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Utility of plant growth regulators in improving fruit production

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Abstract
A phytohormone is an organic compound produced spontaneously in plants that regulates development and other functions at a location far from its source in very small amounts. Auxins, gibberellins, cytokinins, and ethylene, are all examples of plant growth regulators. It is a typical occurrence for fruits to be produced that are of inferior quality. Therefore, it would be beneficial to apply plant growth regulators on fruit crops to increase output and quality. For the majority of cultivated plants, and particularly for fruit plants, the use of growth regulators has become a crucial part of agro-technical procedures. They can currently be used exogenously to reduce severe fruit drops in fruit crops. Auxin and gibberellins are frequently used to reduce fruit drop and enhance fruit quality. Several agents are in charge of removing certain fruits from the ontogenic progression from fruit set to fruit ripening and ultimate reach to the customer. In this review, we concentrate on the function of plant growth regulators in the fruit development.

Keywords: Phytohormone, auxin, cytokinin, fruit development

Introduction
Plant growth regulators, also known as phytohormones, are chemical compounds made naturally in higher plants that regulate growth or other physiological activities at a location far from the plant's source and are only minutely active. Since these hormones are produced by plants, they are known as phytohormones. Auxins, gibberellins, cytokinins, ethylene, and growth inhibitors are all examples of plant growth regulators (Pal *et al.*, 2019) [1]. In order to boost the yield and quality of different fruits, a lot of study has been done in the nation over the past 50 years on a variety of topics, including varieties, propagating plants, water supply, training, and harvesting. It is a typical occurrence for fruits to be produced that are of inferior quality. Therefore, it would be beneficial to apply plant growth regulators to the leaves of fruit crops to increase output and quality. In order to increase the production of high-quality fruits, the use of plant growth regulators has become a crucial component of modern crop husbandry. When utilized in modest concentrations, organic chemical substances known as plant hormones or regulators can significantly alter or control physiological processes in plants [Figure 1]. When applied to various plant parts, they are quickly absorbed and pass through tissues. These substances work in a certain way. In other words, plant growth regulators are organic compounds (apart from nutrients) that, in minute quantities, influence any physiological activity in plants. In terms of growth, yield, and quality, various fruit crops have achieved some excellent results as a result of the usage of regulators for plant growth. The physiological effects that are presently controlled or impacted by PBRs include the promotion of branching, a rise in flower bud development, thinning by encouraging fruit/flower abscission, prevention of pre-harvest drop, improvement of fruit shape, and regulation of vegetative development. Fruit trees are regarded as high-value commodities, and even little adjustments to production methods, product quality, or cosmetic appeal (Kumari *et al.*, 2018).
Utilizing PBRs is a novel aspect of biotechnology and a fresh method of controlling plant biological functions to improve growth, yield, quality, and nutritional value as well as to lessen biotic and abiotic stress in plants. PBRs, such as jasmonic acid, methyl jasmonate (MJ), and other derivatives, together known as jasmonate (JA's), are pervasive signalling molecules that mediate plant reactions towards climatic stress, such as injury, insect and disease attack. Despite the fact that bio-regulators are frequently employed to enhance plant growth, development, pathogen defence, and production, the molecular mechanisms behind these benefits are still not completely understood.

There is several class of plant growth regulators such as Auxins (IAA, NAA, IBA, 2-4D, 4- CPA), Gibberellins (GA3 Cytokinins: Kinetin, Zeatin Ethylene: Ethereal), Abscissic acid (Dormins, Phaseic Acid Phenolic substances: Coumarin), Flowering hormones (Florigin, Anthesin, Vernalin), Growth inhibitors (AMO-1618, Phosphon-D, Cycosel, B-999).

