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Review on application of plant growth regulators in different vegetable crops

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Abstract
To maximize productivity and food safety Plant growth regulators are one of the inputs that have enabled Indian agriculture become more mechanized and scientifically oriented. Plant growth regulators have a quicker effect on the vegetative development and production of the crops. As it has many benefits, like being environmentally friendly and taking less time to treat the plant. Crops grown for vegetables are abundant in vitamins and minerals. When used in vegetable production, growth regulators must have a precise activity and be both toxicologically and environmentally safe. Vegetable crops' physiological activity is regulated, and once growth regulators are applied, the yield of vegetables is ultimately increased.

Keywords: Plant growth regulators, vegetable crops, auxin

Introduction
Plant hormones are also referred to as phytohormones. These hormones, which are tiny chemicals derived from various vital metabolic pathways, help to regulate plant growth. Thimann in 1948, coined the term “Phytohormone” as organic substance that produce naturally in plants.

Plant growth regulators are synthetic in nature, whereas plant hormones are naturally occurring. They are essential for plant as they play important role to the plant's growth (P. Hazra and M.G. Som, 2006) [11]. Plant growth regulators occur in five different varieties, including auxins, gibberellins, cytokinins, abscisic acid, and ethylene. It has been discussed in table 1

Auxin
The discovery of auxin was first proposed by Charles Darwin in 1880. It was the first-ever type of growth regulator to be found. Auxins are substances that have a positive effect on bud development, cell expansion, and root initiation. They also aid in the production of other growth hormones. IAA is a naturally occurring hormone, whereas NAA, IBA, 2-4D, and other hormones are synthetic.

Biosynthesis of Auxin (IAA) in plant
Tryptophan is an essential ingredient in the production of the auxin. It needs tryptophan to make indole 3acetic acid. In plants, it serves as the major precursor of IAA. Tryptophan can be converted into IAA in two separate methods.

- By indole-3-acetaldehyde being produced by deamination of tryptophan to create indole-3-pyruvic acid. Tryptophan deaminase and malate pyruvate decarboxylase, respectively, are the enzymes at work.
- Tryptophan decarboxylase and tryptamine oxidase, respectively, are the enzymes involved in the decarboxylation of tryptophan to create tryptamine, which is then followed by deamination to create indole-3-acetaldehyde. In the presence of indole 3-acetaldehyde dehydrogenase, indole 3-acetaldehyde is easily converted to indole 3-acetic acid (IAA).

Gibberellin
The Japanese scientist ‘Kurosava’ made the discovery of gibberellins in 1926. The second growth regulator after auxin. The fungus “*Gibberella fujikuroi*” was used to extract the gibberellin, which is the responsible agent of “foolish seedling of rice”.

Gibberellic acid promotes floral and fruit development as well as seed germination.

GA Biosynthesis: Gibberellin's precursor is called kaurene. Young leaves (a main location), shoot tips, root tips, and immature seeds are where gibberellins are generated (embryo).

In order to initiate cell division and elongation, germination of seeds, bolting/flowering in response to long days, and preventing genetic dwarfism, GA is essential for the development of flower and fruit. Gibberellin also plays a big part in dormancy and makes dioecious blooms become male, which prolongs shelf life.

GA promotes fruit and floral development as well as seed germination. Encourage cell growth and division, as well as seed germination Increases flower and fruit size, dormancy, increases maleness in dioecious flowers, and prolongs shelf life. Stimulates bolting/flowering in response to long days.

Cytokinin

Skoog experimented in 1995 and found that when *Nicotiana tabaccum* pith tissues were cut off from the vascular tissues, the pith tissues expanded without cell division. There are various different synthetic cytokinins, including kinetin, 6-(benzyl-amino)-9-(2-tetrahydropyranyl)-9H-purine (PBA), 1,3-diphenylurea, 6-benzylamino purine (BAP), and thidiazuron (TDZ).

Biosynthesis: Plants produce cytokinin when purines are present (nucleic acid synthesis). One crucial location for its creation is the root tip. Additionally, cytokinin is made in cambial tissues and developing seeds. They migrate upward in the xylem stream, and isolated stems and petioles also exhibit basipetal movement.

Ethylene

This hormone is a gaseous plant hormone that is produced in all plant organs from the amino acid methionine.

Abscisic acid

It also known by the name plant stress hormone. It functions as an inhibitory chemical molecule that has a direct impact on bud growth, seed development, and bud dormancy. It occurs naturally in plants and has an inhibiting impact. It prevents the creation of mRNA and proteins.

