Review Article

A comprehensive review on Role of Bio- regulators in the growth and development of fruit and vegetable crops

Abstract

This comprehensive review focuses on the role of bio-regulators in the growth and development of fruit and vegetable crops. Bio-regulators, also known as plant growth regulators or plant hormones, play a crucial role in regulating various physiological processes in plants, including cell division, elongation, differentiation, and fruit ripening. The review explores the major types of bio-regulators commonly used in fruit and vegetable cultivation, including auxins, gibberellins, cytokinins, abscisic acid, and ethylene. It examines their functions and effects on plant growth, flowering, fruit set, fruit development, and post-harvest characteristics. The review also discusses the widespread application of bio-regulators in horticultural practices, including seed treatment, foliar application, and post-harvest treatments. It highlights the potential benefits of using bio-regulators, such as improving crop yield, enhancing fruit quality traits, delaying senescence, and reducing post-harvest losses. Moreover, the review delves into the mechanisms of action of bio-regulators at the molecular, physiological, and biochemical levels. It investigates their interactions with various plant growth processes, signaling pathways, and gene expression patterns. Furthermore, the review addresses the challenges and limitations associated with the use of bio-regulators in fruit and vegetable production, such as dosage optimization, application timing, and potential negative impacts on the environment.

Keywords: Auxins, Bio-Regulators, Cell Division, Gibberellins and Plant Hormones.

Introduction:

The regulation of physiological processes in plants is carried out by plant growth substances, also known as plant growth regulators or plant hormones [1]. These substances act as chemical messengers, and even in small amounts, they can enhance, inhibit, or modify various physiological processes in plants [2]. Fruit and vegetable crops are indispensable components of our global food supply, contributing substantially to human nutrition, dietary diversity, and economic prosperity [3]. Their cultivation, however, is often fraught with numerous challenges, including variable environmental conditions, limited arable land, and the need for increased yields to feed a growing global population[4]. To meet these challenges and enhance the productivity and quality of fruit and vegetable crops, agricultural science has been exploring innovative approaches and techniques, with a particular focus on bio-regulators. Bio-regulators, also known as plant growth regulators (PGRs) or plant hormones, are naturally occurring or synthetic substances that play a pivotal role in regulating various aspects of plant growth and development [5]. These compounds can influence processes such as cell division, elongation, differentiation, flowering, fruit set, and ripening [6]. By precisely modulating these critical biological functions, bio-regulators offer the potential to optimize crop production and quality while minimizing resource inputs. In recent years, a growing body of research has investigated the use of bio-regulators in fruit and vegetable crop production, aiming to elucidate their impact on crop physiology, yield, and post-harvest characteristics [7]. This comprehensive review seeks to provide an in-depth exploration of the role of bio-regulators in the growth and development of fruit and vegetable crops. It encompasses a broad spectrum of bio-regulators, both naturally occurring and synthetic, and delves into their mechanisms of action and practical applications in horticultural practices. Throughout this review, we will navigate through the various stages of crop growth, from seed germination and seedling development to flowering, fruit set, and ultimately, post-harvest management. We will examine the influence of bio-regulators on plant architecture, photosynthesis, nutrient uptake, and stress tolerance, all of which are essential factors in determining the overall performance and quality of fruit and vegetable crops. Additionally, we will highlight the sustainable and environmentally friendly aspects of bio-regulator usage in agriculture, aligning with the increasing demand for ecologically responsible farming practices. As we embark on this journey into the world of bio-regulators and their transformative potential in fruit and vegetable crop production, we aim to provide a comprehensive and up-to-date resource for researchers, horticulturists, and policymakers. By deepening our understanding of these bio-regulators and their applications, we can work collectively to address the global challenges of food security, sustainability, and the cultivation of healthy and nutritious crops [8].Plant growth regulatorscan have a significant impact on the growth, yield, and quality of fruit and vegetable crops [9]. In plants, growth refers to the quantitative increase in the size and dimensions of the plant body, such as an increase in stem and root length, the number of leaves, and overall biomass [10]. On the other hand, development refers to the qualitative changes that occur throughout the life cycle of a plant, including processes such as germination, leaf and flower formation, fruit production, and the shedding of leaves and fruits [11]. Both growth and development in plants are influenced by a combination of internal factors such as nutrition and hormones [12]. Nutritional factors provide the necessary raw materials for growth, including minerals, organic substances, proteins, and carbohydrates. These substances are utilized by plants to support their development. Here are some types of plant growth regulators and their roles in fruit and vegetable production:

