A Recent Advances in Use of Plant Growth Regulators in Fruit Crops: A Review

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Abstract
Fruit crops are highly responsive to plant growth regulators (PGRs), and their judicious use has become an integral component of modern horticulture. Classical PGRs (auxins, gibberellins, cytokinins, ethylene, abscisic acid) are now complemented by "new-generation" regulators such as brassinosteroids, polyamines, jasmonates, salicylic acid, melatonin, CPPU and various biostimulant-type molecules. Recent advances include precise, crop-specific protocols for improving fruit set, regulating flowering and fruit drop, manipulating crop load, enhancing colour and sweetness, improving size and firmness, synchronizing ripening, and extending postharvest life in mango, grapes, citrus, apple, banana, sapota, berries and other fruit crops. Meta-analyses and systematic reviews confirm significant positive effects of PGRs on fruit set, yield, berry/fruit size and quality when properly dosed and timed. At the same time, there is a strong shift towards new, eco-friendly molecules and integrated use with biostimulants and good agronomic practices. This review synthesizes recent advances (roughly 2017–2025) in the use of PGRs in fruit crops, with emphasis on mechanisms, crop-wise applications, new-generation regulators, and future prospects for sustainable fruit production.

Keywords: Plant growth regulators, fruit crops, auxin, gibberellin, cytokinin, brassinosteroids, CPPU, polyamines, fruit set, quality, postharvest.

1. Introduction

Plant growth regulators (PGRs) are organic compounds, other than nutrients, which in very low concentrations regulate physiological processes such as cell division, elongation, flowering, fruit set, ripening and senescence. Their role in fruit crops is particularly important because small physiological adjustments can dramatically change yield, fruit quality and marketability. Classical work showed the potential of auxins, gibberellins and cytokinins to improve fruit set, reduce drop and modify growth. Recent research has expanded this toolbox with new-generation PGRs and more precise application strategies tailored to each fruit species.

Growing consumer demand for high quality fruits, combined with climate change-driven stresses, labour scarcity and the need to reduce chemical load, creates a strong case for intelligent use of PGRs in fruit orchards. Recent reviews and meta-analyses support their role in optimizing crop load, enhancing colour and flavour, improving firmness and shelf life, and mitigating certain abiotic stresses in fruit crops.

2. Major Classes of Plant Growth Regulators Used in Fruit Crops

2.1 Classical PGRs

Auxins (IAA, NAA, 2,4-D, 2,4,5-T, IBA)
Promote cell elongation, apical dominance and fruit set; prevent premature fruit drop.
Gibberellins (GA_3, GA_{4+7})
Stimulate cell elongation, seed germination, fruit set, berry enlargement and delay of senescence.
Cytokinins (BA/BAP, kinetin, CPPU)
Promote cell division, delay leaf senescence, increase fruit size and influence fruit set.
Ethylene & ethylene releasers (ethephon/ethrel)
Involved in fruit ripening, abscission, degreening and flowering in some species.
Abscisic acid (ABA)
Regulates stress responses, colour development, sugar accumulation and stomatal behaviour.

2.2 New-Generation and Non-Traditional PGRs

Recent years have seen increasing interest in additional regulatory molecules:
Brassinosteroids (BRs) – e.g., 24-epibrassinolide; enhance fruit set, size, photosynthesis and stress tolerance in many fruits, especially under abiotic stress.
Polyamines (PAs) – putrescine, spermidine, spermine; associated with fruit set, reduced drop and improved firmness and storability.
Jasmonates (JA, MeJA) – influence defence responses, colour and aroma; used in certain berries and grapes.
Salicylic acid (SA) – improves stress tolerance, antioxidant status and sometimes fruit quality.
Melatonin – emerging molecule linked to improved stress tolerance, antioxidant capacity and postharvest quality.
Biostimulant-type regulators – seaweed extracts, protein hydrolysates and microbial products with hormone-like action, often combined with classical PGRs.

