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Plant Hormone Crosstalk in Growth and Stress Adaptation

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INTRODUCTION

Plants constantly encounter environmental stresses such as drought, salinity, extreme temperatures, flooding, and pathogen attack. Since they are immobile, plants rely on highly efficient internal signaling systems to regulate growth and survival. Plant hormones, or phytohormones, are naturally occurring compounds produced in minute amounts that control development and stress responses. Major hormones include auxins, gibberellins, cytokinins, abscisic acid, ethylene, jasmonic acid, salicylic acid, and brassinosteroids. Rather than acting independently, these hormones interact through a complex network known as hormone crosstalk. This interaction integrates developmental and environmental signals, enabling plants to balance growth with defense and adaptation. Understanding hormone crosstalk is essential for improving crop productivity, resilience, and sustainable agricultural systems under changing climatic conditions.

Concept of Plant Hormone Crosstalk

Plant hormone crosstalk refers to the coordinated interaction among two or more phytohormone signaling pathways that regulate plant growth, development, and responses to environmental stresses. Rather than functioning independently, hormones such as auxins, gibberellins, cytokinins, Abscisic Acid (ABA), ethylene, jasmonic acid, salicylic acid, and brassinosteroids communicate through interconnected signaling networks.

These interactions may be synergistic, where one hormone enhances the action of another, or antagonistic, where one hormone suppresses another’s effects. Hormonal crosstalk occurs at several levels, including hormone biosynthesis, transport, receptor perception, signal transduction, transcriptional regulation, protein modification, and metabolic control.

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This complex coordination enables plants to integrate internal developmental cues with external environmental signals. For instance, under drought stress, ABA accumulates to induce stomatal closure and reduce water loss, while gibberellin activity is suppressed to limit growth and conserve energy. The nature of hormone crosstalk depends on plant species, tissue type, developmental stage, nutrient status, and the intensity and duration of stress conditions.

Major Plant Hormones Involved in Crosstalk

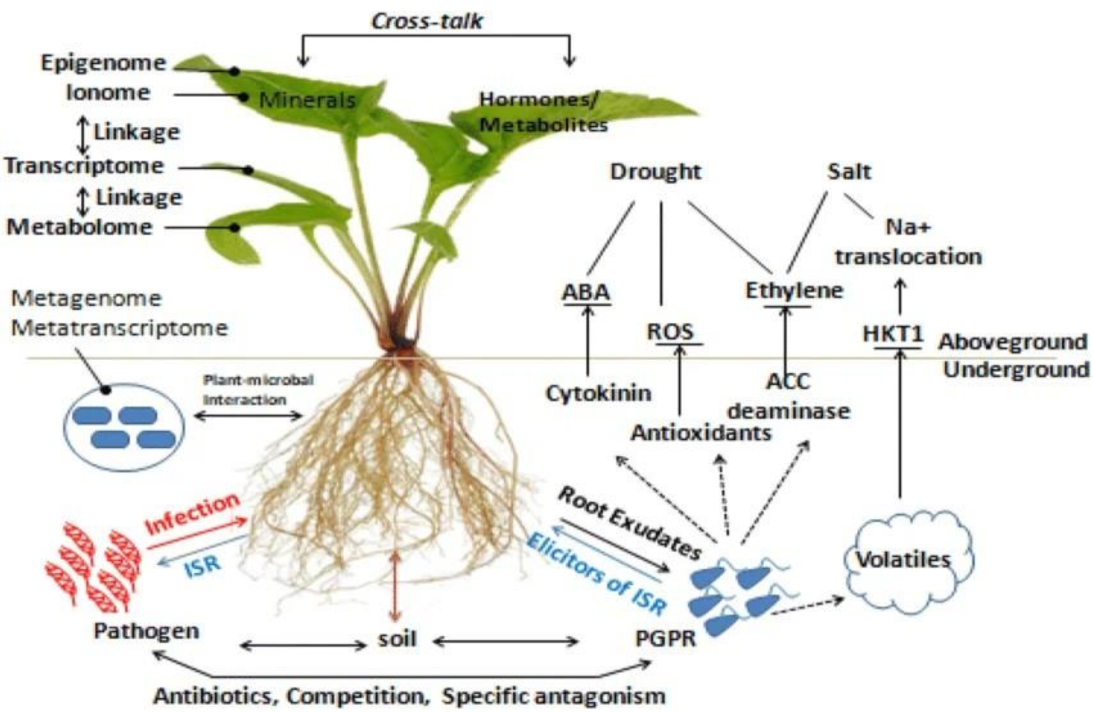
1. Auxins

Auxins are primarily involved in cell elongation, apical dominance, root initiation, vascular differentiation, and tropic responses. Indole-3-acetic acid (IAA) is the most common natural auxin.

