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Plant Growth Regulators in Floriculture Crops: Applications, Mechanisms, and Recent Developments

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ABSTRACT

Plant growth regulators (PGRs) are low-molecular-weight organic compounds that, in trace amounts, orchestrate growth, flowering, senescence and postharvest performance of floriculture crops. This review synthesises current understanding of the five principal PGR classes — auxins, gibberellins, cytokinins, ethylene and abscisic acid, together with synthetic retardants such as paclobutrazol and daminozide — and their mechanisms of action in commercial ornamentals. Applications across the production cycle are examined, including rooting of cuttings, height control of potted plants, flower induction, improvement of stalk and flower quality, and extension of vase life. Recent molecular advances, including ethylene-receptor inhibition by 1-MCP, hormonal crosstalk in petal expansion and abscission, and biostimulant-based formulations, are highlighted. The review concludes that judicious, species-specific PGR use is indispensable for sustainable and profitable floriculture in changing climates.

Keywords: *Plant growth regulators, floriculture, gibberellins, ethylene inhibitors, vase life.*

INTRODUCTION

Floriculture has evolved from a small-scale horticultural pursuit into a multi-billion-dollar global industry that supplies cut flowers, potted ornamentals, bedding plants and landscape stock to consumers worldwide. Production targets — uniform height, dense branching, synchronous bloom, vivid colour and prolonged vase life — cannot be achieved by genetics and cultural practice alone. The endogenous hormonal balance of the plant must frequently be steered with exogenous chemicals to meet aesthetic and economic standards (Rademacher, 2015).

Plant growth regulators (PGRs) are naturally occurring or synthetic organic compounds that, applied in micromolar concentrations, modulate one or more physiological processes (Sponsel, 2016). In floriculture, PGRs are deployed at every stage — from rooting of stem cuttings, through height management of potted crops, to postharvest pulses that delay senescence of cut flowers.

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As Mitchell (2017) emphasises, the success of any PGR application depends on a precise match between target physiology, active ingredient, dose, timing and method of delivery. Misuse can be costly, producing phytotoxicity, distorted flowers or unsaleable plants.

This review consolidates classical and recent knowledge on the use of PGRs in ornamental crop production. Section 2 introduces the five principal hormone classes and synthetic retardants, with their primary mechanisms of action. Section 3 surveys their applications across the floriculture production cycle. Section 4 examines postharvest physiology and vase-life extension, where PGRs deliver the highest marginal economic value. Section 5 highlights molecular and biotechnological developments published over the last decade. Section 6 closes with a discussion of constraints and future directions.

2. Classification and Mechanisms of Plant Growth Regulators

Five endogenous hormone groups — auxins, gibberellins (GAs), cytokinins (CKs), ethylene and abscisic acid (ABA) — together with the newly accepted classes of brassinosteroids, jasmonates, strigolactones and salicylic acid, constitute the molecular language of plant development (Hossain et al., 2022; & Parwez et al., 2022). In floriculture practice, however, the bulk of commercial PGR products fall into the five classical categories, often complemented by synthetic anti-gibberellins (Figure 1).

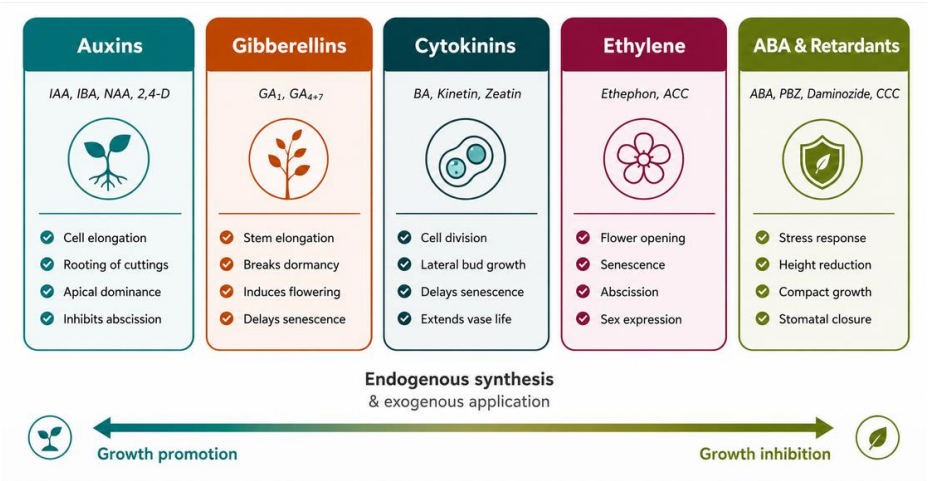

Figure 1. The five major classes of plant growth regulators, with representative compounds and key physiological roles in floriculture crops