Class / group Typical molecules Major roles in fruit crops
Auxins IAA, NAA, 2,4-D, IBA Fruit set, prevention of fruit drop, parthenocarpy, rooting of cuttingsGibberellins GA_3, GA_{4+7} Fruit set, berry/fruit enlargement, delayed maturity, improved cluster loosenessCytokinins BA/BAP, kinetin, CPPU Cell division, fruit size, delayed leaf senescence, improved chlorophyll and vigourEthylene / Ethrel Ethephon Induction of ripening, degreening, synchronized maturity, flower induction in some cropsAbscisic acid (ABA) S-ABA, synthetic ABA analogues Colour development, sugar accumulation, stress responses, partial control of ripening Brassinosteroids (BRs) 24-epibrassinolide, homobrassinolide Stress mitigation, improved fruit set and quality, better photosynthesis Polyamines (PAs) Putrescine, spermidine, spermine Fruit retention, firmness, delayed senescence, improved storability Jasmonates (JA/MeJA) Jasmonic acid, methyl jasmonate Aroma and colour, defence responses, possible role in postharvest quality Salicylic acid (SA) SA, acetyl salicylic acid Disease resistance, antioxidant system, improved shelf life Melatonin & others Melatonin, signalling peptides Stress tolerance, antioxidant protection, emerging roles in fruit development---

3. Recent advances: crop-wise applications of PGRs

3.1 Mango

Recent work has refined the timing and dose of GA_3, NAA, CPPU, BRs and PAs in mango for improved fruit retention, size and quality. Sprays of GA_3 (20–40 ppm) at pea stage significantly reduce fruit drop and enhance fruit size and TSS. NAA (20–40 ppm) at early fruit set reduces June drop.A 2025 study on mango showed that PGR mixtures applied during early fruit development increased perceived sweetness and consumer acceptance, mainly through higher TSS and improved sugar/acid balance. New-generation PGRs like BRs and polyamines also show promise in improving stress tolerance and fruit quality under high temperature or water-deficit conditions.

3.2 Grapes and berries

In grapes, GA_3 sprays around bloom and fruit set are now standard for berry elongation, looseness and improved cluster architecture; cytokinin-type PGRs like CPPU further increase berry size. ABA applications at veraison improve colour and anthocyanin content in red/black cultivars, while also affecting sugar accumulation.A 2025 meta-analysis focusing largely on blueberries and tree fruits reported that GA_3 and cytokinins consistently increased fruit set and yield, with cytokinins also enhancing berry size. This provides quantitative confirmation of the strong response of small fruits to PGRs.

3.3 Citrus

Citrus is highly responsive to auxins and gibberellins. NAA and 2,4-D reduce pre-harvest fruit drop and sustain fruit size; GA_3 delays senescence and improves peel quality in mandarins and oranges. Cytokinins (BA, CPPU) enhance fruit size and peel thickness but must be carefully dosed to avoid excessive granulation or delayed colour development.
BRs and SA have been investigated as eco-friendly tools to mitigate salinity and drought stress in citrus orchards, improving leaf water status and fruit quality.

3.4 Apple and temperate fruits

In apples and pears, PGRs are central to chemical thinning, size management and colour development. Combinations of NAA, 6-BA and ethephon are used for blossom and post-bloom thinning to regulate crop load and improve fruit size and quality.Ethylene-releasing compounds are widely used for uniform ripening and degreening, while synthetic cytokinins (BA) and GA_{4+7} improve fruit size and reduce russeting. ABA and MeJA applications have been explored for enhancing red colour in apple cultivars, particularly under sub-optimal temperature conditions.

3.5 Banana

Banana bunches are often treated with GA_3 or cytokinin-type PGRs to improve finger length, girth and bunch weight. Pre-harvest applications of BRs and SA have been reported to improve stress tolerance and maintain better postharvest quality. Polyamines and melatonin are emerging tools for reducing chilling injury and enhancing antioxidant properties during storage.

