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A comprehensive review of Plant Growth Regulators (PGRs) and their impact on flowering and ornamental crops with insights into effective application methods

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Abstract
Ornamental plants play a crucial role in the expansive horticultural sector on a global scale. Within the field of modern ornamental plant production, a diverse range of organic chemicals known as plant growth regulators (PGRs) holds significant importance. These regulators, whether naturally derived or synthesized, are acknowledged as valuable tools employed by commercial ornamental plant growers in their cultivation practices. Phytohormones, or plant growth regulators, are pivotal in governing the physiological processes, developmental transitions, and responses to environmental cues in plants. These organic compounds, characterized by varied chemical structures, are produced by plants in relatively low concentrations within specialized tissues. These compounds are then transported throughout the entire plant, where they qualitatively and quantitatively impact crucial physiological processes. The primary groups of plant hormones include auxins, gibberellins, cytokinins, abscisic acid, ethylene, brassinosteroids, and jasmonates. PGRs exert rapid effects on both the vegetative growth and flower yield of flowering crops, presenting various advantages, such as application efficiency, time savings, and an environmentally friendly nature. The effectiveness of PGRs hinges on several factors, with the method of application playing a crucial role. Proper absorption by plants is essential for their efficacy. When employing growth regulators in flowering crops, it is imperative that their action is specific, and they are demonstrated to be safe in terms of both toxicity and environmental impact. The application of growth regulators profoundly influences the physiological activities of flowering crops, ultimately shaping their growth and flower production. In this thorough examination, we explore various categories of plant growth regulators, investigating their applications and impacts on flowering plants, foliage plants, and ornamental grasses.

Keywords: Plant growth regulators (PGRs), Auxin, effect and application, ornamental plant, flowers

Introduction

Since the beginning of civilization, flowers have been connected to humans. They stand for beauty, tranquilly, and love. Since the dawn of time, Indians have grown and used flowers. We now take flowers for granted in our daily lives. Due to changing lifestyles, its use, particularly for religious and social offerings, has increased. This has made people appreciate flowers' economic usefulness in addition to their aesthetic appeal. In 2021–22 (3rd Advance Estimate), 283 thousand hectares of the region were being farmed for floriculture. According to the third advance estimate, 833.16 thousand tonnes of cut flowers and 2295.07 thousand tonnes of loose flowers will be produced in 2021–2022. In 2022–2023, the nation exported 21024.41 MT of floriculture goods to the world, valued at Rs. 707.81 crores/88.38 US million. Major Export Markets (2022-23) United States, Netherlands, United Arab Emirates, and United Kingdom. Major Import Markets (2022-23): Germany and Malaysia. Areas of Cultivation Major Floriculture hubs have formed in Tamil Nadu, Karnataka, Madhya Pradesh, West Bengal, Chhatisgarh, Andhra Pradesh, Gujarat, Uttar Pradesh, Assam, and Maharashtra. (APEDA 2023).

Charles Darwin and the Study of Plant Tropisms In the 19th century, Charles Darwin conducted experiments on plant responses to environmental stimuli, such as light and gravity. He observed tropic movements, including phototropism (Growth towards light) and gravitropism (Response to gravity), which hinted at the existence of some chemical substances controlling these processes. Plant growth regulators (PGRs) are synthetically created organic compounds that are used to modify the growth of whole plants or individual plant components. They have the power to either speed up or slow down plant growth. Plant hormone, also known as phytohormone. The term "Phytohormone" was coined by Thimann in 1948

According to Thimann (1948) [151], a phytohormone is an organic compound produced naturally in higher plants that regulates growth or other physiological processes at a location far from where it was formed. Plant growth regulators (PGRs) are defined as organic or inorganic substances that can control the metabolic and developmental processes in higher plants (Sabagh *et al*., 2021) [124]. The term "PGRs" is most frequently used to refer to phytohormones, but it can also apply to substances that prevent the synthesis or translocation of phytohormones as well as substances that block their receptors (Rademacher 2015) [117]. PGRs are frequently used in agriculture, horticulture, and viticulture for a number of advantages, including altering morphological structure, boosting resistance and tolerance to biotic and abiotic challenges, and raising yields both qualitatively and quantitatively. Naeem and Aftab (2022) [99] PGRs and plant hormones are sometimes confused, but they have some differences. For example, the agrochemical industry refers to PGRs as synthetic plant growth regulators, whereas plant hormones are a class of naturally occurring, organic substances that have physiological effects at low concentrations (Davies, 2010) [36].

These PGR compounds are involved in the control of a number of physiological processes, such as the differentiation of tissues and the growth of organs, as well as senescence, flowering, seed germination, dormancy, lowering fruit drop, enhancing fruit set, and preserving the quality of the fruit. Abscisic acid, auxins, brassinosteroids, gibberellins, jasmonates, cytokinins, ethylene, salicylic acid, strigolactones, nitric oxide, and polyamines are some of the primary PGRs (Asgher *et al*., 2015; Bons and Kaur, 2020; Aftab and Roychoudhury, 2021; Sabagh *et al*., 2021) [11, 25, 4, 125].

Another growing area of PGR use is phytohormone priming. In both normal and stressful environments, phytohormones are exogenously supplied to plants to positively modulate a number of biological processes, including cell division, transpiration, photosynthesis, the ascorbate-glutathione cycle, nitrogen metabolism, and antioxidant activities Hossain *et al*. 2022, Malek *et al*. 2022, Tahaei *et al*. 2022) [58, 86, 150]. In order to promote the production of secondary metabolites and improve plant defense against stressors, PGRs are utilized as external supplements for medicinal plants (Jamwal *et al*. 2018) [61]. The application of PGRs to improve turfgrass quality, greenery, and its capacity to withstand environmental stress has been recently begun in the turf and sports industries (Glab *et al*. 2020) [51]. In the landscape, growth regulators are also employed to limit the growth of shrubs and perennial ground covers (Gad *et al*. 2016; Wei *et al*. 2017; Glab *et al*. 2020) [47, 161, 51].

