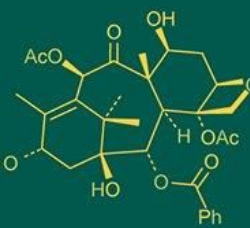
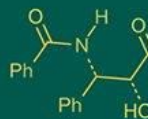


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Use of growth regulators in floriculture: Effects on flower quality and marketability

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Abstract

Growth regulators (PGRs) play a crucial role in modern floriculture by influencing flower development, quality, and marketability. These plant hormones, whether synthetic or natural, are used to manipulate various growth aspects such as size, shape, color, and vase life, allowing growers to produce high-quality flowers that meet consumer demands. The effective use of PGRs enhances flower yield and optimizes flower traits, contributing to increased marketability. However, their application must be carefully managed to avoid overuse and environmental impact. With the rise of sustainability concerns, there is growing interest in eco-friendly, natural, and biologically derived PGRs that are less harmful to the environment. Future trends indicate that advancements in smart agriculture, precision farming, and nano-technology will enable more targeted and efficient use of PGRs, further enhancing flower quality while reducing waste. Additionally, customization for specific flower varieties and the development of PGR-resistant plants are expected to improve the effectiveness of growth regulators. This article explores the current and future applications of PGRs in floriculture, examining their benefits, challenges, and potential for innovation in promoting sustainable and profitable flower production.

Keywords: Growth regulators, floriculture, flower quality, sustainability, smart agriculture

Introduction

Overview of Floriculture

Floriculture, the cultivation and management of flowering and ornamental plants, is a vital branch of horticulture with immense economic importance worldwide. The floriculture industry contributes significantly to both domestic and international markets, supplying flowers for various occasions, such as weddings, festivals, and corporate events, as well as for use in interior decoration. As global demand for high-quality, aesthetically pleasing flowers continues to rise, there is increasing pressure on growers to not only produce flowers in large quantities but also to ensure they meet the desired standards of beauty, longevity, and uniformity ^[1, 2].

With the growing competitiveness in the global flower market, maintaining consistent quality and enhancing the appeal of flowers has become crucial for success ^[2, 3]. To address these challenges, floriculturists increasingly rely on various techniques, including the use of plant growth regulators (PGRs), to optimize flower production and improve marketability. PGRs are chemical substances that influence plant growth and development, often used to modify or control specific physiological processes within plants ^[1, 3].

Role of Growth Regulators

Plant growth regulators, commonly referred to as PGRs, are essential tools in modern floriculture. These substances, although not nutrients themselves, have a profound impact on plant growth by regulating vital physiological functions, such as cell division, elongation, flowering, and senescence (aging process). By modifying these processes, PGRs can significantly enhance flower quality, improve production efficiency, and extend the shelf-life of flowers post-harvest ^[2].

There are several types of PGRs, each with a distinct mechanism of action

- **Auxins:** These are primarily involved in cell elongation and root development.

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- **Cytokinins:** Known for promoting cell division, they also influence branching and bud formation.
- **Gibberellins:** These regulators are crucial for stimulating stem elongation and flower growth.
- **Ethylene:** A gaseous hormone that regulates flower senescence and ripening.
- **Abscisic Acid (ABA):** Plays a role in stress responses and helps in controlling water loss. Each of these growth regulators can be applied in different stages of plant development to achieve specific outcomes, such as improved flower size, color, and overall plant health.

Relevance of Growth Regulators in Floriculture

The application of PGRs in floriculture has become an essential practice to meet the rising demand for high-quality flowers with consistent characteristics [2, 3]. By manipulating the natural growth processes, PGRs can help control flowering time, enhance flower size, optimize blooming patterns, and reduce the likelihood of flower damage during transport and storage [3, 4]. Furthermore, these regulators contribute to increased productivity by improving flowering efficiency and extending the harvest period.

The ability to regulate flowering cycles and enhance flower characteristics also gives floriculturists a competitive edge in the marketplace, where consumers increasingly demand flowers that not only meet aesthetic standards but also last longer and withstand the rigors of shipping. Therefore, understanding how different PGRs affect flower quality and marketability is crucial for both growers and consumers in the floriculture industry [4].

As the floriculture sector continues to evolve, the strategic use of growth regulators will remain a cornerstone of efforts to meet the growing consumer expectations and market demands for superior-quality flowers [5].

Types of Growth Regulators

In floriculture, various plant growth regulators (PGRs) are used to control and enhance the growth and development of flowers [4, 5]. These substances, often classified based on their chemical structure and effects, influence several physiological processes, such as flowering, fruiting, growth rate, and stress responses. Understanding the different types of growth regulators and their specific roles is crucial for optimizing flower quality and marketability. Below are the most commonly used PGRs in floriculture:

Auxins

Role in Floriculture: Auxins are primarily responsible for regulating cell elongation, root development, and flower initiation. They play a key role in the early stages of flower development and can be used to promote rooting in cuttings, ensuring the successful propagation of many flowering plants [2, 3].

- **Effects on Flower Development:** Auxins stimulate the growth of flowers and buds, particularly in plants that produce a large number of smaller blooms. They also regulate the formation of flower structures, influencing their overall size and shape [3, 4].
- **Application in Floriculture:** Auxins are often applied to cuttings to enhance root development, ensuring healthy growth and establishment of the plant. They can also be used to regulate flower initiation, leading to synchronized blooming, which is important for growers seeking uniformity in harvest [4, 5].

Cytokinins

Role in Floriculture: Cytokinins are a class of PGRs that promote cell division and tissue differentiation. They are essential in regulating plant growth, influencing branching, and delaying leaf senescence. Cytokinins are particularly important in increasing the overall vigor of flowering plants [6, 7].

- **Effects on Flower Development:** Cytokinins encourage the development of lateral buds, leading to increased branching and fuller, more abundant flowers. They can also enhance the growth of flower stems and improve flower size.
- **Application in Floriculture:** Cytokinins are used to stimulate the growth of side branches in plants, creating bushier plants with more blooms. They are commonly applied to crops like chrysanthemums, carnations, and orchids to improve flower density and increase yield.

Gibberellins

Role in Floriculture: Gibberellins are among the most versatile and widely used PGRs in floriculture. They promote stem elongation, flowering, and fruit set. Gibberellins are particularly effective in modifying flower size and influencing the timing of flowering.

- **Effects on Flower Development:** Gibberellins are used to increase the size of flowers and to elongate flower stems. They can also delay flowering, which is beneficial when growers want to extend the flowering season. In some cases, gibberellins can help to promote flowering in plants that have specific temperature or light requirements [7].
- **Application in Floriculture:** Gibberellins are commonly applied to plants such as roses, lilies, and tulips to enhance flower size, promote uniform blooming, and adjust flowering schedules to meet market demand. They are particularly useful for growers who need to produce large, high-quality blooms for special occasions [7].

Ethylene

Role in Floriculture: Ethylene is a gaseous plant hormone that plays a critical role in the ripening and senescence (aging) of flowers. It is responsible for regulating processes like flower opening, wilting, and fruit ripening. While ethylene is naturally produced by plants, it is also used artificially to control the timing of flowering and extend the post-harvest life of flowers [7, 8].