3.6 Sapota, guava and other tropical fruits

Recent work on sapota highlights the use of auxins and gibberellins for improved fruit set, size and reduced drop, with a 2025 review specifically summarizing advances in PGR application for this crop. In guava, NAA and GA_3 sprays are used to regulate cropping season (bahar treatment), enhance fruit size and improve TSS and vitamin C.For papaya, pineapple, litchi and pomegranate, PGRs are used to induce flowering, improve fruit set and reduce cracking or fruit drop. While protocols differ among crops, auxins, gibberellins, cytokinins and ethrel remain widely used, with BRs, SA and polyamines increasingly tested to improve quality and shelf life.

4. PGRs and postharvest quality in fruit crops

Recent advances emphasize that pre-harvest PGR applications can strongly influence postharvest behaviour. A 2023 review showed that field-applied PGRs modulate ripening rate, firmness, colour, decay and storage life of fruits, with effects persisting long after harvest.

Key findings include:

ABA, BRs and SA often enhance colour development, antioxidant capacity and resistance to postharvest disorders in grapes, berries, citrus and apples.

Polyamines and melatonin improve firmness and reduce chilling injury in several fruits, thereby extending shelf life.

Ethrel and ethylene modulators (like 1-MCP in postharvest) allow precise manipulation of ripening, especially in climacteric fruits such as banana, mango and apple.

Careful selection of PGR type, dose and timing is critical, because over-use or misuse can lead to undesirable outcomes such as uneven ripening, poor colour or physiological disorders.

5. Integration with biostimulants and sustainable practices

There is a strong trend towards integrating PGR use with:Biostimulants (seaweed extracts, humic substances, microbial inoculants) that contain hormone-like compounds and enhance nutrient uptake and stress tolerance.Balanced nutrition and precise irrigation to ensure that PGR responses are not limited by other constraints.Canopy management and pruning to support the hormonal balance induced by PGRs.Recent reviews stress that new-generation PGRs (BRs, PAs, melatonin etc.) and certain biostimulants can reduce reliance on higher-risk chemicals, making fruit production more eco-friendly and aligned with residue-free market demands.

6. Limitations, risks and research gaps

Despite their success, several limitations remain:1. Crop- and cultivar-specific responses – Same PGR and dose can produce different effects depending on variety, rootstock and local environment.

2. Narrow window of application – Many PGRs are effective only when applied at specific phenological stages; timing errors reduce efficacy.

3. Regulatory and residue concerns – Registration status varies by country; strict adherence to label recommendations is mandatory to avoid residue issues.

4. Limited information on long-term soil and ecosystem effects for some synthetic PGRs and repeated use.

5. Need for more work under climate-change scenarios – High temperature, erratic rainfall and elevated CO_2 may modify plant hormonal responses.

Future research priorities include: high-throughput screening of new molecules, precise delivery systems (e.g., nano-carriers, slow-release formulations), integration with digital decision-support tools, and more multi-location trials under farmer conditions.

8. Conclusion

The last decade has seen substantial progress in understanding and exploiting plant growth regulators in fruit crops. Classical PGRs such as auxins, gibberellins, cytokinins, ethylene and ABA remain the backbone of practical programmes for fruit set regulation, thinning, fruit enlargement, colour improvement and ripening control in mango, grapes, citrus, apple and many other fruits. Recent reviews and meta-analyses provide strong quantitative evidence of their positive impact on fruit set, berry/fruit size, yield and quality when used judiciously.At the same time, new-generation molecules like brassinosteroids, polyamines, jasmonates, salicylic acid and melatonin, along with biostimulant-type products, are expanding the scope of PGR technology towards stress mitigation and residue-safe quality enhancement. Integrating these tools with balanced nutrition, precise irrigation, canopy management and digital decision-support systems will be central to sustainable, climate-resilient fruit production.Proper training of growers, strict adherence to recommended doses and timings, and continuous research into crop-specific protocols will ensure that PGRs continue to be a powerful, yet safe and sustainable, component of modern fruit crop management.---

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