Types of Bio- regulators (plant growth regulators)

1. Auxin
2. Gibberellins
3. Cytokinin
4. Ethylene
5. Abscisic Acid

Table 1: Key functions of Plant growth regulators (bio-regulators) in vegetable Crops

Group	**PGR**	**Key functions**	**References**
Auxins	Indole-3-acetic acid (IAA), naphthalene acetic acid (NAA), 2,4-dichlorophenoxyacetic acid (2,4-D)	Promote cell elongation, root initiation and development, apical dominance, and flower and fruit development	[13]
Gibberellins	Gibberellic acid (GA3), GA4, GA7	Promote stem elongation, seed germination, flower and fruit development, and break dormancy	[14]
Cytokinins	Kinetin, benzyladenine (BA), zeatin	Promote cell division, cell enlargement, shoot development, and break apical dominance	[15]

Ethylene	Ethene	Promotes fruit ripening, abscission of leaves and flowers, and dormancy	[16]
Abscisic acid (ABA)	Abscisic acid	Inhibits cell growth, promotes seed dormancy, and helps plants adapt to stress	[17]

1. Auxin

Auxins, which were discovered by Charles Darwin and Francis Darwin [18], are a group of plant hormones that play a crucial role in various growth and development processes. The name "auxin" comes from the Greek word meaning "to grow" [19]. One of the key roles of auxins is their inhibitory effect on the growth of lateral buds when produced in the apex bud [20]. They are known to stimulate cell elongation by loosening the cell wall, thereby promoting elongation [21]. However, their influence extends beyond cell elongation and can affect a wide range of growth and development responses in plants. The chemical isolation and characterization of auxins were performed by Kogl et al. in 1934 [22]. The major naturally occurring endogenous auxin in plants and crops is indole-3-acetic acid (IAA) [23]. Apart from IAA, plants also contain three other compounds that are structurally similar and elicit similar responses as IAA: 4-Chloroindole-3-acetic acid (CIAA), Phenylacetic acid (PAA), and Indole-3-butyric acid (IBA) [24]. Auxins are primarily synthesized in the stem tip region and young tissues of plants [25]. They predominantly move downward through the plant (basipetal movement), from the shoot tip to the root [26]. Synthetic compounds that mimic the effects of auxins include indole acids, naphthalene acids, chlorophenoxy acids, picolinic acid, and their derivatives [27].

Auxin plays a significant role in various aspects of plant growth and development. Here are some key roles of auxin:

1. Cell division and enlargement: Auxin, in combination with gibberellins (GA), promotes cambial growth in diameter by stimulating cell division and elongation [28].

2. Tissue culture: Auxins like Indole-3-butyric acid (IBA) and benzylaminopurine (BAP) are commonly used in tissue culture techniques for shoot multiplication, callus growth, and root development [29].

3. Breaking dormancy and apical dominance: Auxin inhibits the growth of lateral buds, thereby promoting apical dominance and preventing the growth of side branches. It also helps in breaking dormancy and promoting the growth of dormant buds [30].

4. Shortening internodes: Auxin applications, such as Naphthaleneacetic acid (NAA), can reduce internode length and contribute to the formation of compact and dwarf plant structures [31].

5. Rooting of cuttings: Auxins like NAA, IAA, Phenyl acetic acid (PAA), and IBA are commonly used to promote root growth and development in cuttings [32].

6. Prevention of lodging: Auxin treatments can lead to the development of woody and upright stems, helping to prevent lodging or the bending of stems due to wind or weight [33].

7. Prevention of abscission: Auxins such as NAA, IAA, and 2,4-D (2,4-dichlorophenoxyacetic acid) can delay or prevent the premature shedding of leaves, fruits, and flowers [34].

8. Parthenocarpic fruit development: Auxins, particularly IAA, can induce fruit development without fertilization, leading to the formation of seedless or parthenocarpic fruits in crops like grapes, bananas, and oranges [35].

9. Flower initiation and regulation: Auxins, such as NAA, can promote uniform flowering and fruit ripening in crops like pineapple. They can also delay flowering when applied at specific stages [36].

10. Weed eradication: The synthetic auxin 2,4-D is widely used as a selective herbicide to control broadleaf weeds in various crops and non-crop areas [37].

11. Fruit thinning: Auxin applications, often with NAA, can be used at post-bloom stages to thin the fruit set in certain crops like apples, promoting better fruit size and quality [38].

2. Gibberellins

Gibberellins are a class of plant hormones that were first recognized in 1926 by Japanese scientist Eiichi Kurosawa while studying the "foolish seedling" disease in rice [39]. Gibberellins play a crucial role in regulating plant growth and influencing various developmental processes. They are involved in stem elongation, seed germination, breaking seed and bud dormancy, promoting flowering, inducing enzyme activity, and regulating leaf and fruit senescence [40]. The active principle of gibberellins was isolated from the soilborne fungus *Gibberellafujikuroi*[41]. The concentration of gibberellins, specifically gibberellic acid 3 (GA3), is typically highest in immature seeds and can reach levels up to 18 mg/kg fresh weight in certain plant species like Phaseolus [42]. However, the concentration decreases rapidly as the seeds mature. In general, roots tend to contain higher amounts of GA3 than shoots. Gibberellins have also been found to be effective in overcoming both seed and bud dormancy [43]. Gibberellins have various roles in plant growth and development. Here are some key roles of gibberellins:

1. Shoot elongation: Gibberellins stimulate cell elongation in shoots, resulting in increased height and elongation of seedlings when treated with gibberellin sprays [44].

2. Metabolic activity enhancement: Gibberellins promote the mobilization of reserved food materials, leading to increased growth and height of plants. They also increase root activity and stimulate the production of the plant hormone kinetin in the roots, which then translocates to growing buds [45].

3. Delay senescence: Gibberellins can delay the senescence or aging of plant tissues by increasing photosynthetic activity and protein synthesis. This delay in senescence leads to a decrease in abscission or the shedding of leaves or fruits [46].

4. Cambial growth and differentiation: Gibberellins play a role in increasing cambial growth, which is the division and differentiation of cells in the cambium layer of plants. They can also induce flower and fruit set when combined with other hormones like auxins [47].

5. Dwarfing effect: In some cases, gibberellins can cause genetically dwarf plants to grow to their normal height by promoting shoot elongation [48].

6. Flowering promotion in long-day plants: Gibberellins can substitute for long day conditions and cold treatments (vernalization) in promoting flowering in certain long-day plant species [49].

7. Induction of parthenocarpy in grapes: Gibberellins are involved in several physiological events that lead to parthenocarpy in grapes, including rachis (stem) cell elongation, thinning of flowers, and enlargement of berries [50].

8. Breaking dormancy and leaf expansion: Gibberellins play a role in breaking dormancy in buds and promoting leaf expansion [51].

3. Cytokinins

Cytokinins are a group of plant hormones that were discovered in the 1950s by Skoog, C. Miller, and their colleagues [52]. They were found to promote cell division, which is known as cytokinesis [53]. The first cytokinin that was discovered is called kinetin, which is a derivative of adenine (aminopurine) and was initially identified as a product of DNA degradation [54]. Cytokinins are naturally produced in various parts of the plant, including root meristems, young leaves, fruits, seeds, and developing tissues. They are particularly abundant in germinating seeds, roots, sap streams, developing fruits, and tumor tissues. These plant hormones play a crucial role in plant growth and development. For example, cytokinins have been found to enhance seed germination, especially in darkness. They can also work in combination with other plant hormones like gibberellins to break the photo-dormancy of certain seeds, such as celery. In addition to the naturally occurring cytokinins, synthetic cytokinins have been developed for various purposes in plant research and agriculture. Some examples of synthetic cytokinins include kinetin, benzyladenine, ethoxy ethyladenine, zeatinriboside, isopentenyladenine, isopentenyladenosine, 6-benzylaminopurine, and thidiazuron.