Functions of Auxins

- Cell elongation
- Root development
- Apical dominance
- Phototropism and gravitropism
- Fruit development
- Vascular tissue differentiation

Auxins interact with several hormones including cytokinins, gibberellins, ethylene, and ABA to regulate root-shoot balance and stress adaptation.



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2. Gibberellins (GAs)

Gibberellins (GAs) are a group of plant hormones that regulate various aspects of growth and development. They stimulate stem elongation by promoting cell division and elongation, break seed dormancy and enhance germination, activate hydrolytic enzymes such as α-amylase during germination, induce flowering in certain plant species, and promote fruit set and enlargement. Gibberellins play a vital role in coordinating rapid vegetative growth and reproductive development under favorable environmental conditions.

3. Cytokinins

Cytokinins are essential plant hormones that promote cell division and regulate numerous developmental processes. They stimulate shoot initiation and branching, delay leaf senescence by maintaining chlorophyll and protein content, enhance nutrient mobilization from older tissues to actively growing organs, and support chloroplast development and photosynthetic activity. Cytokinins work closely with auxins to control organ formation and play a crucial role in maintaining plant vigor, productivity, and adaptation to changing environmental conditions.

4. Abscisic Acid (ABA)

Abscisic Acid (ABA) is widely known as the plant stress hormone because it plays a central role in abiotic stress tolerance. It induces stomatal closure to reduce water loss, promotes seed dormancy, enhances drought and salinity tolerance, and regulates osmotic adjustment. ABA also activates stress-responsive genes and coordinates physiological and biochemical mechanisms that help plants survive under adverse environmental conditions such as dehydration, high salinity, and temperature extremes.

5. Ethylene

Ethylene is a gaseous plant hormone that regulates many developmental and stress-related processes. It plays a key role in fruit ripening by promoting color change, softening, and aroma formation. Ethylene also induces leaf abscission, accelerates senescence, and mediates plant responses to drought, flooding, mechanical injury, and pathogen attack. In roots, it stimulates root hair formation, enhancing water and nutrient absorption under stressful conditions.

6. Jasmonic Acid (JA)

Jasmonic acid (JA) is a vital plant hormone involved in defense responses and stress adaptation. It is rapidly produced in response to wounding, insect feeding, and pathogen attack, activating genes associated with protective compounds and defense proteins. JA enhances resistance to herbivorous insects, improves tolerance to abiotic stresses, and regulates important reproductive processes such as pollen development, flower maturation, and seed formation. Through its interaction with other hormones, jasmonic acid helps plants balance growth and defense under adverse conditions.

7. Salicylic Acid (SA)

Salicylic acid (SA) is an important plant hormone involved in defense against pathogens and the establishment of systemic acquired resistance (SAR). It activates defense-related genes and stimulates the production of pathogenesis-related proteins that enhance resistance to bacterial, fungal, and viral infections. SA also contributes to thermotolerance and regulates oxidative stress by modulating antioxidant systems and reactive oxygen species levels. Through interactions with other hormones, salicylic acid strengthens plant immunity while supporting adaptation to environmental stresses.

8. Brassinosteroids (BRs)

Brassinosteroids (BRs) are steroidal plant hormones that play crucial roles in growth regulation and stress adaptation. They promote cell expansion and elongation, stimulate vascular differentiation, and enhance seed germination and seedling establishment. BRs also improve resistance to drought, salinity, temperature extremes, and oxidative stress by activating antioxidant enzymes and stress-responsive genes. Through extensive crosstalk with auxins, gibberellins, and Abscisic Acid (ABA), brassinosteroids help coordinate plant growth and defense, enabling plants to maintain productivity under both favorable and adverse environmental conditions.

