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Exploring the Diverse Effects of Growth Hormones on Crops: A Review

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ABSTRACT: The multifaceted impact of growth hormones is on crops, aiming to enhance our understanding of their diverse effects. Employing a systematic approach, various growth hormones, including auxins, cytokinins, gibberellins, abscisic acid and ethylene were applied to different crops. The research explores the hormones' influence on plant growth, development, yield, and stress responses. Results reveal nuanced outcomes, with some hormones demonstrating stimulatory effects on shoot elongation and flowering, while others exhibit more pronounced impacts on root development and fruit maturation. By comprehensively the varied effects of growth hormones, contributes valuable insights to optimize their application in agriculture for improved crop productivity, resource efficiency, and stress resilience. The dynamic nature of environmental factors such as soil quality, temperature fluctuations, and water availability presents hurdles in isolating the specific impacts of individual hormones on crop growth. Despite the challenges, this review consolidates existing research to offer a comprehensive understanding of the intricate roles played by plant growth hormones in crop development.

Keywords: Growth hormones, Flower, Germination, Inhibitor, Auxin, Cytokinin.

INTRODUCTION

Plant growth regulators or phytohormones are organic substances produced naturally in higher plants, controlling growth or other physiological functions at a site remote from its place of production and active in minute amounts (Suman *et al.*, 2017). The crops, encompassing a wide array of fruits, vegetables, flowers, ornamental plants, cereals, oil seeds, legume and various cash crops are integral components of agriculture and contribute significantly to global food security and aesthetic landscapes. These plants have played important economic and social roles in the human lives and health by providing basic food needs, beautifying urban and rural landscapes, and improving personal esthetics (Chen *et al.*, 2019). The cultivation of these crops often involves intricate manipulation of growth and development processes to achieve desired outcomes in terms of yield, quality, and appearance. One powerful tool in the hands of producer is the strategic application of growth regulators, also known as plant hormones. The plant hormones are extremely important agent in the integration of developmental activities (Suman *et al*., 2017). Growth hormones play a pivotal role in shaping the growth patterns, physiological responses, and overall performance of crops. Plant hormones restricted to naturally occurring plant substances, there fall into five classes which is Auxin, Gibberellins, Cytokinin, ABA and ethylene (Bisht *et al*., 2018). Each has distinct functions and effects on plant development. Plant growth regulator includes synthetic compounds as well as naturally occurring hormones. The precise manipulation of these hormones allows producer to tailor the growth of crops, influencing factors such as root development, flowering, fruit set, and post-harvest characteristics. These modify or regulate physiological processes in an appreciable measure in the plant when used in small concentration (Kumari *at al*., 2018). They are readily absorbed and move rapidly through the tissues, when applied to different plant parts. The diverse effects of growth hormones are on crops, unraveling the intricate interplay between these hormones and plant physiology. From stimulating root growth and controlling plant height to influencing flowering, fruit ripening, and stress responses, growth regulators serve as invaluable tools for grower seeking to optimize crop production and meet the demands of both agricultural and ornamental sectors. Understanding the multifaceted impacts of growth hormones is essential for harnessing their potential in sustainable and efficient cultivation practices.

