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Plant Growth Regulators in Horticulture: Mechanisms, Applications, and Sustainable Prospects

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Abstract

Plant Growth Regulators (PGRs) are essential tools in modern horticulture, functioning as chemical messengers that influence plant growth and development even at low concentrations. The major classes auxins, gibberellins, cytokinins, abscisic acid, and ethylene—regulate key physiological processes such as cell division, elongation, flowering, fruit set, ripening, and stress response. Their application enhances productivity, improves crop quality, and aids in stress tolerance. PGRs can be applied through spraying, dipping, root feeding, or seed treatment, depending on crop needs and developmental stage. Each PGR operates via specific molecular mechanisms, often interacting synergistically or antagonistically with others to fine-tune plant responses. production.

Keywords: Plant growth regulator, auxins, Horticultural Crops, Stress Tolerance

Introduction

Plant growth regulators (PGRs), also known as plant hormones or bioregulators, are chemical messengers that influence various physiological and developmental processes in plants, even at very low concentrations (Small et al., 2018). They can either promote or inhibit key functions such as cell division, elongation, flowering, fruit set, and ripening. Fruit and vegetable crops are critical to global nutrition and economic stability. However, their production faces numerous challenges, including changing climate conditions, limited arable land, and the need for increased productivity. In this context, the use of PGRs has emerged as a promising strategy to

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enhance yield, improve quality, and increase stress tolerance in horticultural crops. PGRs may be either naturally occurring or synthetically formulated and can be applied at various stages of crop growth. Their effects extend from germination and seedling development to flowering, fruit maturation, and postharvest behavior. By influencing plant architecture, photosynthesis, nutrient uptake, and stress response, PGRs play a vital role in sustainable horticultural production.

Types of Plant Growth Regulators:

The main types of bio-regulators, or plant growth regulators, include auxins, gibberellins, cytokinins, ethylene, and abscisic acid.

Auxins

Auxins are a class of plant growth regulators that significantly influence various physiological processes related to growth and development. The term "auxin" is derived from the Greek word meaning "to grow." Their discovery is attributed to Charles and Francis Darwin, who observed their role in phototropism. The major naturally occurring auxin in plants is Indole-3-acetic acid (IAA), though others like Indole-3-butyric acid (IBA), 4-Chloroindole-3-acetic acid (CIAA), and Phenylacetic acid (PAA) also exhibit auxin activity (Conrad, 1965). Auxins are mainly synthesized in the apical meristems and young tissues, and they exhibit basipetal movement, i.e., from shoot apex towards the base. Synthetic auxins include compounds like Naphthaleneacetic acid (NAA), 2,4-Dichlorophenoxyacetic acid (2,4-D), and Indole derivatives, which mimic the action of natural auxins.

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Table 1: Major Applications of Auxins in Horticultural Crops

Application Area	Auxin Function	Common Auxins Used
Cell division & elongation	Promote stem and vascular growth	IAA, GA (in combination)
Tissue culture	Callus formation, root and shoot induction	IBA, NAA
Apical dominance	Inhibit lateral bud growth	IAA
Dwarfing/compact growth	Shorten internodes	NAA
Rooting in cuttings	Induce adventitious roots	IBA, IAA, PAA, NAA
Abscission control	Delay leaf/fruit/flower drop	2,4-D, NAA, IAA
Parthenocarpic fruit formation	Seedless fruit induction	IAA, NAA
Flower & fruit ripening	Uniform flowering and ripening	NAA
Weed control	Broadleaf herbicide action	2,4-D
Fruit thinning	Reduce excess fruit load	NAA

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Gibberellins (GAs)

Gibberellins are a group of plant growth regulators that play a vital role in promoting growth and regulating numerous developmental processes. First identified in 1926 by Japanese scientist Eiichi Kurosawa during research on the "foolish seedling" disease in rice, gibberellins were later isolated from the fungus Gibberella fujikuroi. Among the different gibberellins identified, Gibberellic Acid (GA_3) is one of the most widely studied and utilized in horticulture. Gibberellins are primarily active in young tissues such as developing seeds, shoots, and roots. In many species, the concentration of GA_3 is significantly higher in roots than in shoots. They are known for their ability to break dormancy, stimulate stem elongation, promote flowering, and enhance fruit development, often in synergy with other hormones like auxins (Dayan et al, 2012).