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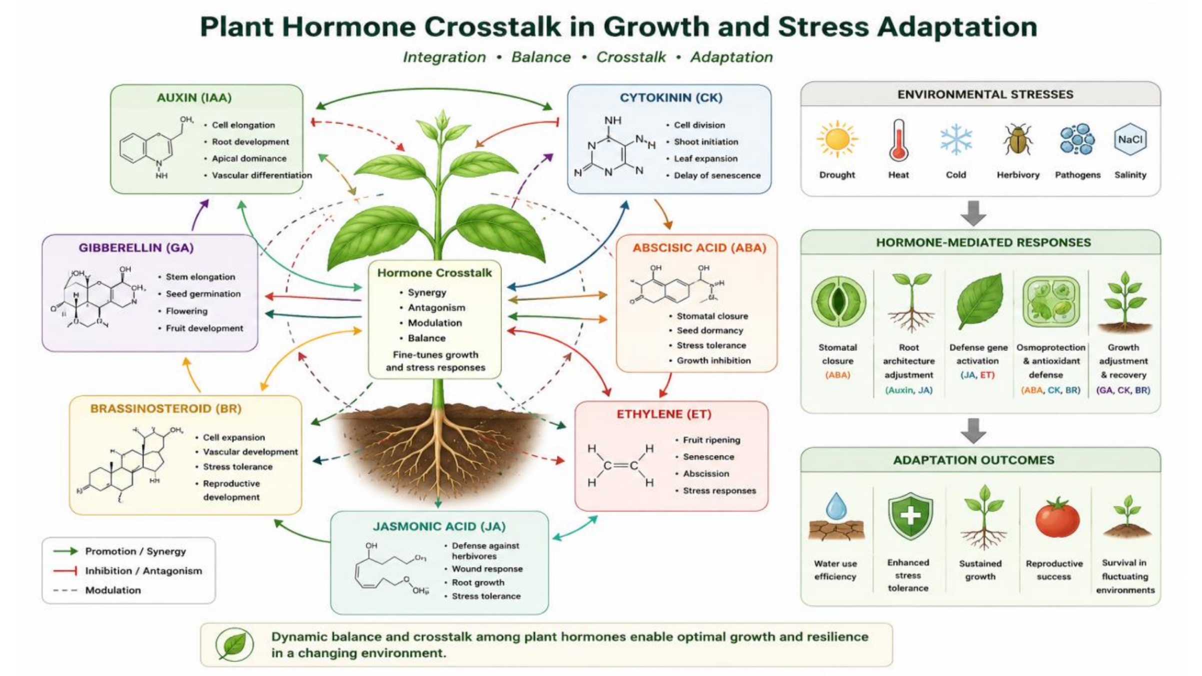

Mechanisms of Hormone Crosstalk

Hormone crosstalk operates through several molecular and biochemical mechanisms.

1. Crosstalk through Hormone Biosynthesis

Plant hormones influence each other's biosynthesis to coordinate growth and stress responses. During drought, Abscisic Acid (ABA) accumulates and suppresses gibberellin synthesis, reducing growth. Auxins stimulate ethylene production, while cytokinins regulate auxin biosynthesis in roots. Such interactions enable plants to adjust physiology and development according to changing environmental conditions.

2. Crosstalk through Signal Transduction

Plant hormone signaling pathways share common components such as protein kinases, transcription factors, secondary messengers, calcium ions, and reactive oxygen species (ROS). These shared molecules integrate signals from multiple hormones, allowing plants to coordinate growth, development, and stress responses efficiently under changing environmental conditions.

3. Crosstalk through Gene Expression

Plant hormones regulate overlapping groups of genes, allowing one hormone to enhance or suppress genes controlled by another. Abscisic Acid (ABA) induces stress-responsive genes, gibberellins activate growth-related genes, and salicylic acid and jasmonic acid regulate defense genes. This transcriptional coordination ensures precise and adaptive plant responses.

4. Crosstalk through Protein Modification

Plant hormones regulate protein phosphorylation, ubiquitination, stabilization, and degradation to coordinate signaling pathways. DELLA proteins act as repressors of gibberellin signaling, while Abscisic Acid (ABA) activates phosphorylation cascades through protein kinases. Ethylene signaling depends on the stabilization of key regulatory proteins. These post-translational modifications enable rapid and precise adaptation to environmental stresses.