- **Effects on Flower Development:** Ethylene can accelerate flower senescence, causing premature wilting. However, it is also used in controlled amounts to induce flowering, particularly in plants that are sensitive to environmental cues such as light and temperature [7].
- **Application in Floriculture:** Ethylene is applied in controlled environments to synchronize flowering, especially in crops like chrysanthemums, carnations, and orchids. It is also used in post-harvest management to extend flower shelf life, delaying wilting and preserving flower appearance during transportation and retail display [8].

Abscisic Acid (ABA)

Role in Floriculture: Abscisic acid is a plant hormone that is primarily involved in plant responses to stress, including

water stress and environmental conditions like drought. In floriculture, ABA is often used to improve flower resistance to environmental stresses and enhance overall flower quality [8].

- **Effects on Flower Development:** ABA can reduce water loss in plants, making flowers more resilient to environmental stressors such as drought and extreme temperatures. It is also associated with improving flower longevity by delaying senescence and preventing premature wilting [9, 10].
- **Application in Floriculture:** ABA is increasingly used in floriculture to enhance stress tolerance in flowers, particularly for those grown in regions with erratic climates or during periods of water scarcity. It also helps improve the post-harvest quality of flowers by maintaining freshness and reducing water loss during transportation and storage [8, 9].

Other Emerging Growth Regulators

While the above PGRs are the most commonly used, ongoing research has identified other promising regulators that may further enhance floriculture practices:

- **Brassinosteroids:** A group of hormones that promote cell expansion and enhance plant resistance to stress. They are being studied for their potential to improve flower size and quality [10].
- **Salicylic Acid:** Known for its role in plant defense mechanisms, salicylic acid is being explored for its ability to enhance flower longevity and protect flowers from diseases during storage [9, 10].

Effects of Growth Regulators on Flower Quality

The quality of flowers—encompassing size, shape, color, fragrance, and longevity—directly influences their marketability and overall value [11]. The strategic use of plant growth regulators (PGRs) in floriculture can significantly improve these quality attributes, ensuring that flowers meet the aesthetic and functional demands of consumers and the market. Below, we explore the primary ways in which growth regulators impact flower quality [10, 11].

Flower Size and Shape

One of the most visible and desirable outcomes of PGR application is the ability to modify the size and shape of flowers.

- **Gibberellins:** Gibberellins are widely used to increase flower size and stimulate stem elongation, making flowers more visually striking. They are particularly effective in crops like roses (treated with GA3 at 50–150 ppm) and chrysanthemums (treated with GA3 at 100–200 ppm), where larger blooms are often more desirable in the market [8, 9].
- **Cytokinins:** Cytokinins promote cell division and can lead to increased branching, creating a fuller, bushier plant with more flowers. In crops like carnations (treated with Benzyladenine (BA) at 20–50 µM) and chrysanthemums (treated with BA at 25–50 µM), this can lead to a more uniform bloom structure with several smaller flowers on each plant, appealing to consumers looking for dense, visually pleasing bouquets [10, 11].
- **Auxins:** Auxins influence the elongation of flower stems, contributing to the overall size of the bloom. For example, Indole-3-acetic acid (IAA) at a concentration

of 10–50 ppm and Naphthalene acetic acid (NAA) at a concentration of 20–100 ppm are commonly used to stimulate stem elongation. They also regulate the formation of flower buds, with Indole-3-butyric acid (IBA) at a concentration of 50–200 ppm promoting bud initiation and petal development, ensuring that flowers develop into aesthetically pleasing shapes [11, 12].

Color Intensity

Flower color is one of the most important qualities that consumers look for when purchasing flowers. PGRs can influence the intensity and vibrancy of flower colors, making them more attractive to buyers.

- **Gibberellins:** In certain flower species, gibberellins can enhance the intensity of flower color by promoting the production of pigments. For instance, Gibberellic Acid (GA3) at a concentration of 50–150 ppm is commonly used to boost pigment production and intensify colors. When applied to roses (treated with GA3 at 50–100 ppm) or tulips (treated with GA3 at 100–200 ppm), gibberellins may lead to deeper, more vibrant hues. This is particularly beneficial in the production of flowers for floral arrangements, where color consistency and intensity are highly valued [12, 13].
- **Auxins and Cytokinins:** Both auxins and cytokinins play a role in color development by influencing the plant's metabolic pathways that produce anthocyanins and carotenoids. For anthocyanin production (responsible for red, purple, and blue colors), Auxins such as Naphthalene Acetic Acid (NAA) at 10–50 ppm and Cytokinins like Benzyladenine (BA) at 20–50 µM are commonly used to enhance pigment synthesis. For carotenoid production (responsible for yellow and orange hues), Auxins such as Indole-3-acetic acid (IAA) at 10–50 ppm and Cytokinins like Kinetin at 5–20 µM are applied to regulate pigment pathways [11, 12].

Petal Texture and Longevity

The texture and longevity of flower petals are crucial quality factors that determine how long flowers will last in the vase and how well they hold up during transport and display.

- **Cytokinins:** Cytokinins can delay leaf and petal senescence (aging), improving the texture and longevity of flowers. By inhibiting the natural process of petal wilting, Cytokinins such as Benzyladenine (BA) at a concentration of 10–50 µM are commonly used to extend freshness and vitality. This can be especially beneficial for flowers like lilies (treated with BA at 20–50 µM), where the petals often wilt quickly without proper management [12, 13].
- **Abscisic Acid (ABA):** ABA is particularly effective in reducing water loss, which is a key factor in preserving petal texture and preventing premature wilting. By increasing the water retention ability of flowers, ABA at a concentration of 10–100 µM helps maintain the firmness and crispness of flower petals, ensuring they remain visually appealing throughout their lifespan [12, 13].
- **Ethylene:** While ethylene generally accelerates flower aging and senescence, it is also used in controlled amounts to regulate flowering and delay wilting. In certain situations, Ethrel (Ethepon) at a concentration of 250–500 ppm can be applied to control the timing of flower opening, allowing flowers to be sold at the peak

of their freshness and ensuring a longer shelf life post-harvest. Additionally, the use of ethylene inhibitors like 1-Methylcyclopropene (1-MCP) at a concentration of 0.5–1 ppm can further delay senescence and preserve flower quality during storage and transit, making them more appealing and durable for consumers [12, 13].

Aroma and Fragrance

Flower fragrance is an essential aspect of flower quality that enhances their appeal. While the aroma is largely determined by genetic factors, PGRs can play a role in enhancing or modifying the scent profile of flowers [14].

- **Cytokinins and Auxins:** These hormones can affect the synthesis of volatile compounds responsible for fragrance. In some flower species, such as jasmine (treated with Cytokinins like Benzyladenine (BA) at 20–50 μ M) or rose (treated with Auxins like Naphthalene Acetic Acid (NAA) at 10–50 ppm), the application of cytokinins or auxins has been shown to increase the production of fragrant compounds, making flowers more aromatic [16, 17].
- **Gibberellins:** In some cases, gibberellins may alter the release of volatile compounds, indirectly affecting fragrance. For example, Gibberellic Acid (GA3) at a concentration of 50–150 ppm can influence volatile compound synthesis, enhancing the aromatic profile of certain flowers [17, 18].