Cytokinins play various important roles in plant biology, including:

1. Cell division, elongation, and enlargement: Cytokinins promote cell division and contribute to the growth and development of different plant tissues and organs. They stimulate the division of cells, leading to the formation of new cells and tissue growth [55].

2. Tissue culture morphogenesis: Cytokinins are widely used in plant tissue culture techniques to induce the regeneration and growth of new plant tissues and organs [56].

3. Induction of flowering and fruit development: Cytokinins are involved in the regulation of flowering and fruit development. They can influence the development and maturation of flowers and fruits by controlling cell division, growth, and hormonal balance [57].

4. Apical dominance overcoming: Apical dominance refers to the inhibition of lateral bud growth by the dominant shoot apex. Cytokinins can overcome apical dominance by promoting lateral bud growth, resulting in the branching of the plant and the growth of lateral shoots [58].

5. Breaking dormancy: Cytokinins play a role in breaking seed dormancy by promoting germination. They can enhance the germination process, particularly in seeds that require specific conditions or undergo physiological dormancy [59].

6. Delaying senescence: Cytokinins can delay the process of senescence in plants, extending their lifespan and allowing them to maintain their physiological activities for a longer period [60].

7. Improving N2 metabolism: Cytokinins are involved in nitrogen metabolism in plants. They can enhance the uptake and utilization of nitrogen, leading to improved overall nitrogen metabolism, which is essential for plant growth and development [61].

4. Ethylene

Ethylene is a gas that was discovered by Glaston and Davis in 1970. It is a hydrocarbon with the chemical formula C2H4, also known as ethane [62]. Ethylene is produced through the breakdown of methionine, which is present in all cells [63]. The production of ethylene occurs at a faster rate in rapidly growing and dividing cells, especially in the absence of light. Because of its role in triggering the ripening process, ethylene is often referred to as the "ripening hormone" [64]. Ethylene has the unique property of being a gaseous hormone that stimulates growth in plants [65]. It plays a crucial role in various physiological processes, including fruit ripening, leaf abscission (the shedding of leaves), and senescence (aging and deterioration) of plant tissues. Manipulation of fruits and vegetables can be achieved through the application of exogenous ethylene or inhibitors of ethylene production. Ethylene inhibitors are used to delay the ripening or senescence process, while exogenous ethylene is used to accelerate these processes when desired [66]. In addition to its natural production in plants, synthetic chemicals such as ethrel, ethephon, and chloroethyl phosphonic acid (CEPA) have been developed to release ethylene when applied to plants [67]. These compounds can be used in agricultural practices to induce specific effects related to growth and development.

Ethylene plays several important roles in plant physiology:

1. Breaking dormancy: Ethylene is involved in the release of dormancy in many plant species. It can trigger seed germination or bud break by promoting certain physiological changes in the plant [68].

2. Inducing fruit ripening: Ethylene is often referred to as the "ripening hormone" because it plays a crucial role in fruit ripening. Ethylene can accelerate the ripening process by promoting changes in color, texture, and flavor of fruits. Synthetic compounds like ethrel and ethephon are commonly used to induce fruit ripening in crops like bananas and mangoes [69].

3. Inducing abscission of leaves: Ethylene promotes leaf abscission, which is the natural process of shedding leaves. It signals to the plant that it is time to shed older or damaged leaves. Ethylene also promotes the senescence, or aging, of leaves and flowers [70].

4. Inducing flowering: Ethylene can also play a role in the induction of flowering in certain plants. Synthetic compounds like ethephon are applied to induce flowering in crops like pineapples [71].