Types and Functions

Auxin

NAA, an artificial auxin plant hormone, is frequently used to propagate plants vegetatively from stems and cuttings. The time of entrance and concentration have a significant impact on NAA's impact on plant growth. In plants, NAA has been found to significantly boost the production of cellulose fibre (Suman *et al.*, 2017) [3]. Spraying NAA in various fruit crops at various concentrations prevents fruit drop in the majority of fruit trees. It is used following fertilization of the blossoms.

Auxin I, which includes indole butyric acid (IBA) and naphthalene acetic acid (NAA), has an impact on banana *in vitro* propagation. They claimed that a greater root induction rate was attained when IBA and NAA were combined (1:1), leading to the expansion of the call, root initiation, and partial success in the *in vitro* propagation of the banana (Inoti 2016) [4].

Banana shoots grown *in vitro* on Murashige and Skoog media supplemented with 2 M 1- naphthylacetic acid (NAA) rooted more quickly and possessed greater adventitious roots than shoots grown on medium devoid of NAA. The adventitious roots that developed on the medium devoid of NAA, however, exhibited increased transverse branching. The significance of auxin in parthenocarpy banana maturation based on exogenous utilization of NAA.

Auxin, or indole-3-acitic acid (IAA), slows down the initial ripening process and causes the fruit to ripen later. Additionally, they note that the GH3 gene encodes the IAA synthase, which converts IAA to amino acids and, in turn, has a favourable link with the application of ABA and sucrose to the formation of ethylene, which results in the ripening process. After applying benzothiazole-2-oxyacetic acid (BTOA), an auxin-like chemical that delays ripening, to grape berries for two weeks, researchers came to the conclusion that BTOA increases the level of abscisic acid (ABA), which affects the ripening process (He, *et al.*, 2020) [5].

Gibberellins

Gibberellins regulate fruit development in a variety of ways and at various stages. Growing fruits is a difficult and well-controlled process. Hormones may modulate the process since growing fruits have very active metabolisms and serve as potent nutritional sinks. Pre-pollination, the pollination process, fertilization, fruit set, post-fruit set, maturation, and senescence are the phases that make up a fruit's development (Cronjé RJ, *et al.*, 2019) [6]. After the ovule has been successfully fertilized, the fruit grows as a result of the division of cells and expansion. Gibberellins are known to have an impact on how cells divide and grow.

The most frequently used is stratification in damp sand at 4-7 °C for three months to break the dormancy of apple (*Malus domestica* B.) seedlings. Better results are obtained and the need for chilling is decreased when seed stratification and GA treatment of seeds are combined. Apple seeds were exposed to GA3 (500 ppm) for 40 hours, which increased germination percentage, seedling growth, and sapling survival. GA has also been shown to be extremely effective in promoting seed germination when combined with additional development hormones. Breaking seed dormancy and applying a mixture of gibberellic acid (GA3), salicylic acid (SA), jasmonic acid, and 6-benzyl amino purine (BAP) while seed stratification promotes seed germination and seedling growth, boosts chlorophyll content, and maximize PSII efficiency.

The precise impact of gibberellins on the induction of flowers and segmentation in citrus is disputed (Fahad, *et al.*, 2015) [7]. Environmental factors were reported to be the real causes of flower induction during the anticipated flower induction and differentiation period. On the other hand, several experiments revealed that GA3 and the GA4+7 mixture actually prevent rather than induce citrus flowering. Early autumn and late summer are when GA3's inhibitory effects are significantly highest, while January is when blossom inhibition is at its highest. Studies show that applying GA before flowering also prevents citrus flowers from being induced.

The development of more focused research and breeding programs, however, has been made possible by the identification of important genes implicated in the responses to GA as a result of recent study. As was previously mentioned, careful planning is essential because changing GA content or signalling routes can have an impact on a number of qualities. The topic of whether knowledge can be transferred between species is raised by the large differences between trees and crops in various GA-related developmental processes, such as adventitious roots or flowering. Relevantly, GA appears to incorporate particular cues, such as light quality or plant age, into its reactions, which could explain those discrepancies. Another important problem is that GA cooperates with other phytohormones in specialized responses like stress and flower development (Castro-Camba R, *et al.*, 2022) [8].