Uniformity in Blooming

Uniformity in blooming is an essential factor in ensuring the flowers are consistent in size, color, and shape, which is highly sought after in commercial floriculture.

- **Auxins and Gibberellins:** The use of auxins and gibberellins can help synchronize flowering, ensuring that all flowers in a crop bloom at the same time. For example, Auxins such as Naphthalene Acetic Acid (NAA) at 10–50 ppm and Gibberellic Acid (GA3) at 50–200 ppm are commonly applied to regulate flowering uniformity. This is particularly useful for flowers like roses (treated with NAA at 20–50 ppm and GA3 at 50–150 ppm), where uniformity is crucial for bouquet production and sale. These growth regulators can also help in controlling the timing of flowering, making it possible to produce flowers that bloom when they are most in demand, thereby increasing marketability and profitability [15, 16].
- **Cytokinins:** By promoting the growth of lateral buds, Cytokinins such as Benzyladenine (BA) at a concentration of 20–50 μ M and Kinetin at a concentration of 5–20 μ M can improve overall plant vigor and ensure that all parts of a plant develop uniformly. This is particularly useful for florists who need consistent and uniform flowers for arrangements, enhancing the aesthetic appeal and commercial value of the final floral products [9, 11].

Impact of Growth Regulators on Flower Marketability

In the highly competitive world of floriculture, marketability plays a crucial role in determining a grower's success. The ability to produce flowers that not only meet high-quality standards but also appeal to the preferences of consumers and distributors is essential for capturing market share. The application of plant growth regulators (PGRs) can significantly influence flower marketability in several ways,

including increasing aesthetic appeal, improving post-harvest longevity, and optimizing production cycles. Below, we explore how the use of growth regulators enhances the marketability of flowers, from their appearance to their ability to endure the rigors of transport and storage [9, 10].

Enhancing Aesthetic Appeal

The first impression a flower makes—its size, shape, color, and overall appearance—greatly influences consumer purchasing decisions. PGRs play a key role in making flowers visually appealing, which directly impacts their marketability.

- **Larger, More Uniform Flowers:** Gibberellins (GA3) are effective in increasing flower size by promoting stem elongation and encouraging cell growth. Larger, more uniform blooms are more attractive to buyers, particularly for flowers like roses (treated with GA3 at 50–150 ppm), lilies (treated with GA3 at 50–100 ppm), and chrysanthemums (treated with GA3 at 100–200 ppm), where size and symmetry are highly valued in bouquets and floral arrangements [10, 11]. Uniformity in bloom size also simplifies packaging and shipping, ensuring that the flowers meet customer expectations when they reach the retail market, enhancing their market appeal and profitability.
- **Vibrant Color:** Flower color plays a crucial role in the decision-making process of consumers. PGRs, such as gibberellins, cytokinins, and auxins, have been shown to enhance flower color by influencing the production of pigments such as anthocyanins and carotenoids. For flowers like carnations (treated with Cytokinins such as Benzyladenine (BA) at 20–50 μ M), tulips (treated with Gibberellic Acid (GA3) at 100–200 ppm), and chrysanthemums (treated with Auxins such as Naphthalene Acetic Acid (NAA) at 10–50 ppm), vibrant, consistent color is essential for making a strong impression at the point of sale [12, 13].
- **Appealing Shape and Structure:** PGRs can also influence the overall shape and structure of flowers, ensuring that they meet consumer expectations for aesthetically pleasing blooms. Cytokinins, such as Benzyladenine (BA) at a concentration of 20–50 μ M, help promote branching, resulting in fuller, bushier plants with more flowers. For instance, in flowers like chrysanthemums (treated with BA at 25–50 μ M) and gerbera daisies (treated with BA at 10–30 μ M), a well-structured plant with multiple blooms is considered more attractive and valuable. Uniformity in petal arrangement and flower head shape, which is regulated by auxins (e.g., NAA at 10–50 ppm) and gibberellins (e.g., GA3 at 50–200 ppm), also enhances the flower's appeal to consumers [12, 13].

Improved Post-Harvest Longevity

Flowers' ability to retain their appearance and freshness after being cut and transported is a significant factor in their marketability. Floriculturists must ensure that their flowers maintain high visual appeal from the moment they are harvested to when they reach consumers, whether they are being sold in floral shops or through wholesale channels [12, 13].

- **Delayed Senescence:** Growth regulators, such as cytokinins, auxins, and abscisic acid (ABA), are widely used to delay senescence (aging) in flowers, thereby

extending their vase life. Flowers like lilies (treated with Cytokinins at 50–100 μM), roses (treated with Auxins such as NAA at 10–50 ppm), and tulips (treated with ABA at 10–100 μM) can benefit from this effect, remaining fresh and vibrant for a longer period. For instance, cytokinins inhibit the natural aging process, allowing flowers to stay fresh for several days or even weeks longer than untreated flowers. This extended longevity ensures that flowers look good for longer, improving their commercial value and reducing wastage during transportation and retail display [14, 15].

- **Reduced Water Loss:** ABA, which helps reduce transpiration (water loss), plays a vital role in improving post-harvest longevity. By increasing water retention in flowers, ABA at a concentration of 10–100 μM reduces wilting, particularly in cut flowers that are transported over long distances. Flowers such as orchids (treated with ABA at 20–50 μM) and carnations (treated with ABA at 30–80 μM) are highly susceptible to dehydration, but the application of ABA helps maintain their structural integrity and freshness, making them more marketable by reducing the risk of premature wilting [7, 14].
- **Ethylene Control:** Ethylene, while promoting flower aging in some plants, is also a valuable tool for controlling the timing of flowering and improving post-harvest longevity. For controlling flowering timing, Ethrel (Ethephon) at a concentration of 250–500 ppm is commonly used to induce or synchronize flowering in certain plants. To improve post-harvest longevity, Ethylene at a concentration of 0.1–1 ppm can be carefully regulated to delay senescence in specific flowers. In addition, ethylene inhibitors, such as 1-Methylcyclopropene (1-MCP) at a concentration of 0.5–1 ppm, are often used to preserve flower freshness and prevent premature wilting during storage and transit. These approaches help ensure that flowers remain in peak condition when they are sold, extending shelf life and enhancing market value [14, 15].

Synchronized and Predictable Flowering

A key factor in maximizing the marketability of flowers is the ability to produce them on demand, with a predictable and consistent bloom schedule. This is particularly important for flowers with high seasonal demand, such as those required for weddings, holidays, and other special occasions.

- **Gibberellins for Timing Control:** Gibberellins can be used to adjust the timing of flowering, allowing growers to synchronize blooms across an entire crop. For example, Gibberellic Acid (GA3) at a concentration of 50–200 ppm is commonly applied to promote uniform flowering and regulate bloom timing. By using gibberellins, growers can adjust the flowering time to coincide with market demand, such as producing blooms in time for specific holidays or events like Valentine's Day, Mother's Day, or Christmas. This synchronization enables floriculturists to plan their harvests and deliveries more effectively, maximizing profits and reducing the chances of a crop arriving too early or too late to meet consumer demand. [12, 13].
- **Auxins for Uniform Blooming:** Auxins also play a role in controlling the timing of flowering. When applied at the right stages of plant growth, auxins can

promote uniform flowering, ensuring that all flowers in a batch bloom at the same time. For example, Indole-3-acetic acid (IAA) at a concentration of 10–50 ppm, Indole-3-butyric acid (IBA) at a concentration of 20–100 ppm, and Naphthalene acetic acid (NAA) at a concentration of 10–50 ppm are commonly used to regulate flowering timing. This uniformity is crucial for florists and distributors who need consistent products to create attractive, standardized bouquets [12, 13].

Increased Yield and Efficiency

Besides improving flower quality, the use of growth regulators can help increase overall yield, which in turn boosts marketability. Higher yields, particularly in terms of flower number, flower size, and overall plant health, contribute to the profitability and competitiveness of flower growers in the market.

- **Enhanced Branching:** Cytokinins promote the growth of lateral branches, resulting in more flower buds per plant. For example, Benzyladenine (BA) at a concentration of 10–50 μM and Kinetin at a concentration of 5–20 μM are commonly used to enhance branching and bud formation. This increased branching leads to higher yields, as plants can produce more flowers, which translates to more products for sale. This is especially important for flowers like carnations (treated with BA at 20–50 μM) and chrysanthemums (treated with Kinetin at 10–30 μM), where multiple blooms per plant are desirable [14, 15].
- **Improved Rooting and Propagation:** Auxins are frequently used to improve rooting in cuttings, ensuring the successful propagation of new plants. For example, Indole-3-acetic acid (IAA) at a concentration of 20–100 ppm, Indole-3-butyric acid (IBA) at a concentration of 500–2000 ppm, and Naphthalene acetic acid (NAA) at a concentration of 50–1000 ppm are commonly applied to stimulate root development. The ability to produce high-quality, well-rooted plants faster enables growers to scale up production, leading to increased output and greater availability of flowers for sale. By enhancing the efficiency of propagation, growers can meet market demand more effectively [15, 16].

Competitive Advantage in the Market

In an industry as competitive as floriculture, growers who adopt advanced techniques like the application of PGRs can gain a significant edge over those who do not. The use of growth regulators not only boosts flower quality but also enables growers to meet specific market demands, ensuring that they stay ahead of their competitors [12, 13].

- **Meeting Consumer Preferences:** By tailoring flower characteristics—such as size, color, fragrance, and shelf-life—through PGR application, growers can cater to the specific preferences of consumers. Flowers with vibrant colors, longer vase lives, and uniform blooms are more likely to sell faster and at higher prices, increasing profitability [12].
- **Reduced Waste and Loss:** By enhancing post-harvest longevity and controlling the timing of flowering, PGRs help reduce waste. Flowers that last longer in the vase or during transport are less likely to be discarded, which ultimately increases the economic value of the flowers produced [12].

Economic Implications of Using Growth Regulators in Floriculture

The use of plant growth regulators (PGRs) in floriculture not only impacts the quality and marketability of flowers but also has significant economic implications for growers, distributors, and retailers. While the initial cost of PGRs can be a consideration, the long-term benefits in terms of higher yield, improved flower quality, reduced waste, and better market positioning often outweigh these expenses. This section explores the economic aspects of using growth regulators in floriculture, examining how they contribute to cost savings, increased profits, and overall business sustainability^[15, 16].

Cost-Benefit Analysis of PGRs

When considering the adoption of PGRs in floriculture, growers need to conduct a cost-benefit analysis to evaluate the financial impact of their use. While PGRs do come with associated costs—such as purchasing the regulators, labor for application, and any necessary equipment—the potential benefits they provide can result in significant returns on investment (ROI).

- **Increased Yield:** One of the most immediate economic benefits of using PGRs is the increase in flower yield. Cytokinins, for example, promote lateral branching, resulting in more flowers per plant. Gibberellins help to produce larger flowers and uniform blooming, which enhances the value of each individual bloom. In essence, PGRs allow growers to get more out of the same amount of land or plant material, increasing output without needing to expand production resources. This directly translates to higher revenue per unit area, making the investment in PGRs more worthwhile^[17, 18].
- **Enhanced Flower Quality:** Higher-quality flowers, with features like larger size, vibrant colors, better fragrance, and longer vase life, are more attractive to consumers and can command higher prices in the market. By producing flowers that meet or exceed industry standards for quality, growers can sell their products at a premium. For example, a well-formed, vibrant rose with a longer shelf-life may sell for 10-20% more than a comparable bloom that is smaller or more likely to wilt within a few days^[17, 18].
- **Improved Marketability and Price Stability:** By increasing flower quality and consistency, PGRs improve the marketability of flowers. Growers who can produce flowers that bloom at the right time, have uniform characteristics, and last longer post-harvest gain a competitive advantage. They can negotiate better prices, secure long-term contracts with distributors, and even enter premium markets such as high-end florists or wedding planners. Consistent product quality also helps stabilize pricing, as buyers are more willing to pay a premium for flowers that they know will meet expectations^[12, 13].

Reducing Losses and Waste

Floriculture is an industry that is highly sensitive to waste, as flowers are perishable products with a limited shelf life. Effective use of growth regulators can help reduce losses at various stages of the production and distribution process, leading to cost savings and higher profitability.

- **Reduced Post-Harvest Losses:** PGRs like cytokinins and abscisic acid (ABA) are used to extend the vase life

of flowers, reducing post-harvest losses. For example, cytokinins (at a concentration of 10–50 μM) help delay petal wilting, while ABA (at a concentration of 10–100 μM) reduces water loss from flowers, helping them stay fresh longer. This results in fewer flowers being discarded due to premature aging or wilting, improving overall profit margins. Extended freshness also reduces the need for immediate sales, giving flowers a longer window to be sold at full price^[12, 13].

- **Efficient Transportation and Storage:** Longer-lasting flowers that are treated with PGRs are less likely to wilt or deteriorate during transit or in storage. This means that growers and distributors can transport flowers over longer distances without worrying about quality degradation, opening up new markets and reducing the need for local sales or discounts due to poor appearance. Reduced spoilage during storage and transport increases the overall efficiency of the supply chain, leading to fewer losses and higher returns^[12, 13].
- **Uniform Harvesting and Reduced Labor Costs:** The application of PGRs, such as gibberellins and auxins, can help synchronize flowering, allowing for more uniform harvesting. This is especially valuable in large-scale production systems where labor costs can be significant. By ensuring that flowers bloom at the same time, growers can reduce the number of harvests required and streamline the workforce needed for flower picking, packaging, and transportation. This results in lower labor costs and increased operational efficiency^[12, 13].

Market Expansion and Profit Margins

PGRs also enable floriculturists to tap into new markets and explore higher-profit segments, such as export markets, premium flower segments, and specialized flower varieties.

- **Export Markets:** Many flowers grown for export must meet strict quality standards, including size, color consistency, and post-harvest longevity. Growth regulators allow growers to meet these international standards, expanding their reach into global markets. For instance, flowers like roses, chrysanthemums, and lilies are frequently exported to countries where they are in high demand, such as the United States and Europe. By improving the overall quality and shelf-life of flowers, PGR-treated blooms are better suited for the rigors of international shipping, making export a viable and profitable option^[16, 17].
- **Premium Segments:** Some segments of the market—such as high-end florists, wedding planners, and luxury floral designers—demand flowers with exceptional quality and unique characteristics. PGRs allow growers to produce flowers that meet these specific needs, such as larger, more vibrant blooms or flowers with unique colors or longer vase life. By catering to premium segments, growers can charge higher prices for their flowers, increasing profit margins^[18, 19].
- **Specialized Flower Varieties:** In addition to improving traditional flowers, PGRs can be used to cultivate specialized varieties with unique characteristics that may command higher prices in niche markets. For example, PGRs can be used to manipulate flowering time or shape in certain exotic flowers, creating a distinct product that can be marketed as rare or unique. This differentiation allows growers to attract a specific

customer base willing to pay a premium for these specialized flowers^[18, 19].

Sustainability and Environmental Impact

Using PGRs in floriculture also offers sustainability benefits, which are increasingly important in modern agricultural practices. PGRs can help growers use resources more efficiently, reducing environmental impact and promoting long-term sustainability^[20, 21].

- **Resource Efficiency:** By increasing flower yield, improving plant health, and reducing post-harvest losses, PGRs contribute to a more efficient use of land, water, and other resources. This is particularly important as the floriculture industry faces growing pressure to produce more flowers with fewer inputs. The ability to grow larger, more consistent crops with fewer resources helps reduce the overall environmental footprint of floriculture operations^[22, 23].
- **Reduced Chemical Use:** Some PGRs can also be used to reduce the need for chemical treatments, such as pesticides and fungicides, by improving plant resilience and health. By promoting stronger, more vigorous plants, PGRs can reduce the need for external interventions, which can lower the environmental and financial costs associated with pest and disease management^[23, 24].

Challenges and Limitations in the Use of Growth Regulators in Floriculture

While plant growth regulators (PGRs) offer significant benefits in improving flower quality, yield, and marketability, their use is not without challenges^[25]. For many floriculturists, integrating PGRs into their cultivation practices requires careful consideration of various factors, including their potential for misuse, environmental impact, and economic costs. This section delves into the challenges and limitations associated with the use of growth regulators in floriculture, helping growers understand both the risks and the strategies for overcoming these obstacles^[26, 27].

1. Risk of Overuse and Misapplication

One of the most significant challenges in the use of growth regulators is the risk of overuse or misapplication. PGRs, when not used correctly, can have unintended consequences that may compromise flower quality or damage the plants^[26, 27].

- **Excessive Application:** The improper use of PGRs, such as applying too high a dose or using them too frequently, can lead to stunted growth, deformities, or poor flower development. For instance, overuse of gibberellins can cause flowers to become excessively elongated or lead to uneven blooming, which can hurt flower appearance and reduce marketability. Likewise, excessive auxin application can lead to abnormal growth patterns, such as excessive branching or delayed flowering, which may not align with market demands^[27, 28].
- **Variety-Specific Sensitivities:** Different flower species have varying sensitivities to PGRs, making it important for growers to carefully research and tailor their applications. For example, some flowers may respond well to cytokinins and gibberellins, whereas others may require more subtle treatment or none at all. Failure to account for the specific needs of the plant variety can

result in poor growth, reduced yield, or even plant death. Therefore, growers must closely monitor their crops and adjust PGR usage based on the plant's reactions^[29, 30].

- **Skill and Expertise:** Successful use of PGRs requires skilled application, which includes knowing the optimal timing, concentration, and method of application for each type of growth regulator. Improper handling—such as uneven spraying, incorrect timing, or exposure to environmental factors like high temperatures—can result in inconsistent effects, reducing the effectiveness of PGRs. This demands expertise and careful attention to detail, which may be a challenge for less experienced growers or those new to PGR use^[30].

2. Environmental and Health Concerns

As with any agricultural input, the use of growth regulators raises environmental and health-related concerns. While PGRs can be highly beneficial in promoting flower growth and quality, improper use or overuse can lead to unintended ecological consequences and health risks for workers and consumers.

- **Chemical Residues:** Some PGRs may leave chemical residues on the flowers, which could potentially be harmful to consumers if not properly managed^[30, 31]. For instance, synthetic growth regulators that are not degraded quickly in the plant may accumulate in flower tissues, raising concerns for food safety, particularly if flowers are used in food-related or ceremonial contexts. Growers must adhere to recommended waiting periods between PGR application and harvest to minimize residue risks and ensure that flowers meet safety standards set by regulatory bodies^[31, 32].
- **Pollution of Soil and Water:** PGRs, like other chemical inputs, can leach into the soil and water systems, potentially causing environmental harm. The overuse or improper disposal of these chemicals can contaminate local ecosystems, harming beneficial insects, soil health, and water quality. For instance, certain PGRs might adversely affect non-target plants and microorganisms, disrupting the natural balance of the ecosystem^[32].
- **Impact on Worker Health:** Growers and farmworkers who handle PGRs regularly must be aware of the potential health risks associated with exposure to these chemicals. Inhalation or skin contact with certain PGRs can cause respiratory issues, skin irritation, or other health problems. Therefore, proper safety measures, including the use of protective equipment, ventilation systems, and safe application techniques, are crucial for minimizing risks to farmworkers^[31, 32].

3. High Cost of PGRs and Accessibility

While the use of growth regulators offers long-term benefits, the initial cost of purchasing PGRs can be a financial burden for small-scale or low-budget floriculture operations. High-quality PGRs, particularly those that are synthetic or imported, can be expensive, making them less accessible to growers with limited resources.

- **Financial Investment:** Although the increased yield and flower quality can offset the costs in the long term, the upfront investment in PGRs can be prohibitive for small-scale or organic growers. For instance, commercial-grade PGRs may require large-scale

purchases to be cost-effective, which could be beyond the budget of small or niche operations. This financial barrier can limit the adoption of PGRs, especially among growers who are uncertain about the efficacy of these products or who are unwilling to take financial risks.

- **Limited Availability in Certain Regions:** In some parts of the world, particularly in developing countries or regions with less advanced agricultural infrastructure, access to high-quality growth regulators may be limited [30]. This lack of availability can restrict the use of PGRs, preventing growers in these regions from benefiting from their advantages. Moreover, the high cost of shipping, import duties, and regulatory hurdles can further exacerbate the problem.
- **Regulatory Restrictions and Costs:** Many countries have strict regulations surrounding the use of growth regulators, especially synthetic ones, due to environmental and health concerns [31]. These regulations often require thorough testing and licensing procedures, which can increase costs for growers. In some cases, the use of certain PGRs may be restricted or banned altogether in specific markets or countries, limiting growers' options and complicating international trade.

4. Potential for Reduced Genetic Diversity

The widespread use of PGRs in floriculture may lead to a reduction in genetic diversity among flower crops. While PGRs can enhance the uniformity of flowers, this standardization may have unintended consequences for long-term plant resilience and biodiversity.

- **Uniformity vs. Genetic Diversity:** The use of growth regulators to achieve uniform flowering and appearance can reduce the genetic variability within a crop [30]. This is particularly true when growers focus on producing specific flower types or sizes that are commercially attractive. Over time, this reduction in genetic diversity can make crops more susceptible to pests, diseases, and environmental stresses, as the lack of genetic variation limits the plants' ability to adapt to changing conditions. In the long run, this could undermine the sustainability of floriculture practices, especially in the face of climate change or new pest outbreaks.
- **Over-Reliance on PGRs:** Excessive reliance on PGRs for controlling flower characteristics and growth patterns may also lead to a loss of traditional cultivation techniques and natural variation. This could be particularly concerning for breeders and growers who focus on developing new, resilient flower varieties [31]. As PGRs are used to standardize growth, there may be less emphasis on breeding for genetic traits such as pest resistance, drought tolerance, or adaptability to local growing conditions.

