



AGRI MAGAZINE

(International E-Magazine for Agricultural Articles)

Volume: 01, Issue: 05 (December, 2024)

Available online at <http://www.agrimagazine.in>

© Agri Magazine, ISSN: 3048-8656

Role of Plant Hormones in Crop Growth and Development

(*Navyashree R¹, S. Vijaya², Zubey Gohari Ansari³, Nity Sharma⁴ and Saket Dubey⁵)

¹Assistant Professor, Department of Crop Physiology, College of Agricultural Technology, Theni, Tamil Nadu, India

²Associate Professor of Botany & Head of the Department, Tara Government College (A), Sangareddy, Telangana, India

³Assistant Professor, BM College of Agriculture, Khandwa, MP, India

⁴Teaching Assistant, PAU, Ludhiana, Punjab, India

⁵Subject Matter Specialist, KVK, Mahasamund, IGKV, Raipur, Chhattisgarh, India

*Corresponding Author's email: navyashreeshakti@gmail.com

Plant hormones, also known as phytohormones, are pivotal in regulating various physiological processes essential for crop growth and development. These signalling molecules influence every stage of a plant's life cycle, from seed germination to flowering, fruiting, and senescence. Key hormones such as auxins, gibberellins, cytokinin's, abscisic acid, and ethylene operate in a finely tuned balance, mediating responses to environmental stimuli and internal cues. Recent advancements in plant biology have uncovered the molecular mechanisms by which these hormones interact in synergistic and antagonistic ways to shape plant architecture, optimize resource allocation, and enhance stress tolerance. This article explores the roles of individual plant hormones in crop physiology, their cross-talk mechanisms, and their applications in modern agriculture. Special emphasis is placed on leveraging phytohormones through genetic engineering and exogenous treatments to improve crop productivity, resilience to abiotic and biotic stresses, and adaptability to changing climates. Understanding the intricate network of plant hormone functions holds great promise for advancing sustainable agricultural practices and ensuring global food security.

Introduction

Plant hormones, also known as phytohormones, are small organic molecules that play a critical role in the regulation of plant growth, development, and response to environmental stimuli. These chemical messengers operate in low concentrations and influence processes such as cell division, elongation, differentiation, organogenesis, and senescence. They act as mediators for both internal signals and external environmental cues, enabling plants to adapt and thrive in changing conditions (Taiz et al., 2015).

In modern agriculture, the strategic manipulation of plant hormones is gaining prominence for improving crop productivity, enhancing stress resilience, and ensuring sustainability. This article explores the roles, mechanisms, and applications of major plant hormones in crop science, highlighting their significance in shaping the future of agriculture.

Types of Plant Hormones and Their Functions

- **Auxins**

Auxins, primarily indole-3-acetic acid (IAA), are among the first discovered plant hormones. They are crucial in cell elongation, apical dominance, and root initiation (Davies, 2010). Auxins are produced primarily in the shoot apex and are transported basipetally, influencing numerous growth-related processes.

- **Key Roles:**

- Regulating vascular differentiation.

- Promoting adventitious rooting and lateral root formation.
- Mediating phototropism and gravitropism.
- Controlling fruit development.
- **Applications:** Auxin-based formulations are widely used to enhance rooting in plant cuttings and to prevent premature fruit drop in horticultural crops. Synthetic auxins like 2,4-D are also employed as herbicides for broadleaf weed control.

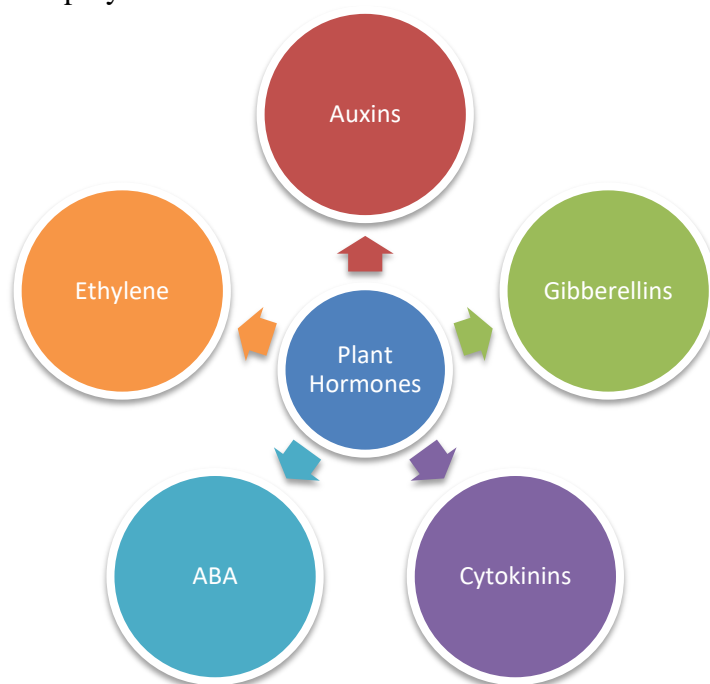


Figure 1: Types of plant hormones

- **Gibberellins (GAs)**

Gibberellins are a class of hormones responsible for promoting cell elongation, seed germination, and flowering. They play a significant role in breaking seed dormancy and initiating starch hydrolysis during germination (Santner et al., 2009).

