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Recent advances of plant growth regulators in vegetable production: A review

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Abstract
Plant growth regulators are artificially produced substances in very low quantities normally. They play an important role in earliness, sex modification, increasing the yield, quality, resistant to insect-disease, regulate the growth of plants and are important measures to ensure production. It decreased susceptibility towards biotic and abiotic stress, improved morphological structure, facilitation of harvesting, and modification of plant constituents. The main plant growth regulators are Auxin, Gibberellin, Cytokinin, Jasmonic acid, ethylene, abscisic acid (ABA) and brassinosteroids etc. They have multiple functions and various combinations of them can act either synergistically (auxins and gibberellins) or antagonistically (abscisic acid and auxins) to promote very specific responses.

Keywords: Vegetable, Plant growth regulators etc.

Introduction
Plant growth regulators (PGRs) are usually the organic compounds, other than nutrients, used in small concentrations, affect the physiological processes of plants. They are applied directly to plant to alter its life processes/structure in some beneficial way so as to enhance yield, improve quality and facilitate harvesting.

Growth regulating substances, plant hormones or simply phytohormones are compounds produced naturally by plants that participate in control of plant growth, as well as they are versatile chemical regulators of plant growth. When these substances are produced synthetically, they are called plant growth regulators (PGRs). These results were reported by Davies (2010; Rademacher (2015) [3, 19].

Table 1: Plant Growth Regulators and their classes

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

Table 2: Various Plant Growth Regulators and their Functions

Name of the plant growth regulators	Functions	Site of production
Auxin	(a) Involved in Apical dominance (b) stimulates Cell division and enlargement (c) Shoot and root growth (d) Plant growth movement (e) Parthenocarpy (f) Abscission (g) root induction (h) control fruits drops	Meristem of apical buds, embryo of seed, young expanding leaves
Gibberellin	(a) Prevent genetical dwarfism (b) Regulation in bolting and flowering (c) Production of parthenocarpic fruit (d) Germination. (e) Increase flower and fruit size.	Immature seeds
Cytokinins	(a) Cell and organ enlargement (b) Seed germination (c) Development of bud and shoot growth(d) Flower induction (e)delay senescence	Root apex, endosperm of seeds, young fruits
Ethylene	(a) Ripening of fruit (b) Seedling growth and emergence (c) Abscission of leaf.	Ripe fruits, flowers and leaves and nodes of stem.
Abscisic acid	(a) Abscission (b)Maintaining Dormancy (c) Inhibit seed germination and development(d) stimulate stomatal closure	

Auxin

Charles Darwin was the first who proposed the existence of auxin in 1880. It was the first class growth regulator that was discovered. Auxins are those substances that give positive effect on enlargement of cell, root initiation and formation of bud. Auxin help for the formation of other growth hormones. IAA is natural occurring hormone while NAA, IBA, 2-4D etc. are synthetic in nature.

Biosynthesis of Auxin (IAA) in plants

In biosynthesis of Auxin tryptophan plays an important role. Tryptophan is converted into Indole 3acetic acid. It is the primary precursor of IAA in plants. IAA can be synthesis from tryptophan by two different pathways.

- By deamination of tryptophan to form indole-3-pyruvic acid followed by decarboxylation to from indole-3-acetaldehyde. The enzymes involved are tryptophan deamintion and in dole pyruvate decarboxylase respectively.
- By decarboxylation of tryptophan to form tryptamine followed by deamination to form indole-3-acetaldehyde and the enzymes involved are tryptophan decarboxylase and tryptamine oxidase respectively. Indole 3-acetaldehyde can readily be oxidized toindole 3-acetic acid (IAA) in the presence of indole 3-acetaldehyde dehydrogenase.

Gibberellic acid

Kurosava discovered gibberellins in 1926. It is the second most important growth regulator. It was extracted from the fungus *Gibberella fujikuroi*.

Biosynthesis: Kaurene is precursor of Gibberellin. Gibberellins is formed in the young leaves (major site), shoot tip, root tip and immature seeds (embryo).

GA plays vital role in germination of seed and maturation of flower and fruit, activate cell division and elongation, germination of seeds, bolting/flowering in response to long days, preventing genetic dwarfism. Gibberellin also plays a significant role in dormancy, induces maleness in dioecious flowers, extending shelf life.