Hormone Crosstalk in Plant Growth and Development

Auxin–Cytokinin Crosstalk

Auxin and cytokinin interactions are essential for organogenesis and root-shoot balance.

Hormone Crosstalk in Root Development

In root development, auxins and cytokinins interact antagonistically to regulate organ formation and growth. Auxins stimulate root initiation, lateral root formation, and root

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elongation by promoting cell division and differentiation in the root meristem. In contrast, cytokinins generally inhibit root growth and reduce meristem activity. A high auxin-to-cytokinin ratio favors root formation, whereas a high cytokinin-to-auxin ratio promotes shoot initiation and bud development. This hormonal balance is fundamental in plant tissue culture, root architecture, and adaptation to soil and environmental conditions.

Hormone Crosstalk in Shoot Development

In shoot development, cytokinins and auxins interact antagonistically to regulate plant architecture. Cytokinins promote shoot branching by stimulating lateral bud growth and cell division, whereas auxins maintain apical dominance by inhibiting the outgrowth of lateral buds. This balance between the two hormones determines the overall branching pattern, canopy structure, and biomass distribution in plants, allowing adaptive growth under varying environmental conditions.

Auxin–Ethylene Crosstalk

Auxins stimulate ethylene biosynthesis. Ethylene in turn affects root growth and gravitropic responses.

Physiological Effects of Hormone Crosstalk

Plant hormone crosstalk regulates key physiological processes such as root hair formation, fruit ripening, leaf abscission, and stress adaptation. For example, during flooding stress, ethylene accumulation alters auxin transport and distribution, leading to the formation of adventitious roots that help plants survive in low-oxygen conditions. This coordinated hormonal interaction ensures adaptive growth and improved tolerance to environmental stresses.

Gibberellin–ABA Crosstalk

Gibberellins and ABA exhibit strong antagonistic interaction.

Hormone Crosstalk in Seed Germination and Stress Conditions

During seed germination, gibberellins promote germination by activating enzymes that mobilize stored food reserves, whereas Abscisic Acid (ABA) maintains seed dormancy by inhibiting germination processes. The balance between these two hormones is strongly influenced by environmental conditions such as temperature, moisture, and light availability. Under stress conditions like drought and salinity, ABA accumulates and suppresses the growth-promoting effects of gibberellins, allowing seeds and plants to conserve energy and enhance survival.

Brassinosteroid–Auxin Crosstalk

Brassinosteroids (BRs) and auxins interact synergistically to regulate key growth processes in plants. This crosstalk enhances cell elongation by promoting cell wall loosening and coordinated cell expansion. Together, they support strong stem growth, improved root system architecture, and proper vascular differentiation. The interaction between these hormones also helps maintain balanced growth under environmental stress conditions, improving overall plant vigor and adaptability.

Hormone Crosstalk in Abiotic Stress Adaptation (Drought Stress)

Abiotic stresses such as drought, salinity, heat, cold, and flooding significantly reduce crop productivity. Hormone crosstalk enables plants to integrate multiple signaling pathways and activate adaptive mechanisms for survival under stress conditions.

1. Drought Stress

Drought stress leads to reduced water availability and loss of cellular turgor. In response, Abscisic Acid (ABA) accumulates rapidly and plays a central regulatory role. ABA induces stomatal closure to minimize water loss, promotes osmolyte accumulation for osmotic adjustment, enhances root growth for improved water uptake, and activates stress-responsive genes that strengthen plant tolerance.

ABA–Ethylene Interaction

ABA promotes stomatal closure during early drought stress, while ethylene may partially counteract ABA effects during prolonged

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stress, helping regulate senescence and stress progression.

ABA–Auxin Interaction

ABA influences auxin transport and distribution, leading to modifications in root architecture that improve water absorption efficiency.

ABA–Gibberellin Interaction

ABA suppresses gibberellin-mediated growth processes, reducing energy expenditure and allowing plants to conserve resources under water-limited conditions.

