

Phytohormones: key regulators of plant growth and cellular processes

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Plant hormones are a group of naturally occurring organic substances that influence physiological processes at low concentrations. Plant hormones have also been referred to as phytohormones. Plant hormones play a crucial role in controlling the way in which plants grow and develop. They stimulate cell division and elongation, promoting overall plant growth. Plant growth regulators have made the way for plant tissue culture techniques. Hormones also regulate cellular processes in targeted cells locally and then move to other locations. They affect the gene expression and transcription levels, cell division and growth.

Keywords: *Phytohormones, cell division, gene expression, transcription level*

Introduction

Hormones play an important role in processes like vernalization, phototropism, seed germination, dormancy, etc. Plants need sunlight, water, oxygen, and minerals for their growth and development as external factors. Apart from these external factors, there are some intrinsic factors that regulate the growth and development of plants. These are called plant hormones or “Phytohormones”. Plant hormones control all the growth and development activities like cell division, enlargement, flowering, seed formation, dormancy and abscission. Plant hormones are vital in regulating various aspects of plant growth, development, and responses to environmental stimuli. These chemical messengers are synthesized in specific plant tissues and then transported to other parts of the plant, where they exert their effects. The intricate network of interactions between different hormones helps coordinate plant physiological processes and ensures optimal growth and adaptation to changing conditions. The hormones used in plant propagation can be naturally occurring and found in many plants, or can be synthetic or synthesized to mimic the structure and response of a naturally occurring hormone. Synthetic hormones are often used instead of naturally occurring versions because they are less expensive to obtain, may cause greater or longer lasting responses, and can be less susceptible to degradation in the plant and during storage. Because exogenous application of hormones plays a role in manipulating or disrupting plant growth, they are used extensively as herbicides (weed killers) and can be targeted to certain types of plants based on how certain species respond to the different structures (Natarajan et al., 2023).

Role of hormones in plant growth, yield enhancement and stress management and quality improvement

Plant growth and development as well as interactions with microorganisms like endophytic fungi, depend heavily on Phytohormones. *Piriformaspora indica*, an endophytic root colonizing fungus, boosts the resilience of colonized plants

to diseases, insects, and abiotic stress while fostering plant growth and performance (Li et al., 2023). Phytohormones are essential for both interplant and systemic signal transmission. *P. indica* stimulates growth, blooming period, differentiation, and local and systemic immune responses through interfering with the production and signaling of plant hormones. In reaction to the bacteria, plants modify the hormone levels in their roots to limit colonization and fungal growth. The knowledge that is currently known about the functions of Phytohormones in advantageous to microbe interactions raises new concerns about how *P. indica* modifies the metabolism of plant hormones to enhance the advantages for both parties in the symbiosis.

Plant hormones may be divided into two divisions based on their physiology. Plant growth-promoting processes such as cell division, cell elongation, seed and fruit development, and pattern of differentiation are all carried out by Phytohormones, which belong to class one (Figure 1). The second class of hormones, on the other hand, is crucial in how plants react to biotic and abiotic stressors. Other hormones that are important to plants include strigolactones, brassinosteroids, salicylic acid, jasmonates, and others (Perumal et al., 2024). Plant hormones make great candidates to improve plant development and/or mediate abiotic and biotic challenges in agriculture due to their biochemical signaling network and their crosstalk capability. Finally, investigating plant hormones and their uses is one of the future directions of plant hormone study.

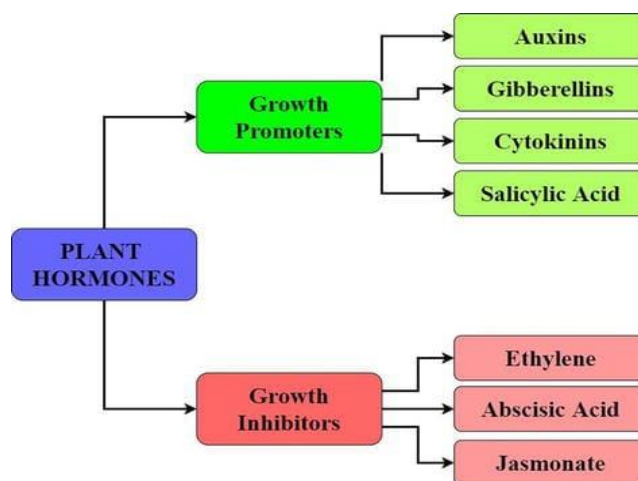


Figure 1. Role of hormones in plants

Phytohormones improving photosynthetic rates in C_3 plants and switching plants from C_3 to C_4 photosynthesis to boost yields, which can solve future concerns of global food security, require knowledge of the hormonal influence on photosynthesis and its management (Senthil et al., 2018). This can also help with a better comprehension of source-sink interactions and whole-plant responses to stress.