Cytokinins

In plants, the cytokinins play a role in amino acid transportation, senescence of cells, cell growth, and differentiation of cells. Applying CPPU 10 ppm and BA 30 ppm enhances pear fruit size. The application of CPPU and BA had a substantial impact on both the weight and size of the fruit of the pear varieties Spadona and Coscia. the effects of various cytokinin concentrations on pear explants and discovered that applying BA @11 m, followed by BA @4.4 m, resulted in the maximum shoot multiplication (Aremu AO *et al.*, 2020). Similarly, 10 ppm BA treatment increased the amount of leaf chlorophyll in pears' leaves, delaying the onset of leaf senescence. BA has a favourable effect on the growth of shoots in prunus species explant. BA significantly affects the rootstock GF-677. According to Nowak *et al.* (2002), media containing TDZ or BAP resulted in an increase in the number of adventitious buds and the number of buds per explant. Application of CPPU 10 ppm, according to Mango, encourages the highest fruit retention, number of fruits per cluster, fruit weight, and leaf area. The highest level of kinetin encourages the growth of plants with the largest stem diameters, the most branches per plant, and the most leaves per plant. Additionally, it lessens the chance of vegetative malformation. BA application encourages maximal fruit drop on pomegranate var. mirdula, while in few studies foliar application of CPPU 5ppm in the month of April increases fruit size and juice quantity in pomegranates.