2.1 Auxins. Indole-3-acetic acid (IAA) is the principal endogenous auxin; indole-3-butyric acid (IBA) and α-naphthaleneacetic acid (NAA) are widely used synthetic analogues. Auxins drive cell elongation, vascular differentiation, apical dominance, root initiation and abscission control (Zhao, 2010). The TIR1 F-box receptor binds auxin and triggers ubiquitin-mediated degradation of Aux/IAA repressors, releasing auxin response factors (ARFs) to activate downstream transcription (Dharmasiri et al., 2005). In rose, the Aux/IAA member RhIAA14 has been identified as a master regulator of petal expansion (Lin et al., 2022).

2.2 Gibberellins. GA_3 (gibberellic acid) and GA_{4+7} dominate floricultural use. They are tetracyclic diterpenoids that promote stem elongation, break seed and bulb dormancy, induce flowering in long-day species and delay leaf yellowing in cut flowers (Sponsel, 2016). Mechanistically, bioactive GAs bind the soluble receptor GID1 to promote degradation of DELLA proteins, derepressing growth genes (Sun, 2010).

2.3 Cytokinins. Zeatin, kinetin and benzyladenine (BA) constitute the most-used cytokinins. They stimulate cell division, release lateral buds from apical dominance, delay senescence and mobilise nutrients

toward developing organs (Zhao et al., 2006). The two-component AHK–AHP–ARR phosphorelay transduces the cytokinin signal, ultimately activating type-B ARR transcription factors that maintain meristematic activity and protect chlorophyll.

2.4 Ethylene. Unlike the other hormones, ethylene is a gaseous olefin. It is synthesised from S-adenosyl-methionine via 1-aminocyclopropane-1-carboxylic acid (ACC) and is perceived by membrane-bound receptors (ETR, ERS) coupled to the CTR1 kinase and the EIN2/EIN3 cascade (Patterson & Bleecker, 2004). In most ornamentals ethylene accelerates senescence, petal abscission, leaf yellowing and bent-neck disorder, although in selected cultivars it promotes flower opening (In et al., 2017; & Macnish et al., 2010). The dichotomous response has been resolved at the molecular level by studies that show the RhEIN3–RhARGOS–RhHYD1 module connecting ethylene and sterol signalling to flower opening (Zhang et al., 2025).

2.5 Abscisic acid and growth retardants. ABA is the principal stress hormone, regulating stomatal closure, dormancy and tolerance to drought and salinity. Synthetic growth retardants — paclobutrazol (PBZ), daminozide (B-9), chlormequat chloride (CCC), uniconazole and ancymidol — block GA biosynthesis at the ent-kaurene oxidase step (Figure 4) and are indispensable for producing compact, marketable potted plants (Rademacher, 2015).

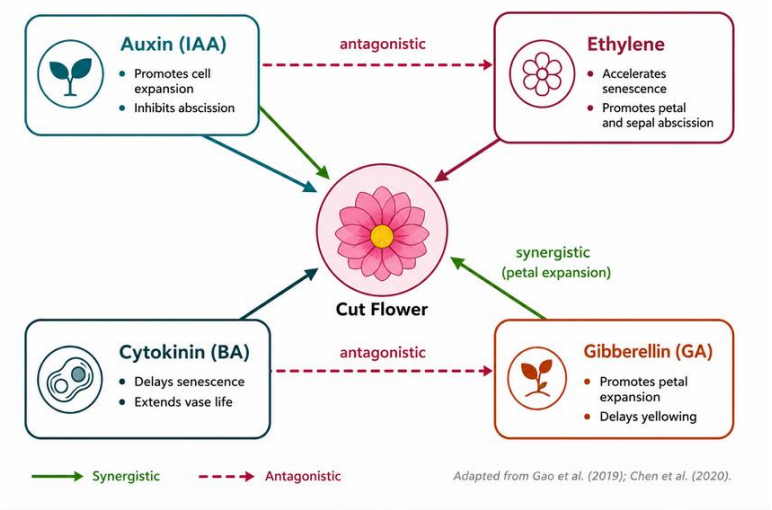

Figure 2. Hormonal crosstalk regulating cut-flower opening and senescence. Auxin and gibberellin act synergistically to promote petal expansion, whereas auxin and ethylene operate antagonistically during abscission; cytokinin counteracts ethylene-driven senescence. Adapted from Gao et al. (2019) and Chen et al. (2020)