GA stimulates germination of seed and maturation of flower and fruit. Stimulate cell division and elongation, stimulate germination of seeds Stimulates bolting/flowering in response to long days, prevention of genetic dwarfism, increase flower and fruit size, dormancy, induces maleness in dioecious flowers, extending shelf life.

Cytokinins

Skoog in 1995 observed that when pith tissues of *Nicotiana tabaccum* were separated from the vascular tissues they grew without division of cell. There are synthetic cytokinins such as 6-benzylamino purine (BAP), kinetin, 6-(benzyl-amino)-9-(2-tetrahydropyranyl)-9H-purine (PBA), 1,3-diphenylurea, thidiazuron (TDZ), etc. Cytokinin stimulate cell division, translocation of nutrients, cell enlargement and cell differentiation, promote bud initiation and root growth, prolong storage life of flowers and vegetables, prevent chlorophyll degradation, delay of senescence.

Biosynthesis of Cytokinins

In case of purines cytokinin are formed in plants (nucleic acid synthesis). Root tip is an important site of its formation. Developing seeds and cambial tissues are also the site of cytokinin production. They move upwards in the xylem stream and basipetal movement in petiole and isolated stems are also observed.

Abscisic acid

It is also known as plant stress hormone. It acts as inhibitory chemical compound that gives direct effect on growth of bud, seed and dormancy of bud. It occurs naturally in plants and has inhibitory effect. Act as plant stress hormone, induces seeds to synthesize storage proteins, dormancy, dormancy induction of buds and seeds, seed development and germination, stomata closing.

Biosynthesis: is produced in mature leaves and fruits. ABA production or biosynthesis occurs via two pathways.

- from mevalonic acid → isopentenyl pyrophosphate →heranylpirophosphate;
- by carotenoid and violaxanthine decomposition →xanthoxin→ abscisic acid.

During genome reprogramming Abscisic acidsynthesis and increasedamounts of ABA-inducing polypeptides, of which lectins are more significant.

Ethylene (The Ripening Hormone)

Nelju bow was the first to tell the importance of ethylene present in the illuminating gas as a growth regulator of plants. Denny (1924) observed that ethylene is highly effective in inducing fruit ripening. It is a natural product of ripening fruits. It acts on protein biosynthesis, DNA, RNA and induction and modification of endospermic reticulum. Auxins increased ethylene level in plants.

Biosynthesis: In higher plants, most of the plant parts produce ethylene. Meristematicregion and nodal regions are main site for ethylene biosynthesis. This hormone production also increases during leaf abscission and flower senescence as well as during fruit ripening. It synthesis inside the plants but it appears that methionine may be an immediate precursor of ethylene. Aminocyclopropane carboxylic acid (ACC) is the penultimate precursor of ethylene.

Commercial Utility of PGRs in vegetable crops

1. PGRs effect on seed germination

Pre-sowing seed treatments with such as gibberellic acid have been found to improve the seedling growth of many plant species. The carrot roots was soaked in 100 ppm GA_3 or spraying young foliage developed from the planted root gave higher seed yield. The non-flowering carrot varieties, spraying and soaking with 100 ppm GA_3 produced high percentage of plantsthose produces flower. The effects of foliar spray of GA_3, Cycocel and ethrel in seed production of carrot at different concentrations. Ghoname *et al.* (2004) [6] reported that GA_3 applied at preor post-planting induced early flowering at all concentrations but application of GA3 at 200 ppm as foliar spray after root soaking in GA3 at 400 ppm was the best treatment for seed production of carrot. Verma & Sen (2006) [34] reported that the effect of plant growth regulators *viz.* IAA, NAA and GA3 each at 10, 20, and 50 ppm concentration and their method of application (pre-plant soaking, spraying 20 days after sowing (DAS) and pre-plant soaking + spraying 20 DAS) on growth, yield, and biochemical constituents (carotenoid and chlorophyll content) of coriander. He also confirmed GA_3 at concentration of 50 ppm applied by pre-plant soaking + spraying 20 DAS significantly improve the vegetative growth of coriander herb while NAA at 50 ppm improved the quality of the coriander herb.