2. Hormone Crosstalk in Salinity Stress

Salinity stress causes ionic imbalance, osmotic stress, and toxicity due to excess sodium and chloride ions, ultimately reducing plant growth and productivity. Plants respond through complex hormone crosstalk that activates multiple adaptive mechanisms.

Hormonal Responses

Under salt stress, Abscisic Acid (ABA) accumulates and enhances overall stress tolerance by regulating stomatal behavior and stress gene expression. Ethylene plays a key role in modulating ion transport and stress signaling pathways. Cytokinins help delay leaf senescence, maintaining photosynthetic activity for a longer period, while brassinosteroids improve antioxidant enzyme activity, reducing oxidative damage.

Crosstalk Mechanisms

These hormones work together to regulate sodium ion exclusion, osmotic adjustment, antioxidant defense systems, and root system adaptation. This integrated hormonal network enables plants to maintain cellular homeostasis, improve water uptake efficiency, and enhance survival under high salinity conditions.

3. Hormone Crosstalk in Heat Stress

High temperature stress disrupts protein structure, membrane stability, and metabolic functions in plants. Hormones such as salicylic acid (SA), Abscisic Acid (ABA), ethylene, and brassinosteroids (BRs) play key roles in thermotolerance. SA induces heat shock proteins, ABA regulates transpiration, ethylene modulates stress signaling, and BRs enhance overall heat resistance. SA–ethylene crosstalk strengthens antioxidant defense systems and protects cellular structures under heat stress conditions.

4. Hormone Crosstalk in Cold Stress

Cold stress reduces membrane fluidity, slows enzymatic activity, and disrupts metabolic processes in plants. Hormonal regulation is essential for cold acclimation and survival under low temperature conditions. Abscisic Acid (ABA) induces cold-responsive genes and enhances stress tolerance mechanisms. Jasmonic acid (JA) activates defense-related pathways, while cytokinins help maintain cellular metabolism and delay cold-induced senescence. ABA–JA crosstalk plays a crucial role in improving freezing tolerance by enhancing antioxidant enzyme activity and regulating osmotic balance, thereby protecting cellular structures from cold-induced damage.

5. Hormone Crosstalk in Flooding Stress

Flooding stress leads to oxygen deficiency in the root zone, severely affecting plant respiration and growth. Under such conditions, ethylene accumulates due to restricted gas diffusion and acts as a key signaling hormone for adaptation. Ethylene promotes the formation of adventitious roots, enhances aerenchyma development for internal oxygen transport, and stimulates stem elongation in some species to maintain contact with the air.

Ethylene–Auxin Crosstalk

Ethylene interacts with auxin by modifying its synthesis, transport, and distribution within plant tissues. This regulated auxin movement supports the initiation and development of adventitious roots, improving oxygen uptake and overall plant survival under flooded conditions.

Hormone Crosstalk in Biotic Stress Adaptation

Plants encounter pathogens such as bacteria, fungi, viruses, and insects. Hormone crosstalk plays a major role in plant immunity.

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Salicylic Acid and Jasmonic Acid Crosstalk

Salicylic acid (SA) and jasmonic acid (JA) are key regulators of plant defense responses. SA is primarily effective against biotrophic pathogens and viral infections, whereas JA provides strong resistance against necrotrophic pathogens and herbivorous insects. These two pathways often interact antagonistically, where activation of SA signaling suppresses JA responses and vice versa. This antagonism enables plants to fine-tune their defense strategies based on the type of invading pathogen, ensuring efficient and targeted immune responses while minimizing unnecessary energy expenditure.

Ethylene and Jasmonic Acid Interaction

Ethylene and jasmonic acid (JA) often interact synergistically to enhance plant defense against necrotrophic pathogens and insect attack. This coordinated signaling activates a wide range of defense genes, leading to the production of antimicrobial compounds and secondary metabolites. It also strengthens structural barriers through cell wall reinforcement, reducing pathogen invasion and spread. Together, ethylene–JA crosstalk significantly improves plant immunity and stress resilience.