These hormones rarely act in isolation. Auxin and gibberellin act synergistically to promote petal expansion in rose (Chen et al., 2023), while auxin and ethylene operate antagonistically during abscission (Gao et al., 2019). The ARF7–SUC2 module shows that auxin maintains sucrose import into the petal abscission zone, thereby suppressing ethylene-induced shedding (Liang et al., 2020). Cytokinin counteracts ethylene-driven chlorophyll degradation, which is the molecular basis for the BA-containing postharvest treatments now used commercially.

3. Applications across the Floriculture Production Cycle

PGRs are applied at every developmental phase, from propagation through harvest (Figure 5). Method of application, concentration and timing are species-, cultivar- and stage-specific.

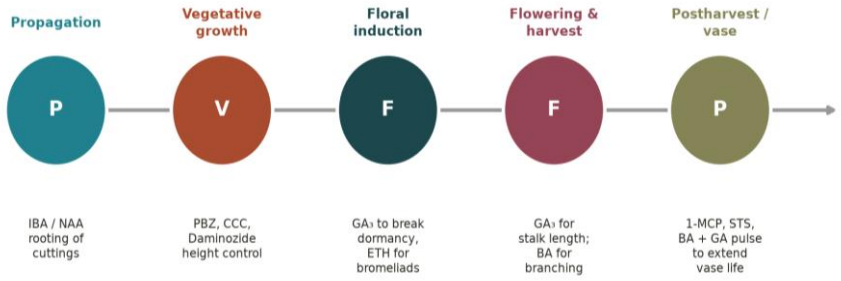

Figure 3. Stage-wise applications of plant growth regulators across the floriculture production cycle

3.1 Propagation. Adventitious-root induction on stem cuttings is one of the oldest and largest uses of synthetic auxins. IBA and NAA, alone or in combination, are formulated as talc dusts, alcoholic quick-dips and aqueous solutions. A combination of NAA 250 ppm + IBA 250 ppm produced the highest survival in rose cuttings (Haixia et al., 2013), and IBA at 2000 ppm is the routine standard for chrysanthemum and carnation. 2,4-D is restricted to in-vitro callus induction because it triggers uncontrolled growth at field doses (Kumar et al., 2021).

3.2 Vegetative growth and height control. Compact potted crops command higher market value, occupy less greenhouse space and tolerate shipping. Foliar sprays or media drenches of paclobutrazol, daminozide, chlormequat chloride or uniconazole are routinely applied to poinsettia, chrysanthemum, lily, geranium and hibiscus. By inhibiting kaurene oxidase, these triazoles reduce bioactive GA levels (Figure 4), shorten internodes, intensify leaf colour and increase chlorophyll concentration (Rademacher, 2015). In China aster, daminozide produced shorter, more branched plants with delayed flowering (Kumar et al., 2015).

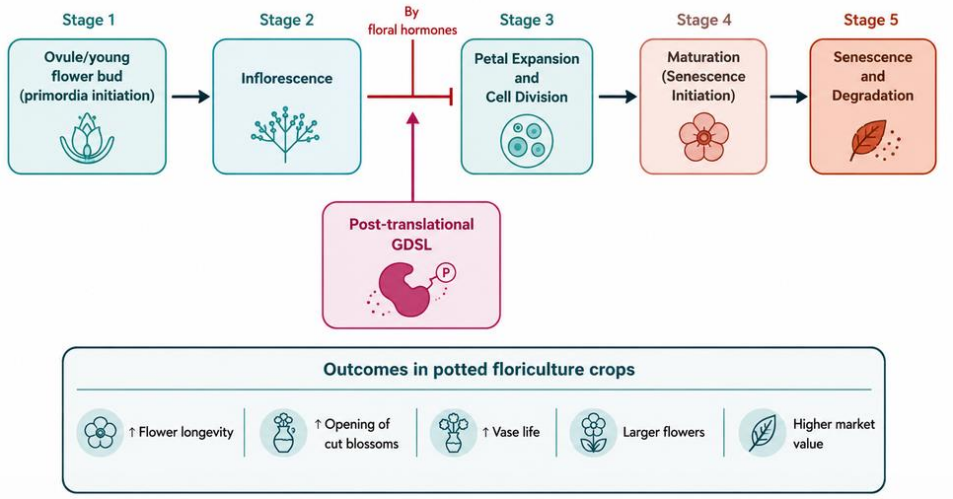

Figure 4. Mode of action of triazole-type growth retardants. Paclobutrazol blocks ent-kaurene oxidase, reducing bioactive gibberellin levels and producing compact, dark-green, high-value potted ornamentals