The early germination recorded in media treated with NAA 0.02mg/L is contrary to the results obtained by Tahir *et al.* (2019) [30] and found the effects of varying concentrations of plant growth regulators (PGRs) on the in vitro propagation of Okra where they recorded early germination in the control.

2. PGRs effect on growth and development

At flowering stage Spraying of GA_3 40 mg/l recorded the maximum number of leaves, leaf area, leaf area index and dry weight of plant at harvest stage. Thapa *et al.* (2014) [31] found the increase in length & breadth of leaves might be due to increase in meristematic activity of the apical tissue on GA_3 application. GA_3 is involved in increasing photosynthetic activity, efficient translocation and utilization of photosynthates causing rapid cell division, cell elongation and cell differentiation at growing region of the plant leaves leading to stimulation of growth. Dhakar and Singh (2015) [4] observes that GA_3 @ 150 ppm gave highest plant height, per plant number of leaves, length of leaf, per plant number of branches and stem diameter as compared to GA_3 @ 100 ppm and 200 ppm and minimum recorded in control. Singh *et al.* (2016) [23] reported that GA_3 at 200 ppm gave significantly increased in height of plant, number of leaves, total number of branches, number of pods, length of pod and 100 seed weight. Tomar *et al.* (2015) [32] conducted a trial to find out the role of Plant Hormones on Vegetative Growth of Tomato (*Lycopersicon esculentum* Mill.). Different plant growth regulator *viz*., Gibberellic acid, naphthalene acetic acid and 2,4-D were used on tomato cv. Azad T-6. Different concentration of GA_3 (@10 ppm, 20 ppm and 30 ppm), NAA (@20 ppm, 25 ppm and 30 ppm) and 2,4-D (@5 ppm, 10 ppm and 15 ppm) were sprayed on the crop to study the vegetative growth behavior attributes of tomato. It was found that there was a linear increase in growth parameters like plant height and number of branches per plant with increasing level of GA_3 and NAA. The maximum plant height was recorded as 99.03 cm and 85.47 cm with the application of GA_3 @ 30 ppm and NAA @ 30 ppm, respectively at the time of harvesting.

Tomar *et al*. (2017) [33] observed the role of Plant growth regulators on Vegetative Growth of Tomato (*Lycopersicon esculentum* Mill.). Different plant growth regulator *viz*., GA_3, NAA and 2,4-D were used on tomato cv. Azad T-6. Different concentration of Plant growth regulators GA_3 (@10 ppm, 20 ppm and 30 ppm), NAA (@20 ppm, 25 ppm and 30 ppm) and 2,4-D (@5 ppm, 10 ppm and 15 ppm) were sprayed on the tomato crop to find the vegetative growth behavior attributes. He reported that there was a linear increase in growth parameters like plant height and number of branches per plant with increasing level of GA3 and NAA. The maximum plant height were recorded as 99.03 cm and 85.47 cm with the application of GA3 @ 30 ppm and NAA @ 30 ppm, respectively at the time of harvesting.

Megbo (2010) [17] used plant growth regulator to control the fruit drop and development in tomato. Gibberellic acid (GA_3), naphthalene acetic acid, 2-4-D, Aminoethoxyvinylglycine (AVG) were used in the experiment. The result show that fruit drop can be controlled by the exogenous application of plant growth regulators such as auxins and gibberellins. These plant growth regulators tend to delay the senescence and reduce unwanted fruit abscission (*i.e.* fruit drop). The application of 2,4-dichlorophenoxyacetic acid (2-4-D) or gibberellic acid (GA_3) Aminoethoxyvinylglycine (AVG) increase the flowering, fruit set, fruit size and control the fruit drop.