ABA in Plant Defense

Abscisic Acid (ABA) plays a dual role in plant defense responses. On the positive side, ABA induces stomatal closure, which limits pathogen entry and helps conserve water under stress conditions. It also regulates the expression of stress-responsive genes that enhance plant survival under adverse environments. However, ABA can sometimes negatively affect immunity by suppressing salicylic acid (SA)-mediated defense pathways, reducing resistance against certain pathogens. Therefore, ABA signaling must be tightly regulated and balanced with other hormonal pathways to ensure effective coordination between stress tolerance and disease resistance in plants.

Role of Reactive Oxygen Species (ROS) in Hormone Crosstalk

Reactive oxygen species (ROS) act as important signaling molecules in plant stress responses and hormone crosstalk. Common ROS include hydrogen peroxide (H_2O_2), superoxide radicals, and hydroxyl radicals. These molecules interact with key hormonal pathways such as Abscisic Acid (ABA), ethylene, jasmonic acid (JA), and salicylic acid (SA). ROS play multiple roles in signaling networks, including amplification of stress signals, activation of defense-related genes, regulation of stomatal closure, and induction of programmed cell death during severe stress. Controlled production and scavenging of ROS are essential, as they help plants balance survival and damage control under environmental stress conditions.

Molecular Basis of Hormone Crosstalk

Advances in genomics and molecular biology have identified key regulatory components that control plant hormone crosstalk. Transcription factors play a central role in integrating multiple hormonal signals and regulating downstream gene expression during growth and stress responses. Important transcription factor families include MYB, WRKY, NAC, bZIP, and AP2/ERF. These regulators act as molecular switches that decode signals from hormones such as Abscisic Acid (ABA), ethylene, jasmonic acid, and salicylic acid, and coordinate the expression of stress-responsive and developmental genes. Through this integration, plants achieve precise control over physiological processes under varying environmental conditions.

Protein Kinases in Hormone Crosstalk

Protein kinases are key components of signal transduction pathways that regulate plant responses to environmental stress. They function by phosphorylating target proteins, thereby activating or inhibiting downstream signaling processes. Important kinase groups include MAP kinases, SnRK2 kinases, and CDPKs (calcium-dependent protein kinases). These kinases integrate multiple hormone signals and coordinate pathways involving ethylene, jasmonic acid (JA), and Abscisic Acid (ABA). Through this regulation, protein kinases ensure precise control of stress responses, growth modulation, and adaptive physiological changes in plants.

MicroRNAs (miRNAs) in Hormone Crosstalk

MicroRNAs (miRNAs) are small non-coding RNA molecules that regulate gene expression and play an important role in plant hormone crosstalk. They fine-tune hormonal signaling by targeting specific mRNAs for degradation or translational repression. miRNAs are involved in regulating auxin signaling pathways, modulating responses of Abscisic Acid (ABA), and enhancing plant adaptation to environmental stresses. They also influence root architecture by controlling genes related to cell division, elongation, and differentiation. Through these regulatory functions, miRNAs provide precise and dynamic control over hormonal interactions, ensuring optimal plant growth and stress responses.

Agricultural Importance of Hormone Crosstalk

Understanding hormone crosstalk has significant agricultural applications.

1. Development of Stress-Tolerant Crops

Manipulation of plant hormone signaling pathways offers a powerful strategy for developing stress-tolerant crops. By modifying hormonal responses, plants can be engineered to better withstand drought, salinity, heat, cold, and flooding stresses. Key hormone pathways involving auxins, gibberellins, cytokinins, and Abscisic Acid (ABA) are often targeted to improve water-use efficiency, root architecture, and stress-responsive gene expression. Modern biotechnology tools such as genetic engineering, marker-assisted selection, and genome editing enable precise manipulation of hormone-related genes. As a result, crop resilience and productivity can be significantly enhanced under changing climatic conditions.

2. Improvement of Crop Productivity

Balanced regulation of plant hormones plays a crucial role in enhancing overall crop productivity. Proper hormonal coordination improves seed germination, stimulates root growth, and increases nutrient uptake efficiency. It also regulates flowering time, enhances fruit set, and contributes to yield stability under varying environmental conditions. Optimizing interactions among key hormones such as auxins, cytokinins, gibberellins, and Abscisic Acid (ABA) ensures better growth–stress balance. As a result, effective management of hormone crosstalk leads to improved crop performance and higher agricultural productivity.