Plant growth regulators' characteristics the characteristics of these compounds include the following:

1. They are intricate chemical substances with a light molecular weight and good solubility.
2. The vascular tissues of the plants are responsible for conducting them.
3. They demonstrate dual control, either fostering growth or stifling it.
4. For plants to grow, develop, and function properly, they are necessary.
5. Even in extremely small amounts, they have a significant physiological impact.

Synthetic plant growth regulators have the potential to be crucial instruments in the fight to raise the global food supply. This study places a focus on contemporary research on synthetic plant growth regulators, particularly on how they affect the yields of commercial crops.

Table 1: Synthetic growth regulators for ornamental plants that are commercially available.

Plant Name	Active Substances	Market names	Basic Results	Reference
Ageratum	Ancymidol	A-Rest, Abide	Regulating plant growth	Bailey and Whipker, 1998 [14]; Whipker, 2013 [162]
Aster	Daminozide	B-Nine, Compress, Dzide	Regulating plant growth	Bailey and Whipker, 1998 [14]; Whipker, 2013 [162]
Begonia	Ethephon	Florel	Improve lateral branching as a pinching agent	Bailey and Whipker, 1998 [14]; Whipker, 2013 [162]
Dhalia	Uniconazole	Sumagic, Concise	Regulating plant growth	Bailey and Whipker, 1998 [14]; Whipker, 2013 [162]
Easter	6-benzyladenine and gibberellins A4 + A7	Fascination, Fresco	Stop the leaf fading of yellow	Latimer, 2009
Fagus	Indole Butyric Acid	Chryzopon, C-mone, Rhizopon	Promote rooting	Percival and Barnes, 2004 [112]
Gomphrena	Chlormequat chloride	Citadel, Cycocel	Regulating plant growth	Bailey and Whipker, 1998 [14]; Whipker, 2013 [162]
Impatiens	Paclobutrazol	Bonzi, Downsize, Paczol, Piccolo	Regulating plant growth	Bailey and Whipker, 1998 [14]; Whipker, 2013 [162]
Kalanchoe	Dikegulac sodium	Atrimmec, Augeo	Improve lateral branching	Bailey and Whipker, 1998 [14]; Whipker, 2013 [162]
Ornithogalum	Gibberellic acid	Florgib, ProGibb	Encourage the growth of plants and flowers	Wang and walter, 2006 [157]
Petunia	6-benzyladenine	Configure	Increase lateral branches	Carey *et al*., 2007
Vinca	Flurprimidol	Topflor	regulating plant growth	Whipker *et al*., 2003a [163]

(Table Source- Sajjad *et al* 2015) [129]

Table 2: Plant Growth Regulators Commonly Used in Plant Tissue Culture

Plant Growth Regulator	Purpose	Recommended Concentrations
Indole-3-acetic acid (IAA)	Callus induction at 10-30 µM concentration. Stimulates organogenesis at 1-10 µM. Inactivated by light and readily oxidized by plant cells.	10-30 µM for callus, 1-10 µM for organogenesis
Indole-3-butyric acid (IBA)	Used for rooting shoots regenerated through organogenesis. Maintain at low concentration (1-50 µM) throughout rooting or expose to a high concentration (100-250 µM) for initial days, then transfer to hormone-free medium.	1-50 µM for rooting, 100-250 µM for initial exposure
2, 4-dichlorophenoxyacetic acid (2, 4-D)	Commonly used synthetic auxin for callus induction and maintenance in dedifferentiated states. Used alone (1-50 µM) or in combination with NAA.	1-50 µM, often with NAA
Para-chlorophenoxyacetic acid (PCPA)	Similar to 2,4-D. Used as sole auxin source (2-20 mM for callus, 0.2-2 µM for root induction) or in combination with 2,4-D.	2-20 mM for callus, 0.2-2 µM for root induction
α-Naphthaleneacetic acid (NAA)	Used similarly to 2,4-D. Commonly used alone (2-20 mM for callus, 0.2-2 µM for root induction) or in combination with 2,4-D.	2-20 mM for callus, 0.2-2 µM for root induction
6-Furfurylaminopurine (kinetin)	Induced in culture media for callus induction, growth, and morphogenesis (1-20 µM). Higher concentrations (20-25 µM) for rapid shoot multiplication.	1-20 µM for callus and morphogenesis, 20-25 µM for shoot multiplication
6-Benzylaminopurine (BAP, BA)	Used for callus induction, growth (0.5-5.0 µM), and morphogenesis (1-10 µM). Common for rapid shoot multiplication (5-50 µM).	0.5-5.0 µM for callus, 1-10 µM for morphogenesis, 5-50 µM for shoot multiplication
N-Isopentenylaminopurine (2iP)	Less common than kinetin or BAP. Used for callus induction and growth (2-10 µM), morphogenesis (10-15 µM), or shoot multiplication (30-50 µM).	2-10 µM for callus, 10-15 µM for morphogenesis, 30-50 µM for shoot multiplication
Zeatin (Zea)	Seldom used in callus or suspension media. Used for morphogenesis (0.05-10 µM). Must not be autoclaved.	0.05-10 µM for morphogenesis
Gibberellic acid (GA3)	Rarely used in callus or suspension medium. Promotes shoot growth at 0.03-14 µM. Enhances development in embryo/ovule cultures (0.3-48 µM). Must not be autoclaved.	0.03-14 µM for shoot growth, 0.3-48 µM for embryo/ovule cultures
Abscisic acid (ABA)	Used at concentrations of 0.4-10 µM to prevent precocious germination and promote normal somatic embryo development.	0.4-10 µM for preventing germination and promoting embryo development