5. Limited Understanding and Research on Long-Term Effects

Despite the widespread use of PGRs in floriculture, there is still a limited understanding of their long-term effects on both plants and the environment [32, 33]. While some studies have demonstrated the efficacy of PGRs in improving flower quality and yield, more research is needed to fully comprehend their impact over extended periods and under various environmental conditions.

- **Lack of Comprehensive Studies:** Most of the research on PGRs has focused on short-term effects, such as immediate improvements in flower size, color, and vase life. However, there is a lack of comprehensive, long-term studies on the cumulative effects of PGRs on soil health, plant genetic diversity, and overall ecosystem balance. Without such research, growers may be unaware of the potential risks of prolonged or excessive use of PGRs.
- **Unpredictable Environmental Interactions:** The effect of PGRs can vary significantly based on environmental conditions such as temperature, humidity, soil type, and light availability. For example, a PGR that works well in one region or climate may have limited or undesirable effects in another. Understanding these interactions requires detailed, site-specific research, which may not always be available to growers.

Future Trends and Innovations in the Use of Growth Regulators in Floriculture

As the floriculture industry continues to evolve, the role of growth regulators (PGRs) is likely to expand, with innovations focusing on sustainability, efficiency, and enhanced flower quality [33]. This section explores the emerging trends and future possibilities in the use of PGRs, highlighting advancements in technology, research, and product development that could revolutionize how growth regulators are used in flower cultivation.

1. Development of More Targeted and Environmentally Friendly PGRs

One of the key trends in the future of PGRs in floriculture is the development of more targeted, environmentally friendly, and sustainable products. As concerns about the environmental impact of synthetic chemicals grow, researchers are focusing on creating growth regulators that are more precise in their action and have minimal negative effects on the environment.

- **Biological and Natural PGRs:** There is increasing interest in using biological and natural growth regulators as alternatives to synthetic chemicals. Plant hormones derived from natural sources, such as seaweed extracts, humic substances, and other plant-based compounds, are being explored for their potential to regulate plant growth. These natural PGRs are often seen as safer, more biodegradable, and less likely to cause harmful residues on flowers. They also tend to be less toxic to non-target organisms, making them more environmentally friendly [34].
- **Nano-Technology in PGRs:** One of the most exciting developments in the future of PGRs is the use of nanotechnology. Nano-formulations of growth regulators can offer more efficient and precise delivery systems. These formulations can enhance the absorption of PGRs by plant tissues, improving their efficacy while reducing the quantity required [31, 32]. Additionally, nano-sized particles are less likely to leach into the environment, making them a more sustainable option for growers. This could lead to more controlled and less wasteful application practices.
- **Precision Application Systems:** The integration of technology into PGR application is becoming increasingly important. Precision agriculture tools, such

as drones, automated sprayers, and sensor-based systems, are enabling more efficient and accurate application of growth regulators [32, 33]. These technologies can monitor factors like soil moisture, temperature, and plant growth stages to deliver the right amount of PGRs at the right time, reducing overuse and minimizing environmental impact. This approach allows for more tailored treatments, ensuring that PGRs are applied only when necessary and at optimal doses.

2. Integration with Smart Agriculture and Data Analytics

The future of growth regulators in floriculture is also closely tied to advancements in smart agriculture and data analytics. As the industry becomes more data-driven, the integration of PGRs with modern farming techniques will provide growers with the tools they need to optimize flower production and quality.

- **Data-Driven PGR Application:** With the help of data analytics and machine learning, growers will be able to make more informed decisions about when and how to apply growth regulators. By collecting data on plant health, environmental conditions, and growth patterns, farms can automate the application of PGRs, adjusting the treatment schedule based on real-time plant needs. This precision not only ensures better results but also reduces the likelihood of over-application or misapplication, improving efficiency and sustainability [31, 33].
- **AI and Machine Learning in PGR Optimization:** The use of artificial intelligence (AI) and machine learning algorithms can further enhance the application and formulation of PGRs. These technologies can analyze large datasets from farms to identify patterns and correlations between PGR application and flower quality or yield. AI models can recommend the most effective PGR treatments based on plant species, growing conditions, and market demands, allowing for more personalized approaches to plant growth regulation. Over time, this could lead to the creation of tailored PGR solutions for specific flower varieties and regions, optimizing results and minimizing waste [32, 33].
- **Internet of Things (IoT) for Monitoring:** The Internet of Things (IoT) enables real-time monitoring of plants and environmental conditions, providing valuable insights into the timing and dosage of PGR application. IoT sensors can track factors such as light intensity, soil moisture, and temperature, and send data to cloud-based platforms. Growers can then use this data to adjust PGR treatments dynamically, ensuring that plants receive optimal care at all stages of growth. This integration of IoT with PGR technology will result in more efficient and cost-effective flower production [33].

3. Customization and Tailored Solutions for Specific Flower Varieties

As the floriculture industry grows and diversifies, the need for customized and tailored PGR solutions will become more pronounced. Different flower species have distinct growth habits, flower shapes, and market demands, requiring growth regulators that are specifically formulated to meet these needs.

- **Species-Specific PGR Formulations:** Future research will likely lead to the development of PGRs that are

optimized for specific flower varieties [32, 33]. Different flowers may require unique growth patterns, such as increased branching in some species or larger blooms in others. By creating PGRs that are tailored to these requirements, growers can achieve better results with fewer side effects. For example, a growth regulator designed specifically for roses might focus on promoting the size and color of the bloom, while one for lilies might aim to increase stem strength and flower longevity [34].

- **Breeding PGR-Resistant Plants:** Another potential development in floriculture is the breeding of plants that are naturally resistant to the effects of growth regulators. By selecting for traits that allow flowers to thrive with less reliance on external growth regulators, breeders could reduce the need for chemical applications altogether. This would not only reduce costs but also minimize the environmental impact associated with synthetic PGRs [35].

4. Focus on Sustainable Practices and Organic Certification

As consumer demand for sustainably grown flowers rises, the floriculture industry is likely to focus on organic and environmentally responsible practices. While organic farming has historically been limited in terms of growth regulator use, there is potential for growth regulators to play a key role in sustainable flower production.

- **Organic Growth Regulators:** The increasing demand for organic and eco-friendly products is driving the search for organic alternatives to traditional synthetic PGRs. Natural products like kelp extract, humic acid, and amino acids are already being used as growth regulators in organic farming, and future innovations may lead to more widely available and effective organic PGRs. These natural alternatives can provide similar benefits to synthetic PGRs without the environmental risks, allowing floriculturists to maintain organic certification while enhancing flower quality [22, 23].
- **Sustainability through Reduced Input Use:** By developing more effective and targeted PGRs, the floriculture industry can minimize the overall use of chemical inputs, reducing the carbon footprint and ecological impact of flower production. This aligns with the broader sustainability goals of reducing chemical usage, conserving water, and promoting biodiversity. PGRs that help plants grow stronger and more resilient with fewer resources can contribute to the long-term sustainability of the industry, benefiting both growers and the environment [23, 27].