Auxin

The word auxin has a Greek origin: auxein means to enlarge or to grow. Auxin is a powerful growth hormone that promotes cell division, stem and root growth and regulates xylem differentiation. The location of the auxin is found in the tips of the shoot. The most well-known auxin is Indole-3-Acetic Acid (IAA). Auxins are produced in the apical meristems (tips) of shoots and roots and are involved in tropisms, which are growth responses to external stimuli (Natarajan et al., 2023). They promote elongation by loosening the cell wall and enhancing cell expansion. Furthermore, auxins have a role in apical dominance, inhibiting the growth of lateral buds. Auxins also play a crucial role in root development, influencing root initiation and growth.

Role of auxin in stress management

Salt stress induces heliotropism, the preferential growth away from areas of high salinity, which is mediated by auxin redistribution to induce root bending. Hydropatterning, the preferential formation of lateral roots near water, is initiated by auxin signaling and depends on the auxin response factor ARF7 (Leftley et al., 2021). Drought stress induces the expression of IAA5 and IAA19, two transcriptional repressors of auxin responses. Additionally, IAA mutants have reduced survival during osmotic stress (Salehin et al., 2019). Heat stress induces auxin biosynthesis via PIF4, and the stabilization of auxin co-receptors. Auxin signaling via ARFs mediates high temperature dependent hypocotyl elongation (Bianchimano et al., 2023).

Gibberellins

Gibberellins (GAs) are plant growth regulators that regulate various developmental processes (Shah et al., 2023), including stem elongation, germination, dormancy, flowering and fruit senescence. GAs strongly promote cell elongation of intact plants. They are concentrated in the regions like the shoot apex, young leaves, embryos, flower buds, fruits and immature seeds. It means that rapidly growing and developing regions of the plant possess higher concentrations of gibberellins. These include a large range of chemicals that are produced naturally within plants and by fungi. They have also been found in algae, mosses, ferns and gymnosperms. All the gibberellins are almost similar in structure. They contain a gibbane ring made up of a cyclohexane ring and a 4-lactone ring. They differ in minute details, viz., the number and position of –OH and sometimes –CH₃ and –COOH groups at different carbon atoms of the gibbane ring.

Stem elongation: The most important effect of gibberellins is the elongation of the stem and leaf sheaths in intact plants. Lack of gibberellins causes shortening of internodes and reduced height. It has been observed in several plants such as pea, bean, cucumber, lettuce, pepper, cabbage, etc. The elongation of the stem results due to cell division and cell elongation induced by gibberellins.

Reversal of dwarfism: One of the most prominent effects of gibberellins is the elongation of genetically dwarf (mutant) varieties of plants like corn and pea.

Bolting and flowering: Certain plants show profuse leaf development but reduced/retarded growth. The rosette habit is due to the deficiency of gibberellins which inhibit cell division at the sub-apical meristem and the stem remains very short at internodes.

Role of gibberellin in stress management

Under drought stress conditions, GA signaling interferes with ABA signaling via DELLA protein interactions with the ABA-regulation. Salt stress reduces the levels of bioactive GAs, likely via ABA signaling. Della-quadruple mutants are hypersensitive to salt stress. Cold stress responses are mediated via DELLA accumulation and interactions with GRF-type TFs. Heat stress induces GA biosynthesis and the degradation of DELLAs in a COP1-dependent manner to regulate hypocotyl elongation (Pierik et al., 2014). Water submergence triggers GA production to induce internode elongation in rice.

Cytokinin

In plants, cytokinins are essential regulators that are involved in almost every aspect of plant growth and development (Wu et al., 2021). During the various stages of leaf development, cytokinins play essential roles by regulating the transcriptional expression of downstream genes (Wu et al., 2021). It promotes cell division and differentiation. They are produced in actively growing tissues, such as root tips and developing fruits. Cytokinins counteract the effects of auxins, helping to maintain a balance between cell division and elongation. Additionally, cytokinins influence organ development, delay senescence (aging) in leaves, and play a role in nutrient mobilization (Wu et al., 2021).

Role of cytokinin in stress management

Drought and salt stress induce the reduction of CK content and signaling, leading to an increased ABA sensitivity. The osmotic stress-dependent hydrotropic response depends on the asymmetric distribution of CK signaling in the root tip, which is enhanced at the lower water potential side.

Abscisic Acid

Abscisic acid (ABA) is mainly known as a stress and dormancy hormone in plants (Wikipedia, 2023b). ABA prevents premature germination and ensures seeds sprout only under favorable conditions (Wikipedia, 2023b). Under drought, ABA accumulates in leaves and signals stomata to close, reducing water loss and improving drought tolerance (Frontiers, 2023; Wikipedia, 2023b). It slows down growth during stress, allowing crops to conserve energy. Helps plants shed older leaves under unfavorable conditions.

Role of Absciscic acid in Stress Management

Abscisic acid (ABA) plays a central role in stress management. Under drought or salinity stress, ABA levels rise and induce stomatal closure to reduce water loss (Shaffique et al., 2023). It activates stress-responsive genes and antioxidant

enzymes that protect cells, and promotes osmotic adjustment by accumulating solutes like proline and sugars (Zulficar et al., 2024). ABA also shifts growth by limiting shoots while encouraging root growth, helping plants explore deeper water sources. Overall, ABA functions as a survival hormone, enabling crops to withstand environmental stresses effectively.