5. Inhibiting elongation and lateral bud growth: Ethylene is involved in inhibiting the elongation of plant stems and the growth of lateral buds. This response can help plants adapt to environmental stresses or regulate their growth under specific conditions [72].

5. Abscisic acid (ABA)

Abscisic acid (ABA) is a plant growth regulator that plays various important roles throughout a plant's life cycle [73]. It is involved in seed development and dormancy, plant response to environmental stresses, and fruit ripening. During fruit ripening, the concentration of ABA is low in unripe fruits but increases as the fruit ripens [74]. ABA plays a significant role in regulating the rate of fruit ripening. ABA, also known as abscisin II and dormin, is a sesquiterpene plant hormone. It has been found to promote leaf abscission and dormancy, and it also has inhibitory effects on cell elongation. Due to its functions in regulating plant responses to stress, ABA is often referred to as a "stress hormone" [75].

Abscisic acid (ABA) has several roles in plants, including:

1. Inhibition of elongation: ABA helps regulate plant growth by inhibiting the elongation of cells. This can be beneficial in situations where limited growth is advantageous, such as during water scarcity or in conditions of high temperature or salinity [76].

2. Induction of dormancy: ABA plays a key role in inducing and maintaining dormancy in seeds, buds, and other plant structures. It helps plants conserve resources during unfavorable conditions and ensures proper timing for growth and development [77].

3. Delaying germination: ABA suppresses the germination of seeds and promotes seed dormancy. It acts as a signal that conditions are not yet suitable for germination, allowing seeds to wait until more favorable conditions are present for successful growth [78].

4. Inhibition of growth processes: ABA can inhibit various growth processes in plants, such as cell division and expansion. This can help plants conserve energy and resources during times of stress or unfavorable conditions [79].

5. Adaptation to environmental stresses: ABA is often referred to as a "stress hormone" because it helps plants respond and adapt to various environmental stresses. It promotes stomatal closure, reducing water loss, and helps regulate osmotic balance, enhancing plant survival under drought, salinity, or extreme temperature conditions [80].

Table 2: Role of Plant growth regulators (bio-regulators) on fruit Crops

S. No.	PGRs	Crops	Effects	References
1	NAA @100 ppm	Pineapple	Increased yield	[81]
2	NAA	"Fuji" apple	Decreased shoot growth	[82]
3	NAA @ 30 ppm	Nagpur mandarin	Increased the fruit weight, acidity, juice per cent peel and yield	[83]
4	NAA @ 20 to 60 ppm	Guava	Fruit weight, organoleptic rating, tss, ascorbic acid and total sugar content	[84]
5	NAA @ 300 ppm	Myovaze Satsuma mandarin	Increased fruit size	[85]
6	NAA @ 15 ppm	Kinnow	Increase Vitamin C contents	[86]
7	GA3 @ 25 ppm	'Nagpur' mandarin	Increased the fruit weight, volume, TSS, ascorbic acid, peel and yield.	[87]
8	GA3 @ 25ppm	Hass avocado	Increased yield and fruit size.	[88]
9	2,4-D @ 10 ppm	'Hamlin' orange	Control pre-harvest fruit drop	[89]

10	Paclobutrazol @ 1000 ppm	'Fuji' apple	Reduced the shoot growth	[90]
11	CCC @ 500 ppm	Sardar guava	Induced earliest flowering and highest flowering, fruit set, retention and yield.	[91]
12	Ethrel @ 25 or 50 ppm	Guava	Enhanced fruit set percentage, Weight, quality of fruit while, reduced number and weight of Seeds thereby increased pulp/seed ratio.	[91]
13	Ethrel @ 200 ppm	Mango cv. "Alphonso"	Increased number of flowers/panical.	[91]