- **Key Roles:**

- Stimulating stem elongation in dwarf plants.
- Promoting seed germination by mobilizing stored nutrients.
- Enhancing fruit set and growth.

- **Applications:** GA3 is frequently applied in viticulture to increase grape size and is used in cereal crops to improve seedling vigour and productivity.

- **Cytokinins**

Cytokinins are primarily involved in cell division and differentiation. They are synthesized in the roots and transported throughout the plant, where they interact with auxins to balance shoot and root development (Vanstraelen & Benková, 2012).

- **Key Roles:**

- Promoting shoot growth and organogenesis.
- Delaying leaf senescence by maintaining chlorophyll levels.
- Enhancing nutrient mobilization and sink strength.

- **Applications:** Cytokinin's are used in tissue culture for shoot induction and in post-harvest management to maintain the freshness of leafy vegetables.

- **Abscisic Acid (ABA)**

Often referred to as the "stress hormone," ABA is critical in regulating stomatal closure during water stress, seed dormancy, and other abiotic stress responses (Salazar et al., 2015).

- **Key Roles:**

- Mediating stomatal regulation to minimize water loss.
- Inducing seed dormancy to ensure germination under favourable conditions.
- Enhancing plant resilience to drought and salinity.

- **Applications:** Genetic engineering targeting ABA biosynthesis pathways has resulted in drought-tolerant crops like rice and wheat.
- **Ethylene**
Ethylene is a gaseous hormone involved in regulating processes such as fruit ripening, flower senescence, and stress responses. It is unique due to its gaseous nature and role in environmental stress adaptations (Jiang and Asami, 2018).
- **Key Roles:**
 - Accelerating fruit ripening and abscission.
 - Mediating stress responses to wounding and pathogen attacks.
 - Regulating leaf and petal senescence.
- **Applications:** Ethylene-releasing compounds like ethephon are widely used to synchronize fruit ripening in crops such as tomatoes, bananas, and citrus.

Hormonal Cross-Talk and Integration

Plant hormones rarely function independently; their effects are shaped by complex networks of interactions. For example, auxins and cytokinin's work antagonistically to regulate root and shoot development. Similarly, ABA and ethylene often interact to mediate plant responses to abiotic and biotic stresses (Santner et al., 2009).

Technological advancements in molecular biology and omics approaches, such as transcriptomics and metabolomics, have revealed the underlying molecular mechanisms of these interactions. Understanding these networks offers novel opportunities for crop improvement.

Applications in Agriculture

1. **Enhancing Crop Yield:** Hormonal bioregulators are increasingly used to optimize plant architecture, improve pollination, and enhance grain filling. Gibberellins, for example, have been employed to increase the productivity of high-yielding dwarf wheat and rice varieties in the Green Revolution (Davies, 2010).
2. **Stress Tolerance:** Phytohormones play a critical role in improving plant resilience to abiotic stresses such as drought, salinity, and temperature extremes. ABA analogs, ethylene inhibitors, and jasmonic acid derivatives are commonly applied to mitigate stress-induced yield losses (Salazar et al., 2015).
3. **Improving Post-Harvest Quality:** Hormonal treatments extend the shelf life and enhance the quality of fruits and vegetables during storage. Ethylene inhibitors like 1-MCP are widely used to delay fruit ripening and prevent spoilage (Jiang and Asami, 2022).
4. **Biotechnological Innovations:** Recent advancements in genome editing technologies, such as CRISPR-Cas9, are being used to fine-tune hormonal pathways for creating crops with enhanced yield, stress tolerance, and resource-use efficiency.

Future Perspectives

The strategic manipulation of plant hormones offers immense potential to address challenges in global food security and sustainable agriculture. With the integration of cutting-edge technologies, researchers can develop crops tailored for specific climatic and agricultural conditions. Continued exploration of hormone signalling pathways and their cross-talk mechanisms will pave the way for transformative agricultural innovations.

Conclusion

Plant hormones are at the heart of plant growth, development, and adaptation. Their versatile roles and intricate mechanisms make them indispensable tools for addressing the challenges of modern agriculture. By leveraging the potential of phytohormones, scientists and farmers alike can ensure higher productivity, sustainability, and resilience in the face of global environmental and population pressures.

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