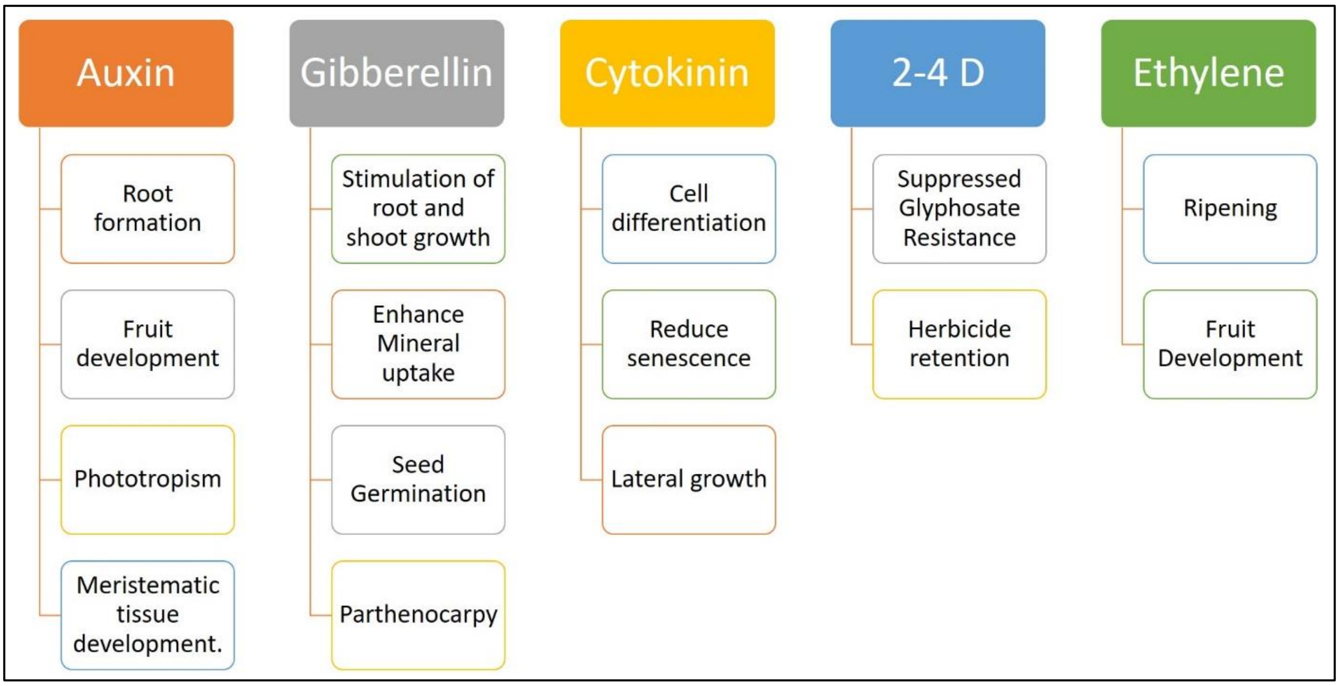

Fig 1: Role of Plant Growth Hormones on Fruit Production

2, 4-D

The absorption of vitamins and minerals to the growing organs and the lifetime of a bud are both influenced by endogenous hormones and their balance. Exogenous administration of 2,4-D or NAA has demonstrated that abscission is dependent on the endogenous auxin content since auxin transport by plants lasts for a long time without appearing to be impacted by ethylene.

The decrease of fruit drops in the pummelo cv. is influenced by 2, 4-D and naphthalene acetic acid (NAA). To set up the experiment, five pummelo trees of comparable age and size were chosen. Each pummelo tree had ten mature branches of the same size that were randomly chosen throughout the canopy to receive 2, 4-D (20 and 40 mg L1), NAA (20 and 40 mg L1), or a control. Selected pummelo branches received all treatments twice, at full bloom and two months following fruit set. The findings demonstrated that at six months after the fruit set, 20 mg L-1 NAA (14.84%) and 40 mg L-1 NAA (12.26%) considerably increased the percentage of fruit retention. However, a study of the leaf's total nonstructural carbohydrate content revealed that the amounts of 40 mg and 20 mg of L1 2, 4-D both produced considerably more total nonstructural carbohydrate than the control (78.44 mg g1). In terms of fruit quality, 40 mg L1 2, 4-D and 20 mg L1 2, 4-D produced the highest peel weights (435.55 and 358.57 g, respectively), the highest peel thickness (20.25 mm), and the statistically highest total soluble solids (20 mg L1 NAA) compared to those produced by 20 mg L1 2,4-D and 40 mg L1 2,4-D. Due to this, 20 mg L-1 of NAA sprayed twice, once at full bloom and once two months after fruit set, significantly enhanced the percentage of fruit retention.

Application of 2, 4-D @ 10 ppm has given the best pre-harvest fruit drop control in 'Hamlin' orange (Aziz *et al.*, 2020). Effect of growth retardants (CCC, daminozide and paclobutrazol) on growth and development under plastic greenhouse conditions and found that application of 500 ppm CCC enhanced anthesia and fruit ripening by about 10 days. In an experiment on the effect of growth substances on flowering and fruiting characteristics of 'Sardar' guava. PBRs such as NAA, GA_3, and CPPU were sprayed to 'Arumani' mango trees at 14 days after blooming which results that CPPU (1-(2-chloro-4-pyridyl)-3-phenylurea) at 10 ppm, gave the best result in increasing fruit retention, number of fruit per cluster, fruit weight, volume and leaf area.

Ethylene

Ethylene, a chemical that occurs naturally that promotes plant growth, has a variety of effects on the emergence, growth, and shelf life of various fruit crops. Both endogenous and external sources of ethylene contribute to its biological activity, which can be purposely or accidentally subjected to biologically active levels in harvested fruits. Several biotic and abiotic stressors, as well as specific plant developmental stages, increase ethylene production and sensitivity **(**Khan, *et al.*, 2020). Many ripening phenomena are assumed to be coordinated by the enormous surge in ethylene production that occurs in climacteric fruit as it ripens. Generally speaking, C_2H_4 stimulates fruit ripening to improve taste and flavour. The amounts of fruit ripened on the plant were never reached by tomatoes that were picked mature-green and ripened with C_2H_4. For instance, the most significant fragrance molecule (Z)-3-hexenal increased by 31% and 17%. In addition to helping to soften tissue during fruit ripening, C_2H_4 has an Unfavourable impact on texture by encouraging unintended softening in cucumbers and peppers and Unfavourable toughening in asparagus and sweet potatoes. Many ripening fruits and vegetables lose some of their firmness when exposed to C_2H_4. When applied to fruit that is ripening, such as apricots, avocados, melons, pears, and tomatoes, it is typically good. However, if applied for too long, ripening can continue into senescence.