EFFECT OF HORMONES ON CROPS

Auxin. The existence of auxin as a mobile growth regulator was famously inferred by Charles and Frances Darwin, as described in their 1880 book, The Power of Movement in Plants (Darwin and Darwin 1880). Pioneer studies in the 19th – early 20th century leading to the discovery of auxin are introduced first. In 1928, Dutch botanist Fritz W. Went finally isolated auxin diffused out from the tip of oat coleoptiles in the gelatin block. Following Went's success, auxin, indole-3-acetic acid (IAA) was then isolated first from human urine, then from fungi, and finally from higher plants. Discovery of auxin is thus the result of the work of many botanists and organic chemists from various countries. Auxins are a class of plant hormones that play a pivotal role in the growth, development and reproduction of plants (Flasiński & Hąc-Wydro 2014). They are found in shoot and root tips and promote cell division, stem and root growth. The term Auxin is derived from the Greek word 'auxein' meaning to grow. The primary auxin in plants is indole-3-acetic acid. Although other compounds with auxin activity, such as indole-3-butyric acid, phenyl acetic acid, and 4-chloroIAA, are also present in plants (Normanly *et al*., 1995), little is known about their physiological role. The Indole-3-acetic acid and indole butyric acid are obtained from natural plant sources, whereas naphthalene acetic acid (NAA), 2, 4-dichlorophenoxyacetic acid (2, 4-D) and 2, 4, 5-trichlorophenoxy acetic acid (2, 4, 5-T) are obtained from synthetic sources. Auxins function primarily in stem elongation by promoting cell growth (Dilworth *et al*., 2017). Auxins, particularly indole-3-acetic acid (IAA) and indole-3-butyric acid (IBA) are increases the number of lateral roots in several plants (Chhun *et al*., 2004). The plant hormone auxin is well known to stimulate cell elongation via increasing wall extensibility and it participates in the regulation of cell wall properties by inducing wall loosening (Majda & Robert 2018). The two phytohormones auxin and cytokinin are shown to play important roles in the induction of cell division and control of cell-cycle progression (Perrot-Rechenmann, 2010). The xylem conducts water and minerals from the root to the shoot and provides mechanical strength to the plant body. The auxin directed the formation of procambium and xylem in plants (Yoshimoto *et al*., 2016). A plant's roots system determines both the capacity of a sessile organism to acquire nutrients and water, as well as providing a means to monitor the soil for a range of environmental conditions. Auxin generated in shoots and roots drives root development (Overvoorde *et al*., 2010). Auxins are involved in the growth of pre-existing roots, lateral root initiation or root branching, and adventitious root formation. But, if the source of the auxin is removed by cutting the shoot tip, the roots will be less stimulated and the growth of shoots will be supported. Auxin mediates the tropistic response of bending in response to gravity and light. The plant shoot architecture often depends on the number of lateral branches or tillers developed and their position along the primary axis of the plant. A branch develops from a bud derived from a group of meristematic cells in the axil of a leaf. In some species, bud outgrowth is inhibited by signals from the apex of the main shoot, a phenomenon known as apical dominance. Soon after the discovery that the apical signal that inhibits axillary bud outgrowth is the plant hormone auxin (Kebrom, 2017). Auxin delays leaf senescence in plants. Auxin can inhibit or promote (via ethylene stimulation) leaf and fruit abscission. Tiwari *et al*. (2017) reported that during fruit growth auxin stimulates cell expansion and GA3 enhances cell division. This, together with the observation that auxin-induced fruits in general are bigger than GA3-induced fruits, suggests that cell expansion is an important determinant of the final fruit size in *C. annuum*. High auxin concentration is increases the synthesis of ethylene and hence helps to promote femaleness in dioecious plants. The effects of auxins on crops are diverse and significant. From promoting root development to influencing flowering, fruiting, and stress responses, auxins play a central role in shaping the growth and productivity of a wide range of crops.

Cytokinin. Cytokinins, a class of plant hormones, play a pivotal role in the growth and development of crops. Cytokinins were discovered by F Skoog, C Miller, and co-workers during the 1950s as factors that promote cell division (Schmülling, 2013). The first common natural cytokinin identified was purified from immature maize kernels and named 'zeatin'. Cytokinins are present in all plant tissues. They are abundant in the root tip, shoot apex, and immature seeds. Cytokinins can act over long distances or in the direct vicinity of the cytokinin-producing cells (paracrine signaling). Cytokinins may act also on the cell that produced them (autocrine signaling). Cytokinins are well-known for their role in promoting cell division (Jameson, 2017) and differentiation. In crops, this effect is crucial during the early stages of plant growth. By stimulating the division of cells in meristematic tissues, cytokinins contribute to the formation of new tissues, leading to increased biomass and overall plant productivity. Cytokinins play a vital role in promoting shoot development and leaf expansion. They encourage the growth of lateral buds, resulting in the formation of more branches and an overall bushier plant architecture. Endogenous CKs can be transported acropetally (towards the shoot apex) in the xylem sap, enter axillary buds and promote their outgrowth. Thus, CKs antagonize auxin in apical dominance (Müller & Leyser 2011)). This characteristic is valuable in crops, as it can lead to increased foliage, improved light interception, and enhanced photosynthetic activity, all of which contribute to higher yields. One of the notable effects of cytokinins is their ability to delay senescence (Wingler *et al.*, 1998). Cytokinin retard the senescence of leaves and promote the light-independent deetiolation response, including greening, of dark-grown seedlings (Srivastava, 2002). Cytokinins are influence chloroplast development and function. It accelerates the light-dependent transformation of etioplasts to fully functional chloroplasts and stimulates chlorophyll formation (Cortleven *et al*., 2016). This impact on photosynthetic machinery is vital for the efficient conversion of light energy into chemical energy, contributing to improved plant growth and productivity. Under high light stress condition it protects the chloroplast (Cortleven and Schmülling 2015). Cytokinins play a role in enhancing a plant's ability to tolerate various environmental stresses. Cytokinin is required for the defence against high light stress and to protect plants from a novel type of abiotic stress caused by an altered photoperiod (Cortleven *et al*., 2019). Seed Germination: cytokinin has been proposed to promote seed germination and postgerminative growth, possibly by antagonizing the ABA-mediated inhibitory effect (Guan *et al*., 2014). They promote the mobilization of reserves in seeds and contribute to the growth of seedlings. Cytokinins play a role in fruit ripening and synchronous fruit development (McAtee *et al*., 2013). The effects of cytokinins on crops are diverse and multifaceted. From promoting cell division and shoot development to delaying senescence and improving stress tolerance, cytokinins play a crucial role in shaping the growth, yield, and quality of a wide range of horticultural produce.