5. Consumer Trends and Market Demand for Quality Flowers

The future of growth regulators in floriculture will also be shaped by evolving consumer preferences. As consumers continue to seek high-quality, long-lasting flowers with unique characteristics, growth regulators will play an integral role in meeting these demands.

Longer Vase Life and Sustainability: Consumers are increasingly looking for flowers that not only look beautiful but also last longer. Growth regulators that enhance flower longevity will become even more popular, as they meet the growing demand for sustainable, long-lasting floral products

[23, 24]. PGRs that extend vase life, reduce water loss, and prevent wilting will be essential for growers targeting the premium and eco-conscious consumer markets.

Customized Flower Traits: As consumers become more interested in personalized and unique floral arrangements, growth regulators that allow for the manipulation of specific flower traits—such as color intensity, shape, and size—will be in high demand. Florists and retailers will seek to offer flowers that meet these customized demands, and PGRs will play a key role in delivering these specialized products [23, 28].

Ethical Sourcing and Transparency: With the increasing focus on ethical sourcing, consumers will demand greater transparency in how flowers are grown, including the use of chemicals and growth regulators. Floriculturists who adopt sustainable practices and use eco-friendly or natural growth regulators will gain a competitive edge in the market, appealing to consumers who prioritize sustainability in their purchasing decisions [34, 36].

Conclusion: The Role of Growth Regulators in the Future of Floriculture

Growth regulators have already proven to be a crucial tool in the floriculture industry, offering growers enhanced control over flower development, quality, and overall productivity. As the demand for high-quality, sustainable, and visually appealing flowers continues to rise, the use of growth regulators is expected to play an even more pivotal role in shaping the future of flower production. However, as with any agricultural practice, the use of plant growth regulators (PGRs) must be approached with caution and precision to ensure that their benefits outweigh potential drawbacks.

1. Enhancing Flower Quality and Marketability

Growth regulators are essential in improving the quality of flowers, enhancing their size, color, shape, and vase life—all crucial factors in meeting market demands. The ability to manipulate these attributes allows floriculturists to produce flowers that cater to consumer preferences, whether for special occasions, retail, or export. Through careful selection and application, growth regulators help produce flowers that not only meet aesthetic standards but also have longer shelf lives, improving their marketability.

The precision with which PGRs can be applied is becoming more refined due to advancements in agricultural technology. With the help of data analytics, smart farming tools, and precision application systems, growers are now able to apply the right amount of growth regulators at the right time, ensuring optimal flower characteristics while minimizing waste and environmental impact. As a result, PGRs will continue to be an indispensable tool for maintaining competitiveness in the global floriculture market.

2. Sustainability and Eco-Friendly Solutions

The growing emphasis on sustainability in agriculture presents both challenges and opportunities for the use of growth regulators in floriculture. As consumers demand more eco-friendly products, floriculturists are increasingly turning to natural and organic PGR alternatives to reduce their environmental footprint. Innovations in biological and

nano-based growth regulators offer promising solutions, providing growers with effective tools to enhance flower quality while maintaining a commitment to sustainability.

The future of floriculture lies in the integration of sustainability with efficiency. By adopting more environmentally responsible PGRs, reducing chemical usage, and embracing natural growth-promoting substances, floriculturists can ensure that they are contributing to the health of the planet while still producing high-quality flowers for the market.

3. Overcoming Challenges through Innovation

Despite the challenges associated with PGR usage—such as the risk of overuse, potential environmental impact, and the high cost of specialized products—ongoing research and technological advancements are paving the way for more efficient and sustainable use of growth regulators. The development of targeted, species-specific PGRs, combined with innovations like precision agriculture tools, offers new opportunities for growers to fine-tune their applications, reducing both the economic and environmental costs.

Additionally, advances in breeding techniques, such as developing PGR-resistant plants, promise to further reduce the reliance on chemical inputs, creating a more sustainable and cost-effective approach to flower cultivation. The combination of technological, scientific, and genetic breakthroughs will ultimately lead to more resilient, high-quality flowers with minimal reliance on synthetic chemicals.

4. Economic Viability and Market Trends

From an economic perspective, the use of PGRs offers significant returns in terms of yield, quality, and efficiency. While there is an initial cost associated with purchasing and applying growth regulators, the long-term benefits—such as improved flower quality, longer vase life, and higher marketability—justify the investment. Growers who embrace modern PGR technology and smart farming tools will be able to maximize their returns and maintain a competitive edge in the industry.

As market trends evolve, with a focus on customization, sustainability, and quality, growth regulators will continue to play a central role in enabling floriculturists to meet these demands. The key to success will be in adopting a balanced approach, ensuring that growth regulators are used strategically and responsibly to optimize flower production without compromising environmental health or consumer safety.

5. Looking Ahead: A Harmonized Approach

The future of floriculture will be shaped by a harmonized approach to growth regulator use, combining scientific research, technological innovation, sustainable practices, and a deep understanding of plant physiology. As the floriculture industry continues to evolve, the role of PGRs will expand, but their use will require careful consideration of local conditions, market trends, and environmental concerns.

Growers who invest in research, stay informed about the latest advancements, and adopt best practices in PGR application will be well-positioned to thrive in an increasingly competitive and sustainable marketplace. The continuous development of new, more efficient PGR formulations, along with smarter application methods, will

ensure that floriculturists can produce the highest quality flowers with minimal input, while also contributing to the preservation of the environment for future generations.