(***Source***: Bahadur and Singh, 2014) [13]

Types of Plant Growth Regulators: There are several different categories of plant growth hormones or regulators

1. Plant Growth Promoters
2. Plant Growth Inhibitors

Plant Growth Promoters: Plant growth promoters are chemicals that speed up a plant's development and flowering. Growth promoters are hormones or plant growth regulators that help plants grow, such as auxins, gibberellins, and cytokinin's**.**

The application of Plant Growth Regulators (PGRs) has been extensively studied and utilized in various ornamental plants to enhance different attributes. Initially confined to scientific experiments, it has now gained popularity among progressive growers for commercial use. The specific objectives of PGR application may vary depending on the type of ornamental plant. Some common objectives include:

1. **Compactness of Foliage:** For certain ornamental plants, achieving compact foliage is a primary goal, as it enhances the plant's appearance and aesthetic value.
2. **Flower Characteristics:** In other ornamental plants, the focus is on improving flower characteristics, such as size, color, and shape, to make them more attractive.
3. **Plant Height Regulation:** PGRs have been used to control plant height. Some studies have focused on increasing plant height, while others have aimed to reduce it.
4. **Enhanced Compactness:** PGR application can lead to more compact growth in plants, which is desirable for certain ornamentals.
5. **Increased Flower Production:** PGRs have been found to boost the number of flowers produced by ornamental plants, resulting in more vibrant displays.
6. **Early Flowering:** The application of PGRs can stimulate early flowering, allowing ornamental plants to bloom ahead of their natural schedule**.**
7. **Stimulated Lateral Shoots:** Some studies have reported an increase in the number of lateral shoots, contributing to a fuller appearance.
8. **Delayed Flowering:** In certain cases, delaying flowering is desirable for ornamental plants, and PGRs can help achieve this objective.

Auxins

The Dutch biologist Frits Warmolt Went first described auxins and their role in plant growth in the 1920s. (Hohm at al. 2013) [57] Kenneth V. Thimann became the first to isolate one of these phytohormones and to determine its chemical structure as indole-3-acetic acid (IAA). Went and Thimann co-authored a book on plant hormones, *Phytohormones*, in 1937.

With a basal quick-dip in a concentrated solution, auxins are well known to begin and encourage the roots of stem cuttings (Hartmann *et al*., 1997) [55].

Synthesis Location= Stem apex, developing fruits Target Tissue= Primary cell wall

Table 3: Utilization of Growth Regulators in Key Ornamental Plants

Sl. No.	Plant Name	Purpose	Growth Regulators Used	Application Methods	References
1	*Grindelia*	Stimulating Root Growth	Indole-3-butyric Acid (IBA)	Dipping	Wassner and Ravetta (2000) [159]
2	*Dieffenbachia*	Promoting Indirect Shoot Growth	Thidiazuron (TDZ) and 2,4-D	Media Solution	Shen *et al*. (2008) [140]
3	Rose	*In vitro* Shoot Regeneration	α-Naphthaleneacetic Acid (NAA), 6-Benzylaminopurine (BAP) for Shoot Generation, and Indole-3-acetic Acid (IAA) and NAA for Rooting	Media Solution	Asadi *et al*. (2009) [10]
4	*Chrysanthemum*	Enhancing Flowering and Chlorophyll Content	Daminozide (Alar-85)	Foliar Spray	Kazaz *et al*. (2010) [65]
5	*Hibiscus*	Promoting Growth and Flowering	Paclobutrazol, Uniconazole, and Flurprimidol	Drenching	Ahmad Nazarudin (2012) [5]
6	Rose	Improving Flower Quality and Vase Life	Spermidine (Spd)	Hydroponic Culture Media	Farahi *et al*. (2012) [42]
7	Tuberose	Enhancing Flower Quality and Bulb Yield	Gibberellic Acid (GA3)	Dipping	Rani and Singh (2013) [122]
8	*Tabernaemontana coronaria*	Promoting Growth, Flowering, and Histological Features	Paclobutrazol and Cycocel	Foliar Spray	Youssef and Abd El-Aal (2013) [74]
9	Marigold	Enhancing Flowering and Yield	Gibberellic Acid (GA3), Ethrel, and Maleic Hydrazide	Foliar Spray	Kumar *et al*. (2014a) [144]
10	Carnation	Improving Rooting Efficiency	Indole-3-butyric Acid (IBA), Indole-3-acetic Acid (IAA), and α-Naphthaleneacetic Acid (NAA)	Dipping	Kumar *et al*. (2014b) [144]
11	Annual *Chrysanthemum*	Enhancing Flower and Seed Yield	Gibberellic Acid (GA3)	Foliar Spray	Sainath Uppar *et al*. (2014) [128]
12	Potted Sunflower, *Zinnia*, Marigold, Petunia	Enhancing Post-Harvest Performance	Paclobutrazol	Drenching	Ahmad (2015) [6]
13	China Aster	Stimulating Growth, Flowering, and Seed Yield	Gibberellic Acid (GA3), Salicylic Acid, Maleic Hydrazide, Alar, and Paclobutrazol	Foliar Spray	Kumar *et al*. (2015)
14	Hippestrum	Enhancing Flower and Bulb Production	α-Naphthaleneacetic Acid (NAA), Ethephon, and Gibberellic Acid (GA3)	Foliar Spray	Jamil *et al*. (2015) [60]
15	*Gladiolus*	Promoting Corm Production and Vase Life	Gibberellic Acid (GA3) and Brassinosteroid	Foliar Spray	Padmalatha *et al*. (2015) [108]
16	*Gladiolus*	Enhancing Growth and Flowering	Gibberellic Acid (GA3) and Chlorocholine Chloride (CCC)	Foliar Spray	Sable *et al*. (2015) [126]
17	Rose	Improving Post-Harvest Flower Quality	Polyamines including Spermine, Spermidine, and Putrescine	Holding Solution	Tatte *et al*. (2015) [151]
18	Rose	Enhancing Growth and Flowering	Spermine and Spermidine	Foliar Spray	Tatte *et al*. (2016)
19	*Zinnia*	Stimulating Growth and Flowering	Brassinosteroids	Foliar Spray	Badawy *et al*. (2017) [12]
20	*Dahlia*	Enhancing Growth and Flowering	Ethephon, Daminozide, and Maleic Hydrazide	Foliar Spray	Malik *et al*. (2017) [87]
21	Rose	Promoting Growth, Flowering, and Vase Life	Putrescine (Put) and Spermidine (Spd)	Foliar Application	Farahi and Jahroomi (2018) [44]
22	*Gladiolus*	Enhancing Morphological, Biochemical, and Post-Harvest Flowering	24-Epibrassinolide (EBR)	Priming of Corms	Mollaei *et al*. (2018) [96]
23	*Chrysanthemum*	Stimulating Growth and Flowering	Cycocel and B-nine	Foliar Spray	Qureshi *et al*. (2018) [117]
24	*Gladiolus*	Promoting Growth, Flowering, and Corm Yield	Methyl-jasmonate and Salicylic Acid	Foliar Spray	Sewedan *et al*. (2018) [136]
25	*Anthurium*	Enhancing Post-Harvest Flower Quality	Gibberellic Acid (GA3) and Spermine (SPM)	Foliar Spray and Pulsing	Simoes *et al*. (2018) [141]
26	China Aster	Enhancing flower yield and prolonging vase life	Gibberellic Acid (GA3), α-Naphthaleneacetic Acid (NAA), and Chlorocholine Chloride (CCC)	Applied via foliar spray	Sindhuja *et al*. (2018)
27	*Chrysanthemum*	Stimulating growth and improving flower yield	Gibberellic Acid (GA3)	Applied via foliar spray	Ashutosh *et al*. (2019) [1]
28	Rose	Enhancing growth, development, and antioxidant enzyme	Polyamines (Putrescine, Spermidine, and Spermine)	Applied via foliar spray	Yousefi *et al*. (2019) [170]