Table2: Major Applications of Gibberellins in Horticultural Crops

Application Area	Gibberellin Function	Notable Crops
Shoot elongation	Promote stem and internode elongation	Lettuce, dwarf beans
Senescence delay	Prolong leaf and fruit life	Leafy vegetables, citrus
Cambial growth	Promote secondary growth and tissue differentiation	Woody fruit trees
Reversing dwarfism	Restore normal growth in dwarf mutants	Peas

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Application Area	Gibberellin Function	Notable Crops
Flower induction	Replace photoperiod/vernalization requirements	Spinach, radish, lettuce
Parthenocarpy	Induce seedless fruits; improve berry size	Grapes, apples
Dormancy breaking	Stimulate seed germination and bud sprouting	Potato, pear, cherry

Cytokinins (CKs)

Cytokinins are a class of plant growth regulators that primarily promote cell division (cytokinesis). First discovered in the 1950s by Skoog and Miller, cytokinins were initially isolated as kinetin, a degradation product of DNA. These hormones are adenine derivatives and are naturally synthesized in root apices, developing seeds, young leaves, fruits and other actively growing tissues. Cytokinins function in coordination with auxins & other hormones to regulate various physiological and developmental processes. They are known for their ability to promote shoot formation, delay senescence, overcome apical dominance, and stimulate seed germination and fruit development. Both naturally occurring (e.g., zeatin) and synthetic forms (e.g., benzyladenine, thidiazuron) are widely used in plant propagation, crop improvement, and stress mitigation strategies (Schaller et al., 2014).

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Table 3: Major Applications of Cytokinins in Horticultural Crops

Function	Mechanism or Effect	Applications/Crops
Cell division and elongation	Promotes mitosis and organ development	General plant growth
Tissue culture regeneration	Induces shoot proliferation and morphogenesis	Banana, tissue culture
Flower and fruit development	Stimulates reproductive growth and fruit setting	Tomato, cucumber, capsicum
Seed dormancy breaking	Enhances germination under suboptimal light conditions	Celery, lettuce, pepper
Senescence delay	Maintains chlorophyll, delays leaf aging	Leafy greens
Nitrogen metabolism enhancement	Boosts uptake, assimilation and utilization	Vegetables under nitrogen-deficient soils

D. Ethylene

Ethylene (C_2H_4) is a simple hydrocarbon gas that functions as a plant hormone. Although its physiological effects were observed much earlier, it was officially recognized as a plant hormone by Glaston and Davis in 1970. Ethylene is unique among plant growth regulators due to its gaseous nature and its multifaceted role in regulating plant growth, development, and stress responses. Ethylene

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is synthesized from the amino acid methionine, with its production being enhanced in actively growing tissues, wounded tissues, and under stress conditions (e.g., mechanical stress, flooding, or drought). Due to its prominent role in fruit ripening, it is often termed the "ripening hormone." In agricultural practice, both ethylene-releasing compounds (e.g., ethephon, ethrel, CEPA) (Bogatek et al., 2012) and ethylene inhibitors (e.g., 1-MCP) are employed to manipulate plant processes such as ripening, flowering, abscission, and senescence for postharvest and agronomic benefits.

Table 4: Major Applications of Ethylene in Horticultural Crops

Function	Mechanism or Effect	Applications/Crops
Dormancy breaking	Stimulates germination and bud break	Potato, onion, lettuce
Fruit ripening	Enhances physiological maturity (color, sugar, aroma)	Banana, mango, apple, tomato
Leaf/flower abscission	Promotes shedding of old/ damaged tissues	Citrus
Flower induction	Induces flowering through ethylene-releasing agents	Pineapple
Senescence promotion	Accelerates aging process; used for synchronized harvesting	Tomato

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E. Abscisic Acid (ABA)

Abscisic acid (ABA) is a sesquiterpenoid plant hormone originally identified for its role in promoting abscission and dormancy, hence the name. Also referred to as abscisin II and dormin, ABA plays a key role in regulating plant development and responses to abiotic stress. Unlike growth-promoting hormones (e.g., auxins and gibberellins), ABA is primarily a growth-inhibiting hormone, especially important under unfavorable environmental conditions such as drought, cold, or salinity. ABA levels fluctuate throughout a plant's lifecycle and increase significantly during stress periods and fruit ripening. It is synthesized in plastids of plant cells, particularly in mature leaves and roots, and is translocated through the xylem and phloem.

Table 5: Major Functions and Horticultural Applications of ABA

Function	Mechanism or Effect	Applications/Crops
Dormancy induction	Triggers and maintains seed and bud dormancy	Temperate fruit trees, onion, potato
Germination suppression	Prevents premature seed germination	Vegetable seed storage
Growth inhibition	Limits division and expansion under stress	Growth control in nursery crops

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Function	Mechanism or Effect	Applications/Crops
Stress adaptation	Closes stomata, enhances water-use efficiency	Drought-prone areas (wheat, tomato)
Fruit ripening regulation	ABA rises during ripening, especially in non-climacteric fruits	Grapes, citrus, strawberries

3. Methods of Application of Plant Growth Regulators

Plant growth regulators (PGRs) can be applied using various techniques depending on the crop, growth stage, and desired physiological response. Common methods of application include:

Method	Description & Application
1. Spraying Method	Closes stomata, enhances water-use efficiency
2. Injection into Tissues	ABA rises during ripening, especially in non-climacteric fruits
Tissues	Direct injection into plant tissues is used in specific cases like disease treatment or to induce targeted responses.

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3. Root Feeding	Solutions are applied around the root zone, enabling uptake via roots for systemic distribution throughout the plant.
4. Powder Application	Dry PGRs in powder form are sprinkled onto plant surfaces or soil for ease of application and storage.
5. Dipping of Cuttings	Stem cuttings are dipped into PGR solutions to stimulate root formation and enhance vegetative propagation.
6. Soaking in Aqueous Solution	Plant parts (e.g., seeds, bulbs) are soaked in dilute PGR solutions for uniform absorption. This is common in seed treatments.

These methods are selected based on factors like the chemical nature of the PGR, target organ, ease of uptake, and type of response desired (e.g., rooting, flowering, or dormancy breaking).

Mechanisms of Action of Bioregulators

The mode of action of plant bioregulators is complex and involves a cascade of molecular and physiological events (Srivastava et al., 2016). Bioregulators bind to specific receptor on plant cell membranes or within the cytoplasm, triggering signal transduction pathways that influence:

- **Gene expression**
- **Protein synthesis**
- **Enzymatic activity**
- **Ion transport**

These changes result in a wide array of physiological responses tailored to the plant's developmental stage or environmental condition.

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Bioregulator	Primary Action Mechanism	Physiological Effects
Auxins	Bind to TIR1/AFB receptors, induce transcription of auxin-responsive genes	Cell elongation, apical dominance, root initiation
Gibberellins (GA)	Promote DELLA protein degradation, leading to activation of growth-related genes	Stem elongation, seed germination, flowering, fruit set
Cytokinins	Interact with cytokinin receptors (histidine kinases) and activate a phosphorelay signaling system	Cell division, shoot initiation, delay of senescence, nutrient mobilization
Abscisic Acid (ABA)	Binds to PYR/PYL/RCAR receptors, inhibits PP2C phosphatases, activating stress-responsive pathways	Stomatal closure, seed dormancy, stress tolerance
Ethylene	Activates transcription factors via ethylene receptors (ETR), triggering genes related to ripening and abscission	Fruit ripening, senescence, leaf/flower abscission

Bioregulator Interactions

PGRs rarely act in isolation. Their effects are often synergistic or antagonistic, depending on the developmental process:

- **Auxin + Cytokinin :** Coordinate root vs. shoot development in tissue cultures.
- **Gibberellin vs. ABA :** GA promotes germination, while ABA enforces dormancy.
- **Ethylene + ABA:** Collaborate in senescence and stress responses.

These interactions regulate key metabolic pathways and balance plant growth with environmental adaptation.

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Conclusion

Plant Growth Regulators (PGRs) are indispensable tools in modern horticulture, significantly contributing to the growth, development, and productivity of fruit and vegetable crops. These regulators namely auxins, gibberellins, cytokinins, abscisic acid, and ethylene—play diverse and critical roles in regulating physiological processes such as cell division, elongation, dormancy, flowering, fruit ripening, and senescence. Each PGR functions uniquely: auxins promote root initiation and fruit development; gibberellins enhance stem elongation and seed germination; cytokinins stimulate cell division and delay leaf senescence; abscisic acid manages stress responses and dormancy; and ethylene facilitates fruit ripening and leaf abscission. Application methods such as foliar spray root drenching, seed treatments, and dipping techniques allow growers to tailor PGR use according to crop needs and developmental stages. With increasing emphasis on sustainable agriculture, the use of PGRs has gained popularity due to their ability to improve yield, enhance produce quality, and reduce dependency on synthetic fertilizers and pesticides. However, careful and informed application is crucial, as misuse or overuse may result in physiological imbalances, reduced yields, or environmental harm. When used responsibly, PGRs offer immense potential in optimizing horticultural production and helping crops withstand biotic and abiotic stresses under varying climatic and soil conditions.

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