Reference

- Wani MA, Nazki IT, Din A, Iqbal S, Wani SA, Khan FU, *et al.* Floriculture sustainability initiative: The dawn of a new era. *Sustainable Agriculture Reviews*. 2018;27:91-127.
- Pal SL. Role of plant growth regulators in floriculture: An overview. *Journal of Pharmacognosy and Phytochemistry*. 2019;8(3):789-796.
- Bhardwaj R, Kumar M, Kaushal N, Kamboj AD, Krishnamoorthi A, Singh A, *et al.* From Lab to Bouquet: The biotechnological frontier in modern floriculture for sustainable and resilient flower farming. *Journal of Advances in Biology & Biotechnology*. 2024 Feb 26;27(2):119-137.
- Wani MA, Din A, Nazki IT, Rehman TU, Al-Khayri JM, Jain SM, *et al.* Navigating the future: Exploring technological advancements and emerging trends in the sustainable ornamental industry. *Frontiers in Environmental Science*. 2023 Jun 12;11:1188643.
- Paradiso R, Proietti S. Light-quality manipulation to control plant growth and photomorphogenesis in greenhouse horticulture: The state of the art and the opportunities of modern LED systems. *Journal of Plant Growth Regulation*. 2022 Feb;41(2):742-780.
- Lastochkina O, Aliniaiefard S, SeifiKalhor M, Bosacchi M, Maslennikova D, Lubyanova A. Novel approaches for sustainable horticultural crop production: Advances and prospects. *Horticulturae*. 2022 Oct 5;8(10):910.
- Sharma R, Singh S, Pant K, Mashiana HK, Dubey RK. Protected cultivation of floriculture crops: Innovative technologies and future challenges. In: *Ornamental Horticulture: Latest Cultivation Practices and Breeding Technologies*. Singapore: Springer Nature Singapore; 2024 Aug 23. p. 15-43.
- Rafique Z, Riaz H, Ahmad A, Iqbal T. Emerging trends in the floriculture industry: Adapting to market demands and consumer preferences.
- Kumar D, Malik N, Sengar RS. Emerging technologies to enrich agricultural and horticultural crop quality and production. *Annals of Horticulture*. 2019;12(1):55-61.
- Ferreira CS, Soares PR, Guilherme R, Vitali G, Boulet A, Harrison MT, Malamiri H, Duarte AC, Kalantari Z, Ferreira AJ. Sustainable water management in horticulture: Problems, premises, and promises. *Horticulturae*. 2024 Sep 6;10(9):951.
- Janbandhu MS, Mehta A, Beese S, Pandey SK, Singh B, Patel A, *et al.* Advances and emerging trends in horticultural production and management. *Journal of Experimental Agriculture International*. 2024 Feb 17;46(3):47-69.
- Kannan B, Rajasekar M, Jayalakshmi K, Thiagarajan G, Selvakumar S, Rajendran V. Protected cultivation and precision farming technologies. *TNAU, India*. 2019. p. 297.
- Tyagi PK, Arya A, Ramniwas S, Tyagi S. Recent trends in nanotechnology in precision and sustainable agriculture. *Frontiers in Plant Science*. 2023 Aug 9;14:1256319.
- Singh J, editor. *Precision farming in horticulture*. New Delhi: New India Publishing Agency; 2013.
- Bauer A, Bostrom AG, Ball J, Applegate C, Cheng T, Laycock S, *et al.* Combining computer vision and deep learning to enable ultra-scale aerial phenotyping and precision agriculture: A case study of lettuce production. *Horticulture Research*. 2019 Dec 1;6.
- Freidenreich A, Barraza G, Jayachandran K, Khoddamzadeh AA. Precision agriculture application for sustainable nitrogen management of *Justicia brandegeana* using optical sensor technology. *Agriculture*. 2019 May 4;9(5):98.
- Zaremba I, Kodors S, Apeināns I, Lācis G, Feldmane D, Rubauskis E. Digital twin: Orchard management using UAV. In: *Environment. Technologies. Resources. Proceedings of the International Scientific and Practical Conference*. 2023 Jun 13. Vol. 1. p. 247-251.
- Ndaba B, Roopnarain A, Haripriya RA, Maaza M. Biosynthesized metallic nanoparticles as fertilizers: An emerging precision agriculture strategy. *Journal of Integrative Agriculture*. 2022 May 1;21(5):1225-1242.
- Khodakovskaya MV, Kim BS, Kim JN, Alimohammadi M, Dervishi E, Mustafa T, *et al.* Carbon nanotubes as plant growth regulators: Effects on tomato growth, reproductive system, and soil microbial community. *Small*. 2013 Jan 14;9(1):115-123.
- Sashika MN, Gammanpila HW, Priyadarshani SV. Exploring the evolving landscape: Urban horticulture cropping systems—Trends and challenges. *Scientia Horticulturae*. 2024 Mar 1;327:112870.
- Kupke BM, Tucker MR, Able JA, Porker KD. Manipulation of barley development and flowering time by exogenous application of plant growth regulators. *Frontiers in Plant Science*. 2022 Jan 3;12:694424.
- Sebastian K, Arya MS, Reshma UR, Anaswara SJ, Thampi SS. Impact of plant growth regulators on fruit production. *International Journal of Current Microbiology and Applied Sciences*. 2019;8(2):800-814.
- Farjon G, Krikeb O, Hillel AB, Alchanatis V. Detection and counting of flowers on apple trees for better chemical thinning decisions. *Precision Agriculture*. 2020 Jun;21:503-521.
- Farjon G, Krikeb O, Hillel AB, Alchanatis V. Detection and counting of flowers on apple trees for better chemical thinning decisions. *Precision Agriculture*. 2020 Jun;21:503-521.
- Keating RL. Increasing harvestability of *Phacelia hastata* seed using plant growth regulators [Doctoral dissertation]. Montana: Montana State University-Bozeman, College of Agriculture.
- Ganesh S, Jawaharlal M, Rajamani K, Visalakshi M, Karthikeyan S, Ganga M, *et al.* Investigating the physiological effects of LEDs with combined spectral emittances in floriculture. *Applied Ecology & Environmental Research*. 2024 Jan 1;22(1).
- Singh R, Kaur S, Bhullar SS, Singh H, Sharma LK. Bacterial biostimulants for climate-smart agriculture practices: Mode of action, effect on plant growth and roadmap for commercial products. *Journal of Sustainable Agriculture and Environment*. 2024 Mar;3(1):e12085.
- Matsumoto TK, Lopez J. Coffee harvest management by manipulation of coffee flowering with plant growth regulators. In: *XXIX International Horticultural Congress on Horticulture: Sustaining Lives*,

- Livelihoods and Landscapes (IHC2014). 2014 Aug 17. p. 219-224.
29. Pallottino F, Antonucci F, Costa C, Bisaglia C, Figorilli S, Menesatti P. Optoelectronic proximal sensing vehicle-mounted technologies in precision agriculture: A review. *Computers and Electronics in Agriculture*. 2019 Jul 1;162:859-873.
30. Bhattacharyya P, Pathak H, Pal S. Crop management for climate-smart agriculture. In: *Climate Smart Agriculture: Concepts, Challenges, and Opportunities*. 2020. p. 85-111.
31. Ganesh S, Jawaharlal M, Rajamani K, Visalakshi M, Karthikeyan S, Ganga M, *et al.* Investigating the physiological effects of LEDs with combined spectral emittances in floriculture. *Applied Ecology & Environmental Research*. 2024 Jan 1;22(1).
32. Karimian N, Nazari F, Samadi S. Morphological and biochemical properties, leaf nutrient content, and vase life of tuberose (*Polianthes tuberosa* L.) affected by root or foliar applications of silicon (Si) and silicon nanoparticles (SiNPs). *Journal of Plant Growth Regulation*. 2021 Oct;40:2221-2235.
33. de Moura OV, Berbara RL, de Oliveira Torchia DF, Da Silva HF, de Castro TA, Tavares OC, *et al.* Humic foliar application as sustainable technology for improving the growth, yield, and abiotic stress protection of agricultural crops: A review. *Journal of the Saudi Society of Agricultural Sciences*. 2023 Dec 1;22(8):493-513.
34. Jaskani MJ, Khan IA. *Horticulture: An overview*. Faisalabad: University of Agriculture Faisalabad. 2021. p. 3-22.
35. Wolfert S, Goense D, Sørensen CA. A future internet collaboration platform for safe and healthy food from farm to fork. In: *2014 Annual SRII Global Conference*. 2014 Apr 23. p. 266-273. IEEE.
36. Campos EV, do ES Pereira A, Aleksieienko I, Do Carmo GC, Gohari G, Santaella C, *et al.* Encapsulated plant growth regulators and associative microorganisms: Nature-based solutions to mitigate the effects of climate change on plants. *Plant Science*. 2023 Jun 1;331:111688.