		activities			
29	Turfgrass	Enhancing visual quality	Trinexapac Ethyl, Paclobutrazol, Flurprimidol, Mefluidide, Ethephon, and Gibberellic Acid	Application methods not specified	Głąb *et al*. (2020) [51]
30	Azalea	Promoting rooting in cuttings	Indole-3-butyric Acid (IBA), α-Naphthaleneacetic Acid (NAA), Salicylic Acid (SA) either alone or in combinations	Applied by soaking	Hou *et al*. (2020) [59]
31	Bahia grass	Enhancing visual quality and conducting biochemical analysis	Paclobutrazol	Applied via foliar application	Lima Bruno Horschut de *et al*. (2020)
32	Carpet grass Plus®	Improving visual quality	Paclobutrazol and Phenoxaprope-pethyl	Application methods not specified	Melero *et al*. (2020) [93]
33	*Gerbera*	Extending vase life, enhancing qualitative features, and affecting enzyme activity	Polyamines like spermine (SPER), γ-aminobutyric acid (GABA), and β-aminobutyric acid (BABA)	Applied via vase solution and spray	Mohammadi *et al*. (2020) [95]
34	*Rhododendron*	Stimulating *in vitro* shoot proliferation	Thidiazuron (TDZ)	Applied via media solution	Novikova *et al*. (2020) [81]
35	*Bougainvillea*	Promoting rooting in cuttings	Indole-3-butyric Acid (IBA)	Applied by dipping	Pirdastan *et al*. (2020) [114]
36	Iraca palm	Facilitating *in vitro* shoot multiplication and rooting	6-Benzylaminopurine (BAP) and α-Naphthaleneacetic Acid (NAA)	Applied via media solution	Sanchez *et al*. (2020)
37	*Gladiolus*	Enhancing growth and flowering	Ancymidol	Applied by dipping	Aljaser and Anderson (2021) [8]

Biosynthesis: Tryptophan or compounds derived from it are the auxin precursor in plants. Three steps are required to create it: transaminase, which catalyses the conversion of tryptophan into tryptamine; decarboxylase, which converts indole pyruvic acid from tryptamine into indole acetaldehyde; and aldehyde dehydrogenase, which catalyses the production of acetic acid from -indole. Autin is produced by the entire body of the plant. However, growing seeds, buds, and shoot tips are where most auxin is produced.

Synthetic Auxins: Many synthetic compounds have biological activities that are comparable to those of IAA. They don't exist in any plant, though. IBA (Indole Buteric Acid), NAA (And-Naphthalene Acetic Acid), 2, 4-D (2, 4-dichlorophenoxyacetic acid), 2, 4, 5-T (2, 4, 5-trichlorophenoxyacetic acid), IPA (Indole Propionic Acid), naphthoxyacetic acid, etc. are some of the significant synthetic auxins.

The two synthetic substances, indole-3-butyric acid (IBA) and naphthalene acetic acid (NAA), were even more effective than the naturally occurring or synthetic IAA for rooting and widely used in rooting of tissue culture produced micro cuttings (Karimi *et al*., 2012) [64]. IBA is the auxin that is most commonly used for commercial rooting.