3. PGRs effect on yield attributed traits

Surendra *et al*. (2006) [28] observed the growth regulators and micronutrients the foliar application of GA_3 (25 & 50ppm) at 60 DAS found significantly higher fresh fruit yield over other treatments. Yield attributing components *viz*., total number of flowers, fruits plant-1, fruit length, seed number fruit-1, seed weight and harvest index is increased due to GA_3 (25 & 50 ppm). As compared to other treatments benefit: cost ratio was higher with application of GA_3 (50 ppm). Ravat *et al*. (2015) [19] observed that GA_3 gave maximum plant height, number of leaves, per plant number of nodes while thiourea @500 ppm gave maximum no. of pods per plant, length of pod (cm), number of seed per pod, per plant seed yield (g) and seed yield per hectare (q). Singh *et al.* (2003) [23] observed the yield attributes was significantly influenced due to curtailed vegetative growth with the encouragement of reproductive phase. With the increasing concentration of plant hormone 15 ppm proved highly beneficial which enhanced the maximum yield of the cabbage varieties. The highest plant height, number of leaves, fresh fruit weight, ascorbic acid, total soluble solid (TSS) estimated in the application of gibberellic acid (GA3) @50 ppm in okra.

Baliyan *et al*. (2013**)** [2] reported the effect of 4-chlorophenoxy acetic acid on the fruit set, yield and economic of tomato. The 75-ppm concentration of 4-CPA resulted not only the highest increasein fruit set but also increased the tomato yield and hence economic benefit in tomato production increased. Sinojiya *et al.* (2015) [27] found GA_3 at 15 ppm increased pulp weight in watermelon cv. Shine Beauty. seed soaking + foliar spray 500 ppm thiourea at branching increased plant height, dry accumulation, LAI, CGR,RGR, NAR and cholophyll content reported by Jharia (2002) [8].

4. PGRs effect on quality attributed traits

Ibrahem *et al*. (2021) [7] found that Foliar spray with the PGRs at different concentrations increased capsaicin content in chili fruits compared to control (spraying with tap water). Foliar spraying of 4-CPA at 40 ppm or with GA_3 at 30 ppm increased capsaicin content in chili fruits. Sarker *et al*. (2009) revealed the spraying NAA at 40 ppm BARI Chilli-1 with significantly increased ascorbic acid content in fruits, and the interaction between spraying the same cultivar with tap water gave the highest values of TSS than other interaction treatments. Sinnadurai. (1973) [26] in 'Bawku' cultivar of onion produced a significant decrease in flowering and maximum effect was obtained with 300 ppm without affecting bulb size and quality. With applications higher than 300 ppm bulbs were soft and light in weight. The control of bolting in the 'Bawku' onion enables farmers to obtain higher yields of good quality onions**.** Mahala *et al*. (2014) [13] found that ethrel plays vital role in improve quality characters of bottle gourd with the application of ethrel @300 ppm significantly increased fruit diameter, crude protein content, ascorbic acid content and TSS in bottle gourd. The application of GA3 at 30 ppm in cv. Durgapura Lal was found effective in increasing chlorophyll content.

Lokhande *and Gaikwad* (2014) [12] reported maximum chlorophyll content was significantly increased in response to GA, Cycoceal, Methionine and Cysteine applications. The chlorophyll a/b ratio was slightly change due to Plant hormone applications while the overall Carotenoid content was slightly decreased in leaves of two onion varieties. He also reported that carbohydrate content was slightly decreased, while total sugars were slightly increased due to foliar application of Plant hormone. Foliar application of ethrel 250 ppm was found most effective in changing the phenotype of plant, increased the plant height, shoot diameter, number of tubers per plant and total yield of tuber as compared to control Application of GA3 at 60 DAT had increased in height of plant but number of tubers, weight and content of dry matter were not affected. Late application of GA_3 leads for induction of high percentage of sprouted tubers prior to harvest and also lead to increase physiological age of tubers**.**

Oaliya *et al.* (2009**)** [18] revealed the biochemical effect of auxin on nutritional quality of tomato. The effect of Indole-3-acetic acid (IAA), Indole-3-butyric acid (IBA) and Naphthalene acetic acid (NAA) at 60, 100 and 140 mg/L was evaluated on some biochemical indices of the nutritional quality of tomato. The parameters were crude proteins, crude fat, crude fiber, ash, dry matter, titratable acidity, total carbohydrate, total soluble solids (0Brix), pH and 0Brix/Acid ratio. All the concentrations of IAA, IBA and NAA increased the levels of crude proteins, crude fat, crude fiber, ash, titratable acidity but decreased the total carbohydrate content.