Biosynthesis of ABA: it produced in properly mature fruit and leaves. There are two methods through which ABA is produced, or biosynthesised.

i. From the breakdown of carotenoid and violaxanthine, mevalonic acid, isopentenyl pyrophosphate, heranyl pyrophosphate, xanthoxin, and abscisic acid.
ii. Abscisic acid synthesis and higher levels of ABA-inducing polypeptides, of which lectins are more prominent, occur during genome reprogramming.

Ethylene

Nelju Bow was the first to explain the significance of ethylene, which is contained in lighting gas, as a plant growth regulator. According to Denny (1924), ethylene is quite effective at causing fruit to mature. It is a byproduct of ripening fruit in nature. It affects DNA, RNA, protein biosynthesis, endospermic reticulum induction, and endosperm modification. Plants' ethylene levels were raised by auxins.

Ethylene Biosynthesis: The majority of plant components in higher plants produce ethylene. The primary sites for ethylene biosynthesis are the monothematic and nodal areas. Along with fruit ripening, this hormone is also produced during floral senescence, leaf abscission, and leaf abscission. Although it appears that methionine may be an immediate precursor of ethylene, it is synthesized inside of plants. The last ethylene precursor is amino cyclopropane carboxylic acid (ACC), which is also known as ACC.

Application of Plant Growth Regulators in different Vegetable Crops

Tomato

The function of plant growth regulators is advantageous for tomato growth parameters. The tomato plants were exposed to various concentrations of NAA at 25, 50, 75, and 100 ppm and GA3 at 20, 40, 60, and 80 ppm. It was reported that the use of NAA at 100 ppm and GA3 at 80 ppm resulted in maximum plant heights of 85.3 cm and 82.3 cm, respectively, and increased yields of 483.6 q/ha and 472.2 q/ha. (Prasad *et al.*, 2013) [20]. The highest plant height, number of leaves, number of branches per plant, number of fruits, number of flowers, number of clusters of fruit, diameter of fruit, yield per plant (kg), yield per plot (kg), and yield per hectare (tonnes) were all obtained with GA_3 at 125 ppm (Akand *et al.*, 2015) [1]. In BARI Hybrid Tomato-8, 4-CPA (4-Chlorophenoxy acetic acid) + GA3 was applied together after 75 days of transplanting, and it was observed that the tallest plant (79.35 cm), the number of flowers (38.11) and fruits (19.04) per plant, height (87.90 cm), the number of flowers (49.04) and fruits (21.9) per plant, the individual fruit weight (61.16 g), and the fruit yield (27.28 tone/ha) (Rahman *et al.*, 2015) [22]. After 45 days of transplanting tomato seedlings, CCC (Cycocel) @ 500 ppm application increased plant height, number of fruits per plant, fruit diameter, and per plant seed yield compared to NAA @ 50 ppm and GA_3 @ 50 ppm (Chauhan *et al.*, 2017) [7].

Chilli and capsicum

The maximum fruit output over control was generated by the treatments 2,4-D @ 2 ppm, triacontanol @ 5 ppm, NAA @ 40 ppm, and GA3 @ 10 ppm, respectively, by 28.75%, 25.70%, 13.61%, and 2.30%. It was noted that 2 ppm 2,4-D resulted in the highest net profit and B: C ratio. The cost of using GA_3 as a foliar spray was high (Chaudhary *et al.*, 2006) [6]. Spraying NAA @ 40 ppm as opposed to control led to the highest seed output per plant (8.30 g), seed yield per fruit (0.35 g), average fresh weight of fruits per plant (39 g), and average dry weight of fruits per plant (19.67 g) (Patel *et al.*, 2016) [19]. In capsicum, NAA at 60 ppm resulted in the highest plant height (120.59 cm), number of branches (16.05), days to first flowering (32.51), number of flowers per plant (11.83), weight of fruit (169.66 g), number of fruits per plant (9.87), number of seeds per fruit (110.78), yield per plant (1.67 kg), and yield per plot (15.07 kg), along with yield per hectare (69.76 t) (Singh *et al.*, 2017) [29]. Different growth regulator concentrations were employed in chilli and applied 30 and 60 days after transplanting, including NAA (25, 50, and 75 ppm), GA3 (20, 40, and 60 ppm), 2, 4-D (5, 7.5, and 10 ppm), and ethrel (300, 400, and 500 ppm). Maximum yield per plant

(182.31 g) and yield per hectare were noted at NAA @ 75 ppm (6.37 t). However, GA3 @ 20 and 60 ppm treated plants produced maximum dry weight of 20 fruit and maximum plant height of 60.67 cm (9.39 g). In 2,4-D @ 7.5 ppm treated plants, the greatest quantity of seeds per fruit (60.47) and plant spread in (N-S) (36.97 cm) were both noted (Raj *et al.*, 2016) [23].

Brinjal

A variety of growth regulators, including NAA (20, 40, and 60 ppm) and GA3 (30, 40, and 50 ppm), as well as two kinds, BARI Begun-5 and BARI Begun -10, are used. Application of NAA @ 40 ppm was reported to produce the maximum percentage of long and medium-styled flowers, leaf photosynthesis, number of fruits per plant, and fruit output (45.50 t/ha). After transplanting, the variety BARI Begun-5 took 40 days to flower, which was earlier than BARI Begun-10's 100% flowering time. The combination of NAA @ 40 ppm with BARI Begun-5 produced the greatest percentage of long-styled flowers, the greatest number of fruits per plant, and the greatest fruit output (49.73 t/ha) (Moniruzzaman *et al.*, 2014) [16]. The largest number of branches, fruits, fresh fruit weight, and total soluble solid were produced by GA_3 at 10 ppm and NAA at 20 ppm (Netam and Sharma 2014) [17]. According to Dhakar and Singh (2015) [10], GA_3 @150 ppm resulted in the highest plant height, number of leaves, length of leaves, number of branches, and stem diameter per plant when compared to GA_3 @100 ppm and 200 ppm and the lowest values observed in control.

Cauliflower

Sitapara *et al.*, (2011) [30] studied the effectiveness of GA_3 and NAA on the "SNOWBALL- 16" type of cauliflower at various stages, including root dipping and foliar spraying. The diameter of the curd (17.78 cm), the length of the stalk (5.22 cm), the net weight of the curd (3.53 kg/plant), the curd yield (12.5 kg/plot), and the necessary minimum days to 50% marketable curd were all observed to be improved by the foliar application of GA_3 at 50 mg/l in cauliflower (88.80 days). By applying IAA 10ppm + GA_3 70ppm instead of control, the highest plant height (63.10 cm), number of leaves per plant (23.66), leaf length (59.05 cm), leaf breadth (18.98 cm), diameter of curd (22.39 cm), and marketable yield per hectare (29.88 t/ha) were observed. Additionally, it was discovered that planting on November 15 produced the highest plant height (65.96 cm), number of leaves per plant (26.42), leaf length (63.64 cm), leaf breadth (20.92 cm), curd diameter (25.75 cm), and marketable yield per hectare (31.03 t/ha) measurements, as well as IAA 10 ppm and GA3 70 ppm (Rahman *et al.*, 2016) [21]. Different doses of NAA@ 100, 120, and 140 ppm were tested by Jadon *et al.*, (2009) [14], They discovered that greater doses of NAA at 140 ppm resulted in higher plant height (33.83 cm), stem diameter (1.65 cm), spread (45 cm), and leaf count per plant (22.10). Characters that contribute to yield, such as curd diameter (15.10 cm), curd weight (0.61 kg), head weight (0.60 kg), length of head per plant (21.58 cm), yield (155 q/ha), and dry weight of curd per 100 g of fresh weight (10.40), were all higher than they were in the control group.

Cabbage

On cabbage, different GA_3 concentrations were used by Islam *et al.*, in 2017 [13]. They ingested GA_3 at four different concentrations: 0, 90, 120, and 150 ppm. According to their findings, GA_3 at 120 ppm produced the best marketable output (65.5 t/ha), while GA 0 ppm produced the lowest yield (41.2 t/ha). Maximum plant height, most loose leaves per plant, and head diameter were measured using GA_3 at 120 ppm, while minimum values were found in GA 0 ppm. On the other hand, maximum days in GA 0 ppm and minimum days in GA 120 ppm were both reported for head formation. They therefore discovered that GA3 at 120 ppm was more efficient. Different amounts of NAA (40, 80, and 120 ppm) and GA3 (30, 60, and 90 ppm) were utilized by Chaurasiy *et al.*, (2014) [5] and given as a foliar spray on cabbage plants at 30 and 45 days after transplanting. According to their findings, when compared to all other treatments and the control, NAA 80 ppm and GA_3 60 ppm gave the highest plant height, number of leaves per plant, spreading, stem diameter, weight of the plant, weight of the head, and head yield.