Auxin distribution in plants

Auxin-like (IAA) is produced in meristematic or developing points of plants, where it is then transferred to other plant components. IAA is therefore present in the highest quantity. In producing auxiliary shoot tips, immature leaves, and shoots. The highest concentration of is seen in monocot seedlings. Coleoptile tips contain auxin, which gradually declines. Towards the bottom. The largest concentration is detected in developing auxiliary shoots, immature leaves, and growing shoot regions in dicot seedlings.

Auxins are a class of plant hormones that play a crucial role in various aspects of plant growth and development, including cell elongation, tissue differentiation, apical dominance, root initiation, and phototropism. The distribution of auxins within plants is not uniform and can vary depending on various factors and plant organs. Here's an overview of auxin distribution in plants:

1. **Apical Dominance**: In the shoot apex (the growing tip of a stem), auxins are typically synthesized and accumulate. This high concentration of auxins inhibits the growth of lateral buds, promoting the growth of the main shoot and maintaining apical dominance. This is why the main stem grows taller and the lateral branches remain shorter.
2. **Root Formation**: Auxins are essential for root initiation and development. They accumulate in higher concentrations in the root tips, particularly in the region known as the root apical meristem. This accumulation of auxins stimulates cell elongation and differentiation, leading to the growth of primary and lateral roots.
3. **Phototropism**: In response to light, auxins accumulate on the shaded side of the stem or shoot. This differential distribution of auxins causes cell elongation on the shaded side, leading to bending of the plant towards the light source.
4. **Gravitropism:** In response to gravity, auxins also accumulate on the lower side of horizontally oriented plant organs, such as roots and stems. This accumulation causes differential cell elongation, resulting in the bending of the organ towards the direction of gravity (positive gravitropism for roots and negative gravitropism for shoots).
5. **Leaf and Fruit Development**: Auxins are involved in leaf expansion and the development of fruits. They promote cell division and elongation in young leaves and fruits, contributing to their growth.
6. **Vascular Tissues**: Auxins are involved in the differentiation and development of vascular tissues, including xylem and phloem. They play a role in controlling the direction of water and nutrient transport within the plant.
7. **Senescence**: In aging or senescing leaves, auxin levels decrease. This reduction in auxin concentration is associated with leaf yellowing and the eventual shedding of leaves.

8. **Wounding Response**: Plants can produce auxins in response to injury or wounding. This helps in the formation of callus tissue and subsequent tissue repair.

Uses of auxin in ornamental plant

- **In Indian lavender (*Bursera delpechiana*):** Swetha (2005) [149] found that 2000 ppm of IBA was more effective in inducing rooting compared to the control.
- **In marigold:** Ullah *et al*. (2013) [154] found that 400 ppm of IBA resulted in the maximum number of roots. They also noted that 100 ppm of IBA led to the maximum root length.
- **In Azalea and Paeonia:** Xian *et al*. (2009) [166] and Hou *et al*. (2020) [59] found that IBA at 2000 mg L-1 enhanced root growth and development.
- **In poinsettia:** Chaudhari *et al*. (2018) [31] reported that 4000 ppm of IBA was the most effective concentration for treating cuttings.
- **In *Hibiscus rosa-sinensis L*.:** Nanda and Mishra (2010) [76] found that NAA at 200 ppm was the most effective for rooting and growth parameters.
- **In *Bougainvillea*:** Parmar *et al*. (2010) [110] and Sayedi *et al*. (2014) [134] found that IBA at 4000 ppm was superior in terms of rooting percentage, survival percentage, and days for sprouting.
- Gupta *et al*. (2002) [53] and Mehraj *et al*. (2013) [92] reported that dipping cuttings in 1000 ppm IBA resulted in the highest number of roots and shoots per cutting.
- Panwar *et al*. (2001) [109] and Sahariya *et al*. (2013) [127] observed the maximum number of roots, rooting percentage, and root length in different *Bougainvillea* cultivars with 2000 ppm IBA.
- Singh *et al*. (2011) found that 3000 mg. L-1 IBA was optimal for the maximum length of sprout/cutting and the number of roots/cutting in *Bougainvillea glabra* in February. However, the maximum length of the root/cutting was observed with 5000 mg.L concentration of IBA.
- Pirdastan *et al*. (2020) [114] noted that applying 400 mg/l IBA for 24 hours dipping improved rooting parameters in *Bougainvillea*. They also suggested that a quick dip in 1000 mg/L IBA for 20 seconds produced satisfactory results, reducing application time and labour costs.