3.3 Flower induction and quality enhancement. Gibberellic acid is the most versatile inducer of flowering in ornamentals. GA_3 sprays advance flowering in long-day species such as gladiolus and tuberose, increase scape length in gerbera and improve spike quality in chrysanthemum (Kumar et al., 2011). Gautam et al. (2006) reported that foliar GA_3 at 200 ppm and NAA at 100 ppm increased growth and flower number in chrysanthemum, while ethrel reduced vegetative growth in the same trial. Ethylene-

releasing ethephon is used commercially to force bromeliad flowering and to promote female flower expression in cucurbitaceous ornamentals (Singh et al., 2023). Cytokinin applications increase axillary branching in cut roses and prolong nutrient mobilisation into developing buds (Zhao et al., 2006).

3.4 Sex expression and parthenocarpy. Although less central to floriculture than to vegetable production, hormonal manipulation of sex expression is exploited in seed-production of ornamental cucurbits and in selected orchid species, where ethephon and silver thiosulphate (STS) reverse sex ratios to favour cross-pollination programmes (Zhang et al., 2018). Auxin-induced parthenocarpic fruit set is occasionally exploited in ornamental capsicum.

4. Postharvest Physiology and Vase-life Extension

The postharvest phase is when PGRs deliver the highest economic value in floriculture. Brief vase life is attributed primarily to negative water balance, premature ethylene-driven senescence and carbohydrate depletion (In & Lim, 2018). Three classes of intervention dominate commercial practice.

4.1 Ethylene inhibitors. 1-Methylcyclopropene (1-MCP) binds the ethylene receptor irreversibly, blocking downstream signal transduction and dramatically extending vase life of ethylene-sensitive species such as carnation, snapdragon, sweet pea and many rose cultivars (Macnish et al., 2010). Silver thiosulphate (STS), though increasingly restricted on environmental grounds, remains effective because the silver ion competes with ethylene at the receptor. Aminoethoxyvinylglycine (AVG) and 2-aminoisobutyric acid (AIB) inhibit ACC synthase upstream and have been shown to delay senescence in both ethylene-sensitive and insensitive rose cultivars (Ha et al., 2020).

4.2 Cytokinin and gibberellin pulses. Pre-shipment pulses of benzyladenine (BA) and GA_{4+7} at 10–20 mg L^{-1} are now an industry standard for many cut flowers. Shimizu-Yumoto and Ichimura (2013) demonstrated that a 24-h pulse of BA plus GA_{4+7} increased vase life of cut dahlias by 43%, improved petal turgor and reduced leaf yellowing. Comparable extension has been reported in lily, chrysanthemum and bouvardia. Figure 3 summarises representative vase-life data across five economically important cut flowers.

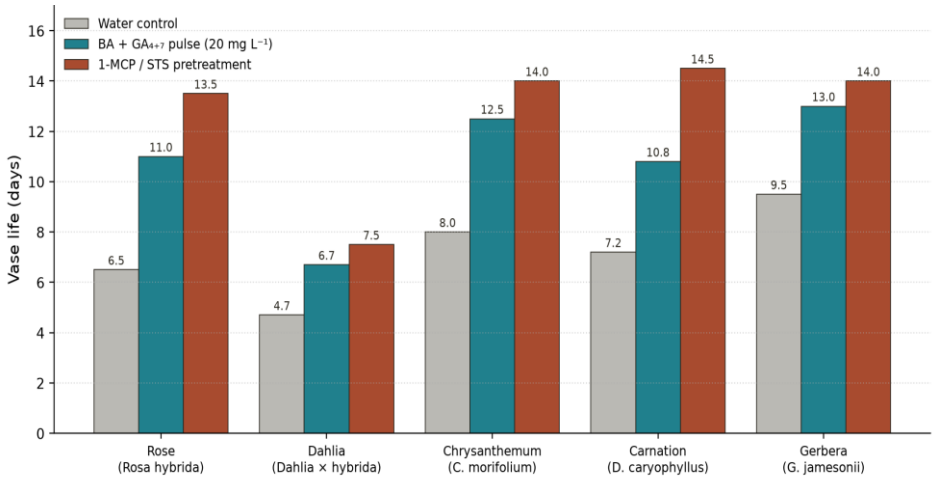

Figure 5. Representative effect of postharvest PGR treatments on vase life of selected cut flower species, compiled from Shimizu-Yumoto and Ichimura (2013), Dole et al. (2009) and In et al. (2017)