- High auxin : cytokinin = root production
- Intermediate auxin : cytokinin = callus growth
- Low auxin : high cytokinin = shoot production

Gibberellins. Gibberellins (GAs) are a class of plant hormones that play a fundamental role in the growth and development of crops. It is a group of plant hormones that occur in seeds, young leaves, and roots. The discovery of gibberellins (GA) is created to Ewiti Kurosawa who found that a fungus was responsible for abnormal rice seedling growth, called the “foolish seedling” disease. The fungus secreted a chemical that caused the rice plant to grow abnormally long and then collapse from weakness. The fungus was Gibberella fujikuroi (Hedden & Sponsel 2015), hence the hormone named as Gibberellin. Many seeds contain a variety of different gibberellins. It is belong to phylum Ascomycota that causes excessive growth and poor yield in rice plants (Encyclopedia Britannica, 2013). Over 100 different GA’s (organic acids synthesized from mevalonic acid) are known. GA’s are produced in roots and younger leaves. Most effects of GA are shown only in concert with Auxins. These hormones are involved in various physiological processes, influencing plant height, flowering, fruit development, and seed germination. Gibberellins promote growth in different ways. These hormones are mainly involved in controlling and promoting stem elongation, flowering, and leaf expansion as well as seed germination (Dilworth *et al*., 2017). They are involved in the transition from the vegetative to the reproductive phase of plant development. Gibberellins (GAs) are a second group of phytohormones that plays a prominent role in coordinating fruit growth and seed development (Pandolfini, 2009). In certain horticultural crops, such as seedless grapes, the application of gibberellins can stimulate fruit development without the formation of seeds (Cheng *et al*., 2013). This is desirable in seedless varieties where the focus is on producing larger, seedless fruits. Gibberellins are essential for breaking seed dormancy and promoting germination (Gupta & Chakrabarty 2013). They stimulate the synthesis of enzymes that break down stored nutrients in the seed, providing the energy and nutrients needed for germination. Gibberellins can enhance the setting of flowers and fruits by promoting pollen tube growth and fertilization. In perennial horticultural crops such as fruit trees, gibberellins play a role in breaking bud dormancy during the spring. The GA3 is a highly effective bud dormancy-breaking agent for blackberry (Lin & Agehara 2020). It induces maleness in dioecious flowers (sex expression). Gibberellins can contribute to the enlargement of fruits by stimulating cell division and elongation. Gibberellins play a role in enhancing nutrient transport within plants. They promote the mobilization of nutrients from source tissues (such as leaves) to sink tissues (such as developing fruits). The findings revealed that GAs influenced N uptake involved in the transcriptional regulation of NRTs and physiological responses in maize responding to nitrogen supply (Wang *et al*., 2020). The effects of gibberellins on crops are diverse and impact various aspects of plant growth and development. From stem elongation and flowering induction to fruit development and seed germination, gibberellins play a central role in shaping the architecture, yield, and quality of a wide range of horticultural produce.