3. Sustainable Agriculture

Hormone-based technologies contribute significantly to sustainable agriculture by reducing reliance on synthetic chemical inputs. Plant growth regulators help optimize crop development and yield, while seed priming with hormonal treatments enhances germination and early seedling vigor. Stress protectants improve plant resilience against drought, salinity, and temperature extremes. In addition, biofertilizers often interact with plant hormone pathways to improve nutrient availability and uptake efficiency. These integrated approaches, involving key hormones such as auxins, cytokinins, and Abscisic Acid (ABA), support environmentally friendly farming systems and long-term soil health.

4. Precision Agriculture and Biotechnology

Modern precision agriculture and biotechnology tools are transforming the understanding and application of plant hormone crosstalk. Techniques such as CRISPR gene editing allow targeted modification of hormone-related genes to improve stress tolerance and yield. Transcriptomics, proteomics, and metabolomics help in analyzing gene expression, protein activity, and metabolic changes involved in hormonal signaling networks. AI-assisted phenotyping enables rapid, high-throughput analysis of plant traits under different environmental conditions. Together, these approaches help decode complex hormonal interactions involving auxins, cytokinins, and Abscisic Acid (ABA), supporting the development of climate-resilient and high-yielding crop varieties.

Challenges in Studying Hormone Crosstalk

Despite significant progress, understanding plant hormone crosstalk remains challenging due to the complexity of hormonal networks. Interactions among hormones are highly dynamic and depend on environmental conditions, making results context-specific. Tissue-specific responses further complicate analysis, as roots, leaves, flowers, and fruits show different hormonal behaviors. Additionally, multiple signaling pathways often overlap, making it difficult to clearly distinguish individual hormone functions. Therefore, advanced molecular tools, omics technologies, and computational modeling are essential to fully decode these intricate regulatory networks.

Future Perspectives

Future research on plant hormone crosstalk will focus on identifying new signaling molecules and decoding complex regulatory networks using systems biology approaches. Advanced gene editing technologies such as CRISPR will help modify hormonal pathways for improved traits. Development of climate-resilient crops, hormone engineering, and precision manipulation of signaling networks will enhance productivity under stress. Integration of artificial intelligence and bioinformatics will further accelerate understanding of hormonal interactions and support sustainable agricultural innovation.

CONCLUSION

Plant hormone crosstalk is a complex regulatory network that controls plant growth, development, and stress adaptation. Phytohormones such as auxins, gibberellins, cytokinins, Abscisic Acid (ABA), ethylene, jasmonic acid, salicylic acid, and brassinosteroids interact synergistically or antagonistically to coordinate physiological processes. These interactions balance growth with survival under varying environmental conditions. Hormone crosstalk regulates seed germination, organ development, flowering, defense responses, and metabolic adjustments. Under abiotic and biotic stresses, it activates protective mechanisms and maintains cellular homeostasis. Understanding these signaling networks is essential for developing stress-tolerant, high-yielding crops and promoting sustainable agriculture. Therefore, plant hormone crosstalk is not only a fundamental aspect of plant biology but also a powerful tool for addressing global agricultural challenges in the era of climate change.

REFERENCES

Aloo, B. N., Dessureault-Rompré, J., Tripathi, V., Nyongesa, B. O., & Were, B. A. (2023). Signaling and crosstalk of rhizobacterial and plant hormones that mediate abiotic stress tolerance in plants. *Frontiers in Microbiology*, *14*, 1171104.

Depuydt, S., & Hardtke, C. S. (2011). Hormone signalling crosstalk in plant growth regulation. *Current biology*, *21*(9), R365-R373.

Guo, F., Lv, M., Zhang, J., & Li, J. (2024). Crosstalk between brassinosteroids and other phytohormones during plant development and stress adaptation. *Plant And Cell Physiology*, *65*(10), 1530-1543.

Munné-Bosch, S., & Müller, M. (2013). Hormonal cross-talk in plant development and stress responses. *Frontiers in plant science*, *4*, 529.

Samanta, S., & Roychoudhury, A. (2025). Molecular crosstalk of jasmonate with major phytohormones and plant growth regulators during diverse stress responses. *Journal of Plant Growth Regulation*, *44*(1), 62-88.