1. ***Bougainvillea* cv. Cherry Blossom:** Parminder and Kushal (2003) [111] noted that the best rooting parameters were achieved when cuttings were treated with a combination of NAA at 1500 ppm + IBA at 1000 ppm.
2. ***Thunbergia grandiflora:*** Vinay kumar *et al*. (2008) [156] found the highest percentage of rooting when using a combination of IBA + NAA at 2000 ppm in stem cuttings.
3. **Night Queen (*Cestrum nocturnum*):** Rahbin *et al*. (2012) [119] reported that stem cuttings treated with IBA at 4000 ppm showed maximum rooting percentage, number of roots, root length, fresh weight, and dry weight of the root.
4. **More Night Queen (*Cestrum nocturnum*) findings:** Singh *et al*. (2013) [145] observed that the highest number of roots per cutting occurred with NAA at 300 ppm, while rooting percentage, length of roots per cutting, fresh weight, and dry weight of roots were higher with IBA at 100 ppm. The maximum length of sprout per cutting was observed under IBA at 300 ppm.
5. **Rose cuttings:** Various reports (Nasri *et al*. 2015; Akhtar *et al*. 2015; Yeshiwas *et al*. 2015; Abbas *et al*. 2015) [77, 7, 168, 2] demonstrated that rose cuttings treated with auxins showed improvements in rooting parameters.
6. **Rose cuttings with combination growth regulators:** Haixia *et al*. (2013) [54] found the highest survival percentage of rose cuttings with a combination of NAA at 250 ppm + IBA at 250 ppm, followed by IBA at 250 ppm.
7. ***Cordyline terminalis:*** Rahdari *et al*. (2014) [120] showed that the highest root fresh weight, root dry weight, and root length were achieved with a combination of NAA at 2000 ppm + IBA at 1000 ppm in stem cuttings.
8. ***Camellia japonica:*** Wazir (2014) [160] examined the efficiency of growth regulators in different types of cuttings and found that hardwood and semi-hardwood cuttings treated with 1000 ppm IBA showed the best performance.
9. ***Ticoma stans L*:** Singh and Negi (2014) [143] treated 50 cm long cuttings with 1500 ppm IBA and noted the best results in rooting with growth parameters in the field.
10. ***Golden Duranta:*** Singh *et al*. (2014) [144] observed the highest number of roots per cutting, length of roots per cutting, diameter of root per cutting, percentage of rooted cutting, and number of sprouts per cuttings with 1400 ppm IBA concentration.
11. **17 Tuberose:** Mishra *et al*. (2005) [94] found that 4.0 mg/l BAP (6-Benzylaminopurine) and 0.2 mg/l IBA (Indole-3-butyric acid) resulted in the maximum number of shoots. Higher concentrations of BAP above 4.0 mg/l inhibited both the number and length of shoots.
12. **18 Multiple shoot induction:** Samanta *et al*. (2015) [131] used various combinations of IAA (Indole-3-acetic acid) and BA (6-Benzylaminopurine) for multiple shoot induction. They noted the best response on media containing 0.5 mg/l IAA and 3 mg/l BAP.
13. ***Gladiolus* cv. Sylvia:** Devi *et al*. (2019) achieved high-quality callus with 2.0 mg/l 2,4-D (2,4-Dichlorophenoxyacetic acid), while BAP at 2.0 mg/l exhibited higher shoot proliferating efficiency (i.e., shoots per explant).
14. **Carnation:** Maurya *et al*. (2019) [91] induced high-quality callus in carnation on media containing 0.25 mg/l BAP and 3.5 mg/l 2,4-D.
15. ***Saintpaulia ionantha:*** Lo *et al*. (1997) regenerated shoots from leaf discs of Saintpaulia ionantha on media containing 2.0 mg/l IAA and 0.08 mg/l BA.
16. **Hybrid roses:** Carelli and Echeverrigaray (2002) [27] developed a protocol for *in vitro* propagation of hybrid roses and found that media supplemented with 3.0 mg/l BA and 0.5 mg/l NAA (Naphthaleneacetic acid) showed maximum shoot proliferation.
17. **Roses with silver nitrate:** Chakrabarty *et al*. (2000) [30] reported that the addition of silver nitrate along with BA and IAA promoted the growth of axillary shoots in roses.
18. **Direct microplantlets in tuberose:** Copetta *et al*. (2020) [34] obtained direct microplantlets in tuberose on media fortified with 1.5 mg/l BA and 0.5 mg/l IAA.
19. **NAA in various plant species:** Bera *et al*. (2015) obtained swell-like structures when explants were cultured on media supplemented with 2.0 mg/l NAA.

- Kabir *et al*. (2014) [63] induced high-quality callus with 7.5 mg/l NAA, while shoots were developed on medium containing 0.5 mg/l BAP and 0.5 mg/l kinetin.
- Emek and Erdag (2007) [41] achieved more shoots per explant with the combination of low-level BA (0.2 mg/l) and high-level NAA (2 mg/l) in *Gladiolus anatolicus*. Maximum callus was induced by 8.5 mg/l NAA.
- Tyagi and Kothari (2004) [153] observed the best shoot regeneration in *Gerbera* with 4 mg/l kinetin combined with 0.5 mg/l IAA.

Rooting hormone

Every plant in nature possesses plant hormones that are located in the stem and root tips and that encourage cell proliferation and hasten root growth. Auxin is the chemical that regulates plant growth. Indole acetic acid (IAA), a weak organic acid by chemical definition, is the most prevalent auxin found naturally in all plants. Among the various auxins available, indole-3-butyric acid (IBA) is the most widely utilized for commercial rooting purposes. In fact, IBA is a preferred choice in the industry due to its effectiveness (Karimi *et al*., 2012) [64].

Tuberose

- Increasing levels of NAA (Naphthaleneacetic acid) greatly affected root length, the number of roots, and rooting percentage in tuberose (Naz *et al*. 2012) [5].
- IBA (Indole-3-butyric acid) at 2.0 mg/l was found to be the most effective for rooting in tuberose (Gajbhiye *et al*. 2011) [48].
- Some reports suggested that lower concentrations of IBA were more effective for *in vitro* rooting. For example, IBA at 0.75 mg/l was most effective in *Gladiolus* (Beura *et al*. 2005) [20], and 0.5 mg/l IBA resulted in the highest frequency of root initiation in tuberose (Upadhyay *et al*. 2001; Bindhani *et al*. 2004; Singh *et al*. 2020b) [155, 23, 142].
- Higher concentrations of IBA (1.0 mg/l) were reported to give maximum root formation and rooting efficiency (91.6%) in tuberose (Jyothi *et al*. 2008) [62], while IBA at 4.0 mg/l was found favourable for *in vitro* rooting in tuberose (Krishnan *et al*. 2003) [69].

Gerbera

- NAA at 2.0 mg/l resulted in the best rooting in *Gerbera* (Shailaja 2002 and Son *et al*. 2011) [138, 147].
- A range of NAA concentrations (0.0–4.0 mg/l) was recommended for *Gerbera* rooting (Rezende *et al*. 2008) [124].
- Feng *et al*. (2009) [46] reported that the best rooting medium for *in vitro Gerbera* involved stem segments fortified with 0.2 mg/l NAA.

Gladiolus

- In *Gladiolus*, 1.0 mg/l IBA was associated with the maximum number of roots and root length, while the thickness of roots was better with 1.0 mg/l NAA (Belanekar *et al*. 2010) [17].
- Emek and Erdag (2007) [41] observed 20% rooting with BA (0.1 mg/l) but no rooting with NAA (0.5 or 2.0 mg/l) in *Gladiolus anatolicus*.
- Increased concentrations of IAA and α-NAA resulted in maximum root formation in *Gladiolus*.

Comparison of rooting growth regulators

- Emek and Erdag (2007) [41] found that BA (0.1 mg/l) resulted in 20% rooting in *Gladiolus anatolicus*, while NAA (0.5 or 2.0 mg/l) did not induce rooting.
- Mateen (2019) [89] observed that 1.0 mg/l NAA resulted in 98% rooting, while IBA induced 96% root induction.
- In the second study by Krishnamurthy *et al*. (2001) [68] involving rose cuttings, IBA at 1500 ppm was associated with significant improvements in bud sprouting, days to sprout, number of leaves per plant, and the chlorophyll index. The study also indicated that IBA had a stronger synergistic effect on all growth parameters compared to NAA (Naphthaleneacetic Acid).

Indole acetic acid (IAA)

- IAA alone has been used for *in vitro* rooting of ornamental and foliage plants. For example, 0.5 mg/l of IAA was recommended for *in vitro* rooting in tuberose (Nazneen *et al*. 2003; Pohare *et al*. 2012, 2013) [80, 115, 116].
- Shabbir *et al*. (2012) [137] suggested that 1.5 mg/l IAA was the best concentration for rooting.

Table 1: Uses of auxin in ornamental plant

Study Reference	Plant/ plant part	Auxin Used	Effect on Rooting Parameters
Osmont *et al*. (2007) [82]	Primary Root (PR)	Auxins	Important role in PR development
Overvoorde *et al*. (2010) [106]	Lateral Root (LR)	Auxins	Important role in LR development
Benfey *et al*. (2010) [18]	Root Hair (RH)	Auxins	Important role in RH development
Saini *et al*. (2013) [128]	Various Root Aspects	Auxins	Important role in various root aspects
Gowda *et al*. (2017) [52]	Carnation Cuttings	IBA	Effective in rooting percentage and parameters
Kumar *et al*. (2014b) [143]	Carnation Cuttings	IBA	Effective in rooting percentage and parameters
Ghofrani (2013) [50]	Carnation Cuttings	IBA	Effective in rooting percentage and parameters
Singh *et al*. (2006) [145]	Various Cuttings	IBA	Initiates earlier rooting in cuttings
Sharma (2014)	Marigold	Various Auxins	Increases rooting percentage and parameters
Majumder *et al*. (2014)	Marigold	Various Auxins	Increases rooting percentage and parameters
Sharma *et al*. (2002) [138]	Acalypha	IBA and IAA	IBA (2000 ppm) found most effective
Grewal *et al*. (2005)	Various Cuttings	IBA and IAA	IBA (2000 ppm) followed by IAA (2000 ppm)
Kumar *et al*. (2014b) [143]	Carnation Cuttings	IBA	Effective in rooting percentage and parameters
Ghofrani (2013) [50]	Carnation Cuttings	IBA	Effective in rooting percentage and parameters
Singh *et al*. (2006) [145]	Various Cuttings	IBA	Initiates earlier rooting in cuttings
Bharathy *et al*. (2003) [21]	Various Cuttings	IBA	Initiates earlier rooting in cuttings
Bhatt *et al*. (2012) [22]	Marigold	Various Auxins	Increases rooting percentage and parameters

Methods of Applying Plant Growth Regulators (PGRs)
Various methods of applying Plant Growth Regulators (PGRs) in plants have been documented in the literature. These methods include

1. **Foliar Application**: This method involves spraying PGR solutions directly onto the plant's foliage.
2. **Drenching:** PGRs are applied by drenching the soil or substrate around the plant. (Matsumoto, 2006) [90]
3. **Pre-Plant Soaking:** PGRs are applied by soaking plant materials or seeds before planting the (Currey and Lopez, 2010) [35].
4. **Seed Priming**: PGRs are used in the treatment of seeds before planting to enhance germination and early growth. (Pill and Gunter, 2001) [113].
5. **Pasting**: This method involves applying PGRs in a paste form, typically to specific plant parts. (Saniewski *et al*., 2010) [133].
6. **Capillary String**: PGRs are delivered using a capillary string system, likely for controlled and precise application. (Carswell *et al*., 1996) [29].
7. **Injection**: PGRs are injected directly into the plant, often for precise dosage control. (de Vries and Dubois, 1988) [37].

Research indicates that the timing of PGR application can significantly influence the desired outcomes. Early application methods, such as pre-plant soaking and substrate drenching at planting time, have been found to be effective and efficient in achieving the desired results (Magnitsky *et al*., 2006; Ranwala *et al*., 2005) [84, 123].