Meena (2008) [16] reported foliar application of gibberellic acid (GA_3) 50 ppm and 75 ppm found significantly lower fruit drop percentage. Significantly higher total soluble solids, ascorbic acid content and TSS/acid ratio and lower acidity percentage were observed with the application of GA3 at 50 ppm in tomato.

5. PGRs effect on sex expression

Kooner *et al.* (2000) [10] observed the influence of ethrel and MH affect on growth and sex expression in bottle gourd.Ethrel is used to increase female flowers in some cucurbits. the application of ethrel @ 200 ppm resulted in earliness to first pistillate flower appearance, delayed male flower appearance, highest female flowers, minimum number of male flowers and narrow sex ratio in bitter gourd cv. VK 1 Priya Aishwarya *et al.* (2019) [1]. Susila *et al.* (2010) [29] reported spraying of ethereal at 300 ppm recorded highest sex ratio was in watermelon production and compare with brassinosteroid, ethereal, paclobutrazol and untreated control.

6. PGRs effect on seed production

Ghoname *et al.* (2004) [6] observed that GA_3 applied at pre or post-planting induced early flowering at all concentrations but application of GA_3 200 ppm as foliar spray after root soaking in GA_3 at 400 ppm was the best treatment for seed production of carrot. Mangal *et al.* (1980) [14] reported GA_3 at 50-250 mg/l was beneficial for seed production of cauliflower. In carrot, foliar applications of GA_3 increased shoot to root ratio, while chlormequat chloride decreased shoot to root ratio in carrot reported by McKee and Morris (1986) [15].

7. PGRs effect on induction of parthenocarpy

Serrani *et al.* (2007) [22] reported that in Parthenocarpic tomato fruit induction of 2,4-D also contains high amount of GA1 and its precursors, similar to levels in pollinated ovaries. In accordance, expression levels of GA20oxs and SlGA3ox1 were found to be high in the parthenocarpic ovaries as compared to levels in the unpollinated ovaries, whereas transcript levels of SlGA2ox2 were low.

Table 3: List of plant growth regulators and their important uses in vegetable crops

Growth regulators	Conc. (mg/l)	Method of application	Crops	Attributes affected
Cycocel (CCC)	250-500	Foliar spray	Cucurbits, tomato, okra	Flowering, sex expression, fruit yield
Para – Chloro Phenoxy Acetic acid (PCPA)	50	Foliar spray	Tomato	Fruit set and Yield
Ethephon (CEPA)	100-500	Foliar spray	Cucurbits, okra and tomato	Flowering, fruiting, sex expression and yield
	2000	Post- harvest	Tomato, chillies	Fruit ripening
Gibberellic acid (GA)	10	Foliar spray	Water melon, tomato	Sex expression, fruiting, yield
Indole-3-Acetic acid (IAA)	10-15	Foliar spray	Okra, tomato, brinjal,	Seed germination, fruit set and yield
Naphthalene acetic acid (NAA)	0.2	Seedling roots	Tomato, brinjal, onion	Growth and yield
	10-20	Foliar sprays	Chillies and tomato	Flower drop, fruit set and yield
	25-30	Seed/ foliar	okra, Tomato, brinjal, onion, cucurbits	Seed germination, growth and yield
Naphthoxy-Acetic acid (NOA)	25-100	Seed/ foliar	Tomato, okra	Germination, growth and yield
Silver nitrate	500	Foliar spray	Cucumber	Induction of male flower in gyn, lines
Silver thiosulphate	400	-	Musk melon	Induction of male flower in gynoecious lines
2,3-5, tri-iodobenzoic acid (TIBA)	25-50	Foliar sprays	cucurbits	Flowering, sex expression and yield
Tricontanol	2	Foliar sprays	Chilli and peas	Fruit set and yield

8. Economic of PGRs effect in vegetables

Net return and B:C ratio are important economic parameters to access the profitability of any treatment & the ultimate goal of any treatment is to achieve profit in term of Net return and benefit cost ratio. Dixit *et al.* (2020) [5] reported the effect of different concentration of PGRs were applied on cauