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Plant Growth Retardants

Mechanisms, Classifications and Applications

Arumugam Tamilselvan, Ramesh Rajendran, Arul selvam, Poomani S, Durga Lakshmi Y, Kalieswari*

ICAR- Indian Agricultural Research Institute -New Delhi- 110012.

*Corresponding author- 1999kalies@gmail.com

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Introduction

Plant growth retardants (PGRs) are vital chemical agents used in modern agriculture to regulate plant growth, enhancing crop management and improving productivity. These compounds function by selectively inhibiting vegetative growth, especially stem elongation, while leaving flowering, fruiting, and root development largely unaffected. PGRs primarily act by disrupting key hormonal pathways, including those of gibberellins, auxins, cytokinins, ABA, and ethylene, which are essential for controlling plant growth and development. This review provides an overview of the classifications, mechanisms of action, and applications of various plant growth retardants in agronomy.

Major Classifications of Growth Retardants

1. Triazole Group: Triazole compounds are some of the most effective and widely used plant growth retardants. They are mainly recognized for inhibiting the biosynthesis of gibberellic acid (GA), a plant hormone that significantly influences stem elongation and overall plant growth.

Key Triazole Compounds

Paclobutrazol: Extensively used in fruit trees and field crops.

Uniconazole: Commonly used for container crops and in greenhouse settings.

Propiconazole: A dual-action fungicide and retardant.

Tebuconazole: Applied to cereal crops for growth regulation.

Mechanism of Action: Triazoles work by inhibiting the cytochrome P450 enzymes responsible for the conversion of ent-kaurene to ent-kaurenoic acid, a precursor of gibberellic acid. By blocking this key step in the GA biosynthesis pathway, triazoles reduce the synthesis of active gibberellins, leading to reduced shoot elongation.

Systemic Activity

These compounds are systemic and are translocated through both the xylem and phloem, ensuring that their effects are widespread across the plant. Their action typically lasts between 8 and 16 weeks, depending on the application rate.

Compound	Concentration Range	Primary Applications	Key Effects
Paclobutrazol	10-200 ppm	Fruit trees, field crops	Reduces shoot growth, enhances flowering
Uniconazole	5-50 ppm	Container crops, greenhouses	Compact growth, reduced height
Propiconazole	50-150 ppm	Dual action (fungicide/retardant)	Reduced plant height, disease control
Tebuconazole	25-100 ppm	Cereal crops	Reduced height, better grain yield

2. Quaternary Ammonium Compound: Quaternary ammonium compounds, such as Chlormequat chloride (CCC) and Mepiquat chloride, also inhibit gibberellin biosynthesis, but at an earlier stage compared to triazoles.

Mechanism of Action: These compounds block the conversion of copalyl diphosphate to active gibberellins, resulting in controlled plant growth and increased stem strength. They are particularly useful in preventing lodging in cereal crops.

Primary Applications

- Chlormequat chloride is widely used in cereal crops such as wheat and barley to reduce lodging.
- Mepiquat chloride is used in cotton to control excessive vegetative growth, promoting better boll development.

Compound	Concentration Range	Primary Use	Key Effects
Chlormequat chloride	1000-3000 ppm	Cereal crops, wheat	Reduces lodging, strengthens stems
Mepiquat chloride	25-75 g/ha	Cotton	Controlled plant height, enhanced boll development

3. Pyrimidine Derivatives: Pyrimidine derivatives, such as Flurprimidol and Ancymidol, offer selective inhibition of gibberellin biosynthesis with minimal effect on flowering, making them suitable for sensitive crops.

Mechanism of Action: These compounds specifically inhibit gibberellin biosynthesis, reducing stem elongation and promoting a more compact plant structure.

Compound	Concentration Range	Primary Use	Key Effects
Flurprimidol	5-25 ppm	Ornamental crops, nurseries	Precise growth control, minimal impact on flowering
Ancymidol	5-50 ppm	Nursery crops, ornamental	Root-applied growth control

4. Acylcyclohexanedione Compounds: Trinexapac-ethyl, a member of the acylcyclohexanedione group, is primarily used for turfgrass management.

Mechanism of Action: Trinexapac-ethyl inhibits gibberellin biosynthesis at a later step compared to triazoles, thereby reducing vertical growth while enhancing turf density and stress tolerance.

Compound	Concentration Range	Primary Use	Key Effects
Trinexapac-ethyl	0.1-0.4 kg/ha	Turfgrass management	Reduced mowing, enhanced stress tolerance

Ethylene Inhibitors: Ethylene is a plant hormone that regulates processes such as fruit ripening, senescence, and abscission. Ethylene inhibitors are used to delay senescence, preserve fruit quality, and extend shelf life.

Key Ethylene Inhibitors:

- **Aminoethoxyvinylglycine (AVG):** Inhibits the synthesis of ethylene by blocking the enzyme ACC synthase.
- **Silver Thiosulfate (STS):** Inhibits ethylene's action by competing for receptors.
- **1-Methylcyclopropene (1-MCP):** Irreversibly binds to ethylene receptors, preventing ethylene from initiating its response.

Compound	Mechanism of Action	Applications
1-MCP	Binds ethylene receptors irreversibly	Extends storage life, prevents fruit drop
Silver Thiosulfate	Inhibits ethylene receptors	Used for cut flower preservation, fruit drop prevention in apples
AVG	Inhibits ethylene biosynthesis	Delays ripening and senescence

Auxin Transport Inhibitors: Auxins are key hormones that regulate plant growth, particularly in terms of elongation and branching. Auxin transport inhibitors disrupt the polar transport of auxins, leading to modified plant architectures.

Key Compounds:

- **TIBA:** Inhibits auxin efflux carriers, increasing lateral branching.
- **NPA:** Blocks auxin transport proteins, enhancing shoot proliferation.
- **Quercetin:** A flavonoid that inhibits polar auxin transport, promoting branching.

Compound	Concentration Range	Primary Use	Key Effects
TIBA	10-100 ppm	Enhances lateral branching	Increases shoot branching, alters gravitropic responses
NPA	10-100 ppm	Research purposes	Inhibits auxin transport, modifies root-shoot ratio
Quercetin	Variable	Research and specialized uses	Inhibits polar auxin transport

Gibberellic Acid Inhibitors: The synthesis of gibberellins (GAs) involves several enzymatic steps starting from mevalonic acid. Inhibitors of GA biosynthesis, such as triazoles and quaternary ammonium compounds, block various key enzymes in this pathway, thus preventing the production of active GAs.

Mechanism of Action:

- Triazoles target ent-Kaurene oxidase, inhibiting the conversion of ent-kaurene to ent-kaurenoic acid.
- Quaternary ammonium compounds inhibit the action of Copalyl diphosphate synthase.
- Other inhibitors, such as those targeting GA 3β-hydroxylase, further regulate GA activity by affecting its conversion into active forms.

Enzyme Target	Inhibitor Class	Compounds	Selectivity
ent-Kaurene oxidase	Triazoles	Paclobutrazol, Uniconazole	High
Copalyl diphosphate synthase	Quaternary Ammonium	CCC, Mepiquat chloride	Moderate
GA 3β-hydroxylase	Various	Mixed retardants	Variable

Conclusion

Plant growth retardants (PGRs) are crucial tools in modern agricultural practices, offering precise control over plant morphology and enhancing crop productivity. The broad range of PGR classes—triazoles, quaternary ammonium compounds, pyrimidines, acylcyclohexanediones, and various hormone inhibitors—provide specific solutions for different growth regulation needs across a variety of crops. By understanding the underlying mechanisms of action and tailoring application methods to specific crops, PGRs contribute significantly to improved yield, quality, and sustainable farming practices.