There are three primary methods of applying auxins to stimulate rooting in plants

1. **Prolonged Soak Treatment**: In this method, cuttings are soaked in a solution containing low concentrations of auxins (Typically ranging from 25 to 100 ppm) for an extended period, typically around 24 hours.
2. **Quick Dip Method**: This technique involves briefly dipping the basal portion of the cuttings into a solution with higher auxin concentrations (Ranging from 1000 to 10000 ppm). The specific duration of the dip varies based on the type of cuttings, whether they are soft or hard wood.
3. **Cuttings are dipped in talc mixed with auxins**, with concentrations typically ranging from 500 to 12000 ppm, focusing on the wet basal portion of the cuttings.

In the literature, various techniques have been documented for the application of Plant Growth Regulators (PGRs) in plants. These methods encompass foliar application (As discussed by Sajjad *et al*., 2015) [129], drenching (As demonstrated by Matsumoto, 2006) [90], pre-plant sowing (As outlined in Currey and Lopez, 2010) [35], seed priming (As described by Pill and Gunter, 2001), pasting (As explored in Saniewski *et al*., 2010) [113], capillary string application (As mentioned in Carswell *et al*., 1996) [29], and injection (As detailed by de Vries and Dubois, 1988) [37]. Among these methods, the most widely adopted approaches for ornamental plants in commercial settings are foliar spraying, drenching, and pre-plant application. Research into PGR application methods has indicated that early application, such as dipping before planting and substrate drenching at planting time, can yield favourable outcomes and contribute to the efficient utilization of these chemical compounds (Ranwala *et al*., 2005) [123].

The application methods of plant growth regulators in ornamental plants

1. African violet - Method of Application: Foliar sprays (Martin-Mex *et al*., 2005) [88].
2. Allium moly - Method of Application: Pre-plant soaking/dipping
3. *Argyranthemum frutescens* - Method of Application: Pre-plant soaking/dipping (Blanchard and Runkle, 2007) [24]
4. *Bletilla striata* - Method of Application: Pre-plant soaking/dipping (Yoon *et al*., 2002) [169].
5. *Bougainvillea glabra* - Method of Application: Foliar sprays (Moneruzzaman *et al*., 2010) [72]
6. *Caladium bicolor* - Method of Application: Pre-plant soaking/dipping (Whipker *et al*., 2005) [165]
7. *Chrysanthemum morifolium*-Method of Application: Foliar spray (Sugiura, 2004) [148]
8. *Codiaeum variegatum* - Method of Application: Foliar sprays (Eid and Abou-Leila, 2006) [40]
9. *Dahlia pinnata* - Method of Application: Foliar sprays (Mahgoub *et al*., 2011) [85]
10. *Euphorbia pulcherrima* - Method of Application: Drenching (Lodeta *et al*., 2010) [83]
11. *Gladiolus grandiflorus* - Method of Application: Foliar spray
12. *Hemerocallis lilioasphodelus*- Method of Application: Foliar sprays (Amling *et al*., 2007) [9]
13. *Hibiscus coccineus* - Method of Application: Foliar spray (Warner and Erwin, 2003)
14. *Hosta* spp. - Method of Application: Foliar sprays – (Witomska *et al*., 2010) [165]
15. *Hyacinth orientalis* - Method of Application: Pre-plant soaking/dipping (Krug *et al*., 2006) [70]
16. *Hylocereus undatus* - Method of Application: Foliar spray (Khaimov and Mizrahi, 2006) [67]
17. *Iris germanica* - Method of Application: Foliar sprays
18. *Lilium longiflorum* - Method of Application: Pre-plant soaking/dipping (Christopher and Lopez, 2010) [33]
19. *Miltoniopsis vexillaria* - Method of Application: Drenching (Matsumoto, 2006) [90]
20. *Nandina domestica* - Method of Application: Foliar sprays (Keever and Morrison, 2003) [66]
21. *Phalaenopsis amabilis* - Method of Application: Foliar sprays (Blanchard and Runkle, 2007) [24]
22. *Philodendron Schott* - Method of Application: Foliar sprays (Chen *et al*., 2003) [32]
23. *Reichardia tingitana* - Method of Application: Drenching (Banon *et al*., 2003) [15]
24. *Rhododendron catawbiense* - Method of Application: Drenching (Gent, 2004) [49]
25. *Rosa damascene* - Method of Application: Foliar sprays (Abbas *et al*., 2007) [3]
26. *Salvia officinalis*- Method of Application: Foliar sprays (Carey *et al*., 2013) [28]
27. *Scaevola aemula* - Method of Application: Pre-plant soaking/dipping (Schnelle and Barrett, 2010) [135]
28. *Solidago rugosa* - Method of Application: Foliar sprays
29. *Tulipa gesneriana* - Method of Application: Pre-plant soaking/dipping (Ramzan *et al*., 2014) [121]

Conclusion

Plant growth regulators serve as valuable tools in cultivation, capable of improving the quality and market appeal of products while minimizing the need for labor-intensive tasks like pinching and pruning, as well as overall plant maintenance. However, it is crucial to use these regulators in conjunction with other essential cultural practices, with particular emphasis on proper management of fertility and irrigation. It's important to note that while plant growth regulators can be beneficial, they cannot compensate for inadequacies in overall production methods.

Plant Growth Regulators (PGRs) have proven to be valuable tools for improving flower production in diverse ornamental plants grown in field conditions. Even in small quantities, PGRs can effectively influence plant growth and alter the flowering pattern of ornamental plants, ultimately leading to increased flower yields through various physiological processes.

While the application of Plant Growth Regulators (PGRs) is promoted in modern ornamental production systems for their capacity to modify various growth traits, it's important to note that their indiscriminate use can pose environmental risks and impact consumer acceptance. This is mainly because commercially available PGR formulations often contain synthetic growth regulators.

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