4.3 Holding solutions and carbohydrate supply. Sucrose acts as both a respiratory substrate and a regulator of auxin–ethylene crosstalk. The auxin-induced RhARF7 directly activates the sucrose transporter RhSUC2, sustaining sucrose import into petals and

repressing ethylene-induced abscission (Liang et al., 2020). Commercial holding solutions typically combine sucrose with a biocide and a low concentration of citric acid to lower solution pH and improve hydraulic conductivity.

5. Recent Molecular and Biotechnological Developments

Three lines of recent research are reshaping PGR practice in floriculture. First, transcriptomics and reverse-genetics have begun to dissect the molecular underpinnings of flower opening and senescence in commercially important species, especially rose. Lin et al. (2022) identified RhIAA14, an Aux/IAA family gene whose stage-specific repression by ethylene determines petal expansion and final flower size. The RhMYB24–RhbHLH71 transcription-factor complex was shown to mediate auxin–gibberellin–ethylene crosstalk during flower opening (Wang et al., 2024), providing a target for cultivar improvement through CRISPR-based editing.

Second, genetically engineered ethylene-insensitive ornamentals have entered late-stage development. Transgenic chrysanthemums expressing a mutated etr1-1 receptor exhibit reduced ethylene sensitivity, continue to elongate at low temperatures and remain green during shipping (Narumi et al., 2008). Such cultivars offer a permanent alternative to repeated 1-MCP treatments and may eventually displace silver-based postharvest chemistry.

Third, novel biostimulants and "new-generation" PGRs are reaching commercial floriculture. Strigolactones, brassinosteroids and melatonins have been shown to modulate ornamental physiology under abiotic stress (Hossain et al., 2022). Foliar melatonin delays petal senescence in cut lilies and intensifies pigmentation; brassinosteroids increase tolerance to heat and water deficit in greenhouse-grown roses; strigolactones manipulate axillary branching for plant architecture. Microbial biostimulants, particularly Trichoderma- and Bacillus-based formulations, induce endogenous IAA and GA biosynthesis in ornamental seedlings, offering a sustainable substitute for repeated synthetic PGR sprays (Editorial, 2023).

Finally, precision-delivery technologies — controlled-release granules, nanocarrier formulations and spot-application drones — are reducing the chemical footprint of PGR programmes. Combined with sensor-driven phenotyping, these tools support stage-specific, dose-optimised applications consistent with sustainable and climate-smart floriculture (Rademacher, 2015).

6. Constraints and Future Outlook

Despite their indispensable role, PGRs carry several constraints. Cultivar-specific responses make protocols non-transferable: ethylene sensitivity in roses, for example, varies by an order of magnitude between cultivars (In et al., 2017). Mis-timed applications produce phytotoxicity, distorted flowers or loss of fragrance. Regulatory and environmental concerns surround silver-based products and certain triazoles, particularly with respect to residue in greenhouse run-off. Resistance, in the form of reduced plant responsiveness after repeated applications, is documented for some growth retardants.

Future research should integrate (a) genome-wide association studies that link cultivar genotype to PGR response phenotype, (b) gene-edited cultivars with built-in ethylene insensitivity or reduced GA signalling, (c) low-risk biostimulants that can partially replace synthetic PGRs, and (d) decision-support systems that match dose and timing to real-time crop physiology. Integrated PGR management, analogous to integrated pest management, offers the most promising path toward sustainable, climate-resilient ornamental production (Mitchell, 2017).

CONCLUSION

Plant growth regulators are the chemical fine-tuners of modern floriculture. From auxin-mediated rooting of cuttings, through gibberellin- and retardant-based control of plant architecture, to cytokinin and 1-MCP-based postharvest pulses, every stage of ornamental production now depends on the

precise manipulation of endogenous hormone balance. Recent molecular dissection of phytohormone crosstalk — particularly the auxin–ethylene–gibberellin network governing flower opening and abscission — has provided new targets for both chemical and genetic intervention. Coupled with emerging biostimulants and precision-delivery technologies, these advances point toward an era of stage-specific, dose-optimised and environmentally responsible PGR programmes that will sustain a globally competitive floriculture industry under climate pressure.

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