Table 3: Role of Plant growth regulators (bio-regulators) on vegetable Crops

S. No.	**PGRs**	**Crops**	**Effects**	**References**
1	4-CPA, or 2,4-D@2-5 ppm or PCPA 50-100 ppm.	Tomato	Stimulation of fruit set (enhance the fruit set, and earliness).	[92]
2	MH @ 2500 ppm 15 days before harvesting.	Onion (stored)	Inhibition of sprouting: Application of MH @ 2500 ppm 15 days before harvesting prevents sprouting of onion in storage.	[93]
3	Soaking potato tuber in IAA @ 250 to 1000 ppm solution.	Potato	Prolongs tuber dormancy.	[94]
4	Soaking potato tuber with thiourea @ 1%.	Potato	Breaking tuber dormancy.	[95]

5	GA at 50 mg/l to young leaves (non- flowering varieties of potato).	Potato	Flowering (flower induction)	[94]
6	Maleic hydrazide	Okra	Delayed flowering	[96]
7	GA	Lettuce	Induce early flowering	[97]
8	IAA, NAA @ 20ppm	Okra	Enhances seed germination	[98]
9	GA3 @ 0.5 mg/l, and 2,4-D at 0.5 mg/l	Tomato	Enhances seed germination	[94]
10	Soaking of seeds in ethephon at 480 mg/l for 24 h	Muskmelon, bottle gourd, squash melon and watermelon	Improved germination	[94]
11	Ethylene chlorhydrin (1 liter/20q) followed by dipping in thiourea (1%) for 1hr and GA (1 mg/l) for 2 seconds.	Potato	Breaking rest period.	[94]
12	GA 3 (10-25ppm), IAA (100 ppm) and NAA (100ppm) at 2-4 leaf stage.	Cucurbits	Induces female flower production	[94]
13	GA 3 (1500-2000 ppm), silver nitrate (300-400 ppm) and Silver thiosulphate (300-400 ppm) sprayed at 2-4 leaf stage.	Cucurbits	Induces male flower production	[94]
14	GA 3 (10-25ppm), IAA (100 ppm) and NAA (100ppm) at 2-4 leaf stage.	Okra and pepper	Change sex expression	[94]
15	Auxin	Cucumbers and	Produced seedless fruits.	[94]

		watermelon		
16	PCPA 50-100 ppm.	Tomato and brinjal	Induced parthenocarpy	[94]
17	2,4-D at 0.25% in lanolin paste to cut end of styles or foliar sprays to freshly opened flower.	Cluster	Induced parthenocarpy	[94]
18	MH at 100 to 500 mg/l in okra, okra, peppers and tomato, GA3 in onion, 2,3-dichloro-isobutyrate (0.2 to 0.8%) in okra.	Okra, peppers and tomato	Gametocidal actions (produce male sterility)	[94]
19	GA3	Onion	Produce male sterility	[94]
20	2,3- dichloro-isobutyrate (0.2 to 0.8%)	Okra,muskm elon, okra, onion, root crops, spinach and tomato	Produce male sterility	[94]
21	GA @ 100 mg/l	Pepper	Produce male sterility	[94]
22	Ethephon	Cucurbits	Producing female lines	[94]
23	Silver thiosulphate at 400 mg/ l (foliar sprays)	Muskmelon	Inducing male flower on gynoecious lines.	[94]
24	Application of ethephon at 1000 mg/l	Fruit crops	Induced early ripening	[94]
25	Postharvest dip treatment with ethephon at 500-2000 mg/l	Tomato	induce ripening in mature green tomatoes.	[94]
26	Soaking of seed in NOA @ 25-50 mg/l, GA @ 5-20	Tomato	Enhance fruit yield	[94]

	mg/l and CIPA @ 10-20 mg/l, 2,4-D, 0.5 mg/l or thiourea @ 10^{-1} M			
27	Soaking of seedlings roots in NAA @ 0.2 mg/l and ascorbic acid @ 250 mg/l	Brinjal	Enhance higher fruit yield	[94]

Methods of Application of Plant Growth Regulators Growth

Plant growth regulators, or plant hormones, can be applied in various ways for different purposes. Some common methods of application include [99]:

1. Spraying method: Plant growth regulators can be applied as a spray using a sprayer or misting system. This method allows for uniform coverage of the plant's foliage and can be used for both leaves and flowers.