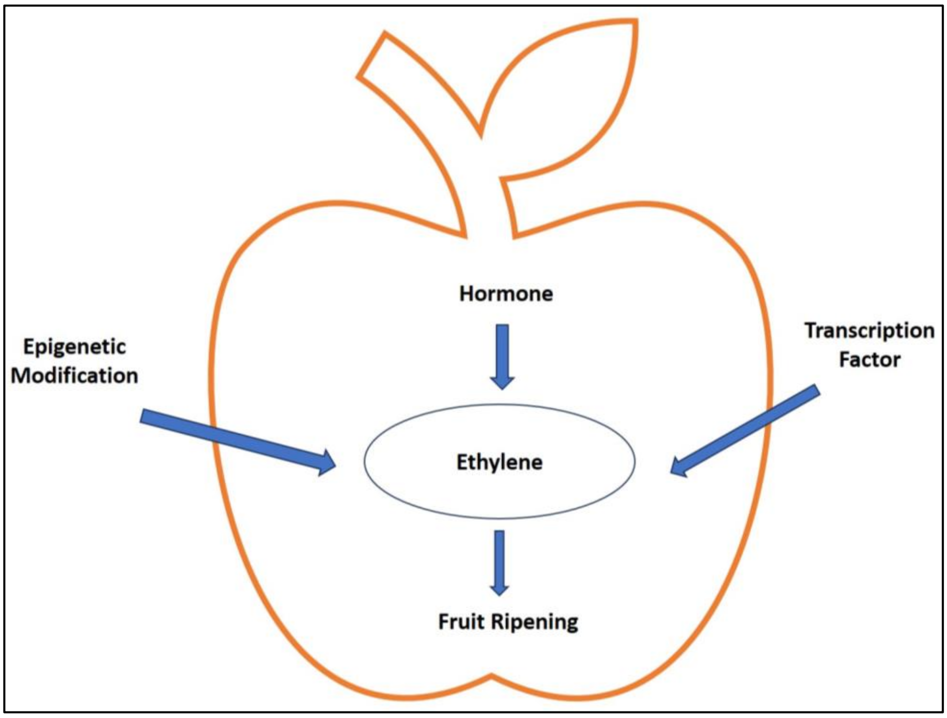

Fig 2: Role of Ethylene in Fruit ripening

The inorganic C_2H_4 concentration in tropical fruit rapidly climbs to saturation point once ripening has begun, and exogenous administration of C_2H_4 has no additional ripening-promoting effects. Due to the high resistance to diffusion of both the flesh and the skin of bulky fruit, such as apples (*Malus domestica*), [Figure 2], bananas (*Musa spp*.), melons, and tomato products, reducing the exterior concentration of C2H4surrounding these ripening seasonal fruits almost has no effect on diminishing the internal concentration (Khadivi 2019) [12]. The rate of production in these fruits greatly outpaces the rate of diffuse losses up until a certain point. Even though the external concentration is zero, the internal C2H4 concentration can be greater than 100 l l1.

As a result, lowering the external C_2H_4 content through ventilation or the use of C_2H_4 scrubbers typically has no impact on the future ripening of fruit that has advanced a few days into its climacteric. While internal C_2H_4 levels are still low during the early stages of ripening, increasing the rate of diffusion using low-pressure storage or preventing C_2H_4 from being produced or acting can greatly slow down ripening.

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