Table 1: Plant Growth Regulators and their classes

Plant growth Regulators	Classes
Auxins	Indole-3-acetic acid (IAA), 1-Naphthaleneacetic acid (NAA), Inode-3-butyric acid (IBA), 2,4-Dichlorophenoxyacetic acid (2-4D), 4 Chlorophenoxyacetic acid (4-CPA).
Gibberellins	Gibberellic acid (GA_3)
Cytokinin	Kinetin, Zeatin
Ethylene	Ethereal
Abscisic acid	Dormins, Phaseic acid

(Jatinder Singh 2014) [27]

Table 2: Various Plant Growth Regulators and their Functions

Plant growth regulators	Functions
Auxins	(a) Apical dominance (b) Cell division and enlargement (c) Shoot and root growth (d) Plant growth movement (e) Parthenocarpy (d) Abscission
Gibbberellins	(a) Prevent genetical dwarfism (b) Regulation in bolting and flowering (c) Production of parthenocarpic fruit (d) Germination.
Cytokinins	(a) Cell and organ enlargement (b) Seed germination (c) Development of bud and shoot growth
Ethylene	(a) Ripening of fruit (b) Seedling growth and emergence (c) Abscission of leaf.
Abscisic acid	(a) Abscission (b) Dormancy (c) Inhibit seed development and germination of seed (d) Stomatal closing (e) Helps during water stress

(Jatinder Singh 2014; and P. Hazra and M.G. Som 2006) [27, 11]

Okra

IAA @ 100 ppm gave maximum plant height (107.74 cm), intermodal length, according to Dhage *et al.*, 2011 [9] (3.1 cm). However, the use of GA3 @ 150 ppm needed a minimum number of days for first blooming (39.67 days) and a minimum number of days for first harvesting (44.67 days). The best seed quality attributes were provided by GA_3 @ 50 ppm, such as average pod weight (g) and 100 seed weight (g). While thiourea @ 500 ppm gave the largest number of pods per plant, length of pod (cm), number of seeds per pod, per plant seed yield (g), and seed production per hectare, GA_3 gave the maximum plant height, number of leaves, and number of nodes per plant (q) (Ravat *et al.,* 2015) [24].

Onion and Garlic

According to Patel *et al.*, (2010) [18], root dipping treatment with NAA @ 100 ppm dramatically decreased physiological weight loss and decreased loss in spoiling. According to Anbukkarasi *et al*. (2013) [3], fungicides, ethylene, and CCC all have a significant impact on the shelf life and delay of sprouting in onions. In order to increase the shelf life of onions, pre- and post-harvest treatments have been studied, according to Bannu Priya *et al*., (2014) [4].

Cucurbits

According to Hidayatullah *et al.*, (2012) [12], bottle gourds grown with GA3 @ 30 ppm produced more pistillate flowers, the greatest number of fruits, and heavier fruits than controls. According to Dalai *et al*. (2015) [8], GA_3At 20 ppm + NAA @ 100 ppm produced the most wine length/plant (cm) and amount of leaves/plant. However, for cucumber, GA_3 @ 20 ppm + NAA @ 100 ppm had the highest yield. According to Sandra *et al*., 2015 [26], NAA at 200 ppm, GA3 at 50 ppm, and ethereal at 50 ppm were all highly efficient for enhancing vegetative growth, fruit and seed yield, and modifying sex expressions. GA_3 at 50 ppm was also successful in producing hybrid seed in bitter gourd.

Potato

Ethrel at 250 ppm applied topically changed the phenotypic of the plant and increased plant height, shoot diameter, number of tubers produced per plant, and overall tuber output as compared to the control (Awati *et al.,* 2016). The plant's height increased after GA_3 was applied 60 days after transplanting, but the quantity of tubers, weight, and dry matter content were unaffected. Inducing a large percentage of sprouted tubers before harvest and increasing the physiological age of the tubers are both results of late application of GA_3 (Alexios *et al.,* 2006) [2].

Pea

According to Singh *et al*. (2016) [28], GA_3 at 200 ppm greatly enhanced plant height, the number of leaves, the total number of branches, the number of pods, the length of the pods, and the weight of 100 seeds.

This review's findings suggest that PGRS regulate physiological processes in crop plants, such as roots, flowering, growth, sprouting, and ripening, and that its application in the production of diverse vegetable crops has been proven to be advantageous for yield and yield-contributing traits.

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