Ethylene

Ethylene is a simple gaseous hormone often called the “ripening hormone” of plants. It controls fruit ripening, leaf abscission, senescence, and stress responses, making it vital for both growth regulation and post-harvest management.

Role of Ethylene in Stress Management

Ethylene is an important stress hormone in crop physiology that helps plants adjust to adverse conditions. During flooding, ethylene promotes the formation of aerenchyma and adventitious roots, improving oxygen supply to submerged tissues (Aslam, 2023). Under pathogen attack or mechanical stress, it works with other hormones like jasmonates and salicylic acid to activate defense mechanisms. Ethylene also accelerates leaf senescence and abscission during stress, allowing plants to conserve energy and resources. In this way, ethylene serves as a key signal that enables crops to adapt and survive under stressful environments.

Brassinosteroids

Brassinosteroids are natural steroidal hormones in plants, often called the “growth-promoting hormones”. They regulate cell elongation, seed germination, vascular development, and stress tolerance, making them essential for both growth and adaptation.

Role of Brassinosteroids in stress management

They help crops survive drought and salinity by promoting osmotic adjustment, maintaining photosynthesis, and reducing water loss. BRs also boost the plant’s antioxidant defense system, which minimizes oxidative damage caused by stress. Under temperature extremes or pathogen attack, they activate stress-responsive genes that protect cellular structures and improve recovery. By integrating growth regulation with defense responses, brassinosteroids act as important hormones that enable crops to withstand adverse environmental conditions while sustaining productivity.

Jasmonates

Jasmonates are lipid-derived plant hormones, often called the “defense hormones” (Koo, 2018). In crop physiology, they regulate plant defense against herbivores and pathogens, while also influencing growth, senescence, tuber formation, and fruit ripening, making them vital in balancing growth with stress responses.

Role of Jasmonates in stress management

Jasmonates (JAs) are central regulators of stress responses, especially against insect herbivory and pathogen attack. When crops are wounded or infected, jasmonates accumulate and activate the production of defensive compounds such as proteinase inhibitors, alkaloids, and secondary metabolites that deter pests and restrict pathogen growth. They also interact with other hormones like ethylene and salicylic acid to strengthen the immune response (Shaffique et al., 2023). Beyond biotic stress, jasmonates help plants tolerate abiotic stresses such as drought, salinity, and wounding by modulating antioxidant activity and stress-responsive genes. Thus, jasmonates act as key defense signals that allow crops to survive and adapt under stressful environments.

Salicylic Acid

Salicylic acid (SA) is a phenolic plant hormone best known as the “immunity hormone”. In crop physiology, it regulates disease resistance, systemic acquired resistance (SAR), flowering, stomatal movement, and thermogenesis, making it vital for plant health and defense (Sangwan et al., 2022).

Role of Salicylic Acid

Salicylic acid (SA) plays a central role in managing biotic and abiotic stresses. It is the key hormone that triggers systemic acquired resistance (SAR), a long-lasting immune response that protects plants against a wide range of pathogens. SA activates the production of pathogenesis-related (PR) proteins and enhances antioxidant enzyme activity, which reduce

cellular damage during stress (Sangwan et al., 2022). It also helps crops tolerate abiotic stresses such as salinity, drought, and temperature extremes by regulating osmotic balance and protecting membranes (Sangwan et al., 2022). Thus, salicylic acid acts as a vital defense signal, enabling crops to survive and adapt under challenging conditions.

Strigolactones

Strigolactones are carotenoid-derived plant hormones known as the “branching inhibitors” (Cheng et al., 2013). In crop physiology, they regulate shoot branching, root architecture, and symbiotic interactions with mycorrhizal fungi, while also influencing seed germination of parasitic weeds like *Striga*.

Role of Strigolactones in stress management

Strigolactones play an important role in managing stress by regulating plant architecture and root interactions. Under nutrient deficiency, especially low phosphorus or nitrogen, Strigolactone levels increase and promote the growth (Brewer et al., 2013) of fewer but deeper roots, helping crops explore soil more efficiently. They also encourage symbiotic associations with arbuscular mycorrhizal fungi, which improve nutrient and water uptake under stress conditions. By suppressing excessive shoot branching, Strigolactones ensure better allocation of limited resources. Thus, Strigolactones act as adaptive (Saeed et al., 2017) signals that help crops survive nutrient stress and maintain productivity in poor soils.

Conclusion

Plant growth regulators play a significant role in modern agriculture by modulating the physiological processes of plants to achieve desired growth outcomes. PGRs are designed to influence specific aspects of growth, development and productivity, making them an essential tool in precision farming and sustainable agriculture.

Author contributions

Conceptualization – Ashok Subiramaniyan, Chandrasekaran Perumal, Ashokkumar Natarajan, Selvakumar Gurunathan. Writing (original draft) -Sonali Vergin Philips, Subaleka Subramaniyan, Abinaya Dharmalingam, Maha Gunasekaran. Writing (review & editing) – Sonali Vergin Philips, Ashok Subiramaniyan, Chandrasekaran Perumal, Ashokkumar Natarajan, Selvakumar Gurunathan.

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