2. Injection of solution into internal tissues: In certain cases, such as treating specific plant diseases or disorders, plant growth regulators can be injected directly into the internal tissues of the plant. This method may require specialized tools and techniques.

3. Root feeding method: Plant growth regulators can be applied to the soil around the plant's roots, allowing for absorption through the roots and distribution throughout the plant. This method is commonly used for systemic effects.

4. Powder form: Some plant growth regulators are available in powder form. This allows for easy measurement and application, typically by sprinkling or dusting the powder onto the plant or soil.

5. Dipping of cuttings in solution: When propagating plants from cuttings, some plant growth regulators can be applied by dipping the cut end of the stem into a solution containing the growth regulator. This helps promote rooting and enhance the success of the propagation process.

6. Soaking in dilute aqueous solution: For certain plant parts or specific treatments, soaking them in a dilute aqueous solution of plant growth regulators can be an effective method of application. This allows for absorption and distribution of the growth regulators.

Mechanisms of action of bio-regulators

The mechanisms of action of bio-regulators for fruit and vegetable crops involve complex interactions at the molecular, physiological, and biochemical levels [100]. Although the exact mechanisms may vary depending on the specific bio-regulator and crop, some general principles can be recognized.Bio-regulators interact with specific receptors on plant cells, triggering signal transduction pathways that lead to various physiological responses. These responses include changes in gene expression, protein synthesis, enzymatic activity, and ion transport.For instance, auxins bind to receptor proteins, promoting cell elongation by inducing the synthesis of cell wall components. They also influence root development and apical dominance.Gibberellins stimulate cell division and elongation, influencing shoot and fruit growth [101]. They also break seed dormancy and promote flowering in some crops.Cytokinins regulate cell division and differentiation, influencing plant growth and development [102]. They play a role in promoting shoot initiation and growth, delaying senescence, and enhancing nutrient uptake and transport.Abscisic acid regulates various physiological processes, including seed dormancy, stomatal closure, stress responses, and senescence [103]. It also plays a role in fruit maturation and stress tolerance.Ethylene acts as a signaling molecule, regulating various developmental processes in plants, including fruit ripening, flower senescence, and leaf abscission.These bio-regulators modulate gene expression by activating or inhibiting specific transcription factors, leading to changes in the synthesis of proteins and other molecular components necessary for plant growth, development, and response to environmental cues [104].Moreover, bio-regulators can interact with each other, leading to synergistic or antagonistic effects on plant growth and development. These interactions can further modulate the activities of enzymes and genes involved in various metabolic pathways.

Conclusion:

Plant growth regulators (PGRs) play a crucial role in the growth and development of fruit and vegetable crops. They can be used to improve yields, quality, and resistance to abiotic and biotic stresses. The main PGRs used in fruit and vegetable production are auxins, gibberellins, cytokinins, abscisic acid, and ethylene. Each PGR has a unique set of effects on plant growth and development. Auxins promote cell elongation and division, and are involved in root initiation and development, shoot growth, and flower and fruit development. Gibberellins promote stem elongation, cell division, and flowering. Cytokinins promote cell division and differentiation, and delay senescence. Abscisic acid inhibits growth and promotes dormancy. Ethylene regulates fruit ripening, senescence, and abscission. PGRs can be applied to plants in a variety of ways, including foliar sprays, root drenching, and seed treatment. The application method and timing will depend on the specific PGR being used and the desired effect. The use of PGRs in fruit and vegetable production has become increasingly popular in recent years. This is due to the many benefits that PGRs offer, such as increased yields, improved quality, and reduced use of pesticides and fertilizers. However, it is important to note that PGRs are powerful chemicals and should be used carefully. Overuse of PGRs can have negative consequences, such as plant damage and reduced yields. Overall, PGRs are a valuable tool for fruit and vegetable growers. When used correctly, PGRs can help to improve yields, quality, and resistance to abiotic and biotic stresses.

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