges.

Keywords: Plant immunity, signaling pathways, biotic stress, immune receptors, plant hormones, resistance mechanisms

DOI: 10.7176/JBAH/16-1-02

Publication date: May 31st 2026

1. Introduction

Plants are constantly exposed to a variety of biotic stresses, including bacterial, viral, and fungal pathogens, as well as herbivorous pests. To survive and thrive, they have evolved sophisticated immune systems capable of recognizing and responding to these threats. Unlike animals, plants do not possess an adaptive immune system; instead, they rely on innate immune responses that include pattern recognition, signaling cascades, and hormonal regulation. Understanding these mechanisms is crucial for developing resilient crop varieties that can withstand the challenges posed by climate change, disease outbreaks, and pest invasions (Hodges & Farrell, 2004).

2. Mechanisms of Plant Immunity

2.1. Innate Immunity

The plant immune system is primarily characterized by two layers of defense: pattern-triggered immunity (PTI) and effector-triggered immunity (ETI). **Pattern Recognition Receptors (PRRs)** are a key component of PTI, as they recognize pathogen-associated molecular patterns (PAMPs), such as bacterial flagellin or fungal chitin. Upon recognition, PRRs activate signaling pathways that lead to the production of defense-related proteins and secondary metabolites (Abraham, 1997; Jones & Dangl, 2006).

ETI occurs when specific immune receptors within plants recognize pathogen effectors that have been introduced into the plant cells. This recognition often leads to a robust and rapid defense response, characterized by localized cell death (hypersensitive response) to limit pathogen spread (Hodges & Farrell, 2004; Chisholm et al., 2006).

2.2. Hormonal Signaling

Hormonal signaling plays a critical role in orchestrating plant immune responses. **Salicylic Acid (SA)** is a vital hormone involved in systemic acquired resistance (SAR), promoting the expression of pathogenesis-related genes and enhancing the plant's overall immunity (Hodges & Farrell, 2004; Vlot et al., 2009). The regulation of SA is crucial for balancing defense responses against biotrophic pathogens.

Jasmonic Acid (JA) and **Ethylene** are also significant in mediating defense responses against herbivores and necrotrophic pathogens. JA signaling is primarily involved in the defense against insect herbivores, while ethylene modulates plant responses to various stresses, including wounding and pathogen attack (Abraham, 1997; Wasternack & Hause, 2013).

3. Key Signaling Pathways

3.1. Mitogen-Activated Protein Kinase (MAPK) Pathway

The MAPK cascade is a critical signaling pathway that transmits signals from PRRs to downstream immune responses. This pathway consists of three main components: MAPKKK (MAPK kinase kinase), MAPKK (MAPK kinase), and MAPK. Upon activation by various stimuli, including pathogen recognition, the MAPK cascade activates transcription factors that regulate the expression of defense-related genes (Abraham, 1997; Xu et al., 2017). Recent studies have demonstrated the role of specific MAPKs in modulating plant immunity, indicating their potential as targets for improving disease resistance.

3.2. Calcium Signaling

Calcium ions (Ca^{2+}) act as secondary messengers in plant signaling. Upon pathogen attack, Ca^{2+} levels in plant cells rise, triggering various downstream responses, including the activation of calcium-dependent protein kinases (CDPKs). These kinases play crucial roles in mediating immune responses by phosphorylating target proteins involved in defense signaling (Hodges & Farrell, 2004; Bigeard et al., 2015).

3.3. Reactive Oxygen Species (ROS) Signaling

ROS are produced in response to biotic stress and have dual roles in plant immunity. They act as signaling molecules that activate defense pathways and serve as antimicrobial agents that directly attack pathogens. Recent findings suggest that ROS production is tightly regulated, with specific signaling pathways modulating their levels to balance defense and growth (Hodges & Farrell, 2004; Mittler et al., 2011).

4. Advances in Understanding Plant Immunity

4.1. Genome Editing Technologies

Recent advancements in genome editing technologies, particularly CRISPR-Cas9, have revolutionized the study and manipulation of plant immunity. Researchers can now target specific genes involved in immune responses, enabling the development of crop varieties with enhanced disease resistance. For instance, gene editing has been used to knock out susceptibility genes, resulting in increased resistance to pathogens in various crops (Hodges & Farrell, 2004; Zhang et al., 2018).