Abscisic Acid. Abscisic Acid (ABA) is a plant hormone that plays a crucial role in regulating various physiological processes, particularly in response to environmental stress. In 1963, abscisic acid was first identified and characterized as a plant hormone by Frederick T. Addicott and Larry A. Davis. It is a 15-C weak acid that was first identified in the early 1960s as a growth inhibitor accumulating in abscising cotton fruit (“abscisin II”) and leaves of sycamore trees photoperiodically induced to become dormant “dormin” (Finkelstein, 2013). The hormone was first isolated by Addicott (1963) from Cotton bolls. It is produced in many parts of the plants but more abundantly inside the chloroplasts of green cells. The hormone is formed from mevalonic acid or xanthophyll. It is transported to all parts of the plant through diffusion as well as transport channels (phloem and xylem). Its effects on crops are diverse, influencing aspects of growth, development, and stress responses. Plants perceive and respond adaptively to abiotic stress imposed by salt, cold, drought and wounding and the adaptive process is controlled mainly by the phytohormone, abscisic acid

(ABA), which acts as an endogenous messenger in the regulation of the plant's water status (Tuteja, 2007). ABA triggers various adaptive mechanisms, including stomatal closure to reduce water loss, synthesis of protective proteins, and adjustments in metabolic processes, enhancing the plant's overall stress tolerance. ABA plays a critical role in regulating seed dormancy and germination (Del Carmen *et al*., 2009). It is responsible for maintaining dormancy in seeds, preventing premature germination under unfavorable conditions. ABA acts through a gene expression network involving the transcription factor ABSCISIC ACID INSENSITIVE 3 (ABI3) (Liu *et al*., 2013). When conditions become favorable for germination, ABA levels decrease, allowing the initiation of germination processes. This control over seed dormancy is essential for proper timing of seedling emergence in horticultural crops. ABA regulates stomatal closure, influencing by reducing water loss and gas exchange in plants (Bharath *et al*., 2021). During periods of water stress, ABA accumulates, leading to stomatal closure to minimize water loss through transpiration. This is particularly important for crops, as it helps conserve water and maintain plant hydration under challenging environmental conditions. ABA is associated with the promotion of leaf senescence, contributing to the orderly degradation of older leaves (Asad *et al*., 2019). This process reallocates nutrients from senescing leaves to actively growing tissues, optimizing resource use efficiency in crops. However, excessive ABA levels can lead to premature senescence, affecting crop yield and quality. ABA is involved in the regulation of fruit ripening and abscission. In some horticultural crops, ABA levels increase during the ripening process, influencing the synthesis of enzymes responsible for fruit softening and flavor development. It is clear that ABA regulates ethylene biosynthesis and signaling during fruit ripening, but the molecular mechanism controlling the interaction between ABA and ethylene has not yet been discovered (Gupta *et al*., 2022). In root crops such as potatoes, ABA is associated with tuber dormancy. Adequate levels of ABA maintain dormancy in tubers, preventing premature sprouting. Proper control of ABA levels is crucial for managing the storage and post-harvest quality of root crops in horticulture. ABA interacts with other plant hormones, such as gibberellins and auxins, to regulate overall plant growth and development. ABA can inhibit root growth, especially under conditions of water stress. Mild soil drying stimulates root growth but inhibits root growth when it becomes more severe (Li *et al*., 2017). Similarly, ABA acts as an inhibitor of plant growth under water deficit. This response helps plants allocate resources to above-ground tissues during periods of limited water availability. Abscisic Acid exerts a wide range of effects on horticultural crops, impacting responses to stress, seed germination, stomatal regulation, leaf senescence, fruit development, and overall plant growth.

Ethylene. Ethylene (C_2H_4) is a simple gaseous hydrocarbon that has profound effects upon plant growth and development (Schaller & Kieber 2002). Dimitry Neljubov identified ethylene as the "active" component in illuminating gas and published his results in 1901. In the 1930s, plants were demonstrated to produce ethylene themselves, thereby establishing ethylene as an endogenous regulator of plant growth and development (Schaller & Kieber 2002). One of the most well-known effects of ethylene is its role in fruit ripening. Ethylene acts as a ripening agent, triggering the conversion of starches to sugars, softening of fruit tissues, and the development of characteristic flavors and aromas. Climacteric fruits display a burst in respiration and biosynthesis of the gaseous hormone ethylene at the onset of ripening, in contrast with non-climacteric fruits which have no significant change in respiration and ethylene production during the transition from unripe to ripe (Gao *et al*., 2020). For climacteric fruits, such as apples, kiwifruits, and tomatoes, the plant hormone ethylene is known to play an essential role in controlling most aspects of fruit ripening (Lin *et al*., 2009; Liu *et al*., 2015). Ethylene influences the senescence of leaves, flowers and fruit (Iqbal *et al*., 2017) leading to the shedding of petals and overall flower decay. The hormone promotes the expression of genes associated with the breakdown of cellular structures in petals. The pollination-induced ethylene in carnation is translocated from stigma to the petals via the style and ovary, where it upregulates ethylene biosynthetic genes and induces the production of ethylene (Tripathi & Tuteja, 2007). Once the process is initiated the evolution of ethylene becomes autocatalytic and accelerates the senescence process. Ethylene is involved in the abscission or shedding of leaves. This process is important for the efficient allocation of resources within the plant. Ethylene can influence seed germination, either promoting or inhibiting the process depending on the concentration and timing of exposure. Ethylene can stimulate seed germination and overcome dormancy in many species (Nascimento, 2003). Wang *et al*. (2020) reported that Ethylene treatment can recover the germination rate of alfalfa seeds under salt stress. Proper management of ethylene levels is crucial for controlling tuber sprouting during storage and post-harvest handling. Ethylene, a chemically neutral and more eco-friendly chemical, acts as a growth regulator (Foukaraki *et al*., 2016; Dako *et al*., 2021) to control the ripening of tubers and inhibits the deterioration of plant tissue. Ethylene is an endogenous, gaseous plant hormone that is involved not only in a variety of physiological and developmental processes, from regulating organ growth to inducing fruit ripening, but also in multiple stress responses (Chen *et al*., 2021). It acts as a stress hormone, responding to various environmental stresses such as drought, flooding, and pathogen attack (Chen *et al*., 2021). Desikan *et al*. (2006) reported that in wild-type leaves, ethylene induces stomatal closure that is dependent on H_2O_2 production in guard cells, generated by the nicotinamide adenine dinucleotide phosphate hydrogen (NADPH) oxidase AtrbohF. Ethylene-induced closure is inhibited by the ethylene antagonists 1-MCP and silver. Fruit Abscission: Ethylene is involved in the abscission of fruits, leading to the shedding of mature fruits from the plant. Ethylene was first identified as the primary abscission inductive factor (Botton & Ruperti 2019). It is considered to be an important phytohormone in regulating fruit abscission (Hu *et al*., 2021). This process is crucial for regulating fruit load and ensuring optimal resource allocation. Ethylene-induced fruit abscission is particularly important in crops where thinning is necessary to promote the development of larger, high-quality fruits. Ethylene is regarded as a multifunctional phytohormone that regulates both growth, and senescence. It promotes or inhibits growth and senescence processes depending on its concentration, timing of application, and the plant species (Iqbal *et al*., 2017). Ethylene has multifaceted effects on crops, influencing processes such as fruit ripening, flower senescence, leaf abscission, seed germination, tuber sprouting, stress responses, fruit abscission, and senescence regulation.

CONCLUSIONS

The diverse effects of growth hormones on crops underscore the intricate relationship between plant physiology and external stimuli. The extensive research highlighted in this exploration demonstrates that growth hormones can serve as powerful tools for manipulating plant growth, development, and yield. From enhancing flowering and fruiting to regulating height and branching, these compounds offer valuable solutions for grower aiming to optimize crop production.

FUTURE SCOPE

The future scope of exploring growth hormones' diverse effects on crops lies in advancing precision agriculture through tailored hormonal applications. Research may focus on optimizing hormone combinations for specific crops, enhancing stress tolerance, and increasing yield without compromising quality. Integrating biotechnological tools like CRISPR to modulate hormone pathways could lead to resilient, climate-adaptive crops. Furthermore, understanding hormonal interactions with environmental factors could pave the way for sustainable agricultural practices, reducing resource usage while boosting productivity. This comprehensive exploration may revolutionize farming techniques, ensuring food security amidst evolving climatic challenges and global population growth.

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