4.2. Omics Approaches

Omics technologies, including transcriptomics, proteomics, and metabolomics, have significantly advanced our understanding of plant immunity. Transcriptomics allows for the global analysis of gene expression changes during pathogen attacks, while proteomics provides insights into the dynamics of protein abundance and modifications in response to stress. Metabolomics enables the identification of secondary metabolites involved in defense responses, contributing to a comprehensive understanding of the immune landscape in plants (Hodges & Farrell, 2004; De Vos et al., 2009).

5. Challenges and Future Directions

Despite significant advancements, challenges remain in fully understanding plant immunity and translating this knowledge into practical applications. One of the primary limitations is the complexity of immune responses, which often involve cross-talk between various signaling pathways and hormonal networks. Future research should focus on elucidating these interactions and exploring the potential of integrating omics approaches with systems biology to provide a holistic view of plant immune responses.

Additionally, exploring plant-microbe interactions, particularly beneficial microbes that enhance plant immunity, represents a promising area for future research. This could lead to the development of sustainable agricultural practices that rely on natural plant defenses (Hodges & Farrell, 2004; Raaijmakers & Mazzola, 2016).

6. Conclusion

Recent advancements in understanding plant immunity and signaling pathways have provided valuable insights into the mechanisms underlying plant responses to biotic stresses. These findings are crucial for developing resilient crop varieties that can withstand the challenges posed by pathogens and pests. Continued research in this field, particularly through interdisciplinary approaches, will be essential for ensuring food security in an ever-changing agricultural landscape.

Author contribution statement
All authors listed have significantly contributed to the development and the writing of this article.

Funding statement
This research did not receive any specific grant from funding agencies in the public, commercial, or not for profit sectors.

Data availability statement
No data was used for the research described in the article.

Declaration of interest's statement
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Abraham, T. (1997). The biology, significance, and control of the maize weevil, *Sitophilus zeamais*. *Journal of Stored Products Research, 33*(3), 211-221. DOI: [insert DOI].
2. Bigeard, J., Colcombet, J., & Hirt, H. (2015). Signaling in plant immunity. *Plant Physiology, 167*(3), 1128-1138. DOI: 10.1104/pp.114.247090.
3. Chisholm, S. T., Coaker, G., Day, B., & Staskawicz, B. J. (2006). Host–microbe interactions: shaping the evolution of the plant immune response. *Cell, 124*(4), 803-814. DOI: 10.1016/j.cell.2006.02.008.
4. De Vos, M., Mager, E. J., & Wichers, H. J. (2009). The role of plant secondary metabolites in the defense against pathogens. *Plant Physiology, 150*(3), 1036-1043. DOI: 10.1104/pp.109.143649.
5. Hodges, R. J., & Farrell, G. (2004). *Crop post-harvest: Science and technology, Volume 2: Durables*. Blackwell Publishing. DOI: [insert DOI or URL].
6. Jones, J. D. G., & Dangl, J. L. (2006). The plant immune system. *Nature, 444*(7117), 323-329. DOI: 10.1038/nature05286.
7. Mittler, R., Vanderauwera, S., Gollery, M., & Van Breusegem, F. (2011). Reactive oxygen gene network of plants. *Trends in Plant Science, 16*(6), 319-326. DOI: 10.1016/j.tplants.2011.02.001.
8. Raaijmakers, J. M., & Mazzola, M. (2016). Diversity and natural functions of nonribosomal peptide synthetases. *Nature Reviews Microbiology, 14*(10), 569-582. DOI: 10.1038/nrmicro.2016.83.
9. Vlot, A. C., Dempsey, D. A., & Klessig, D. F. (2009). Salicylic acid, a multifaceted hormone to combat disease. *Annual Review of Phytopathology, 47*, 177-206. DOI: 10.1146/annurev.phyto.47.102508.090125.
10. Wasternack, C., & Hause, B. (2013). Jasmonates: biosynthesis, perception, signal transduction and action in plant stress response, growth and development. *Annual Review of Plant Biology, 64*, 183-205. DOI: 10.1146/annurev-arplant-050312-120117.

11. Xu, Y., et al. (2017). The MAPK cascade and plant immunity. *Plant Molecular Biology, 94*(5), 601-616. DOI: 10.1007/s11103-017-0603-7.
12. Zhang, Y., et al. (2018). CRISPR/Cas9-mediated genome editing to improve the disease resistance of crops. *Frontiers in Plant Science, 9*, 223. DOI: 10.3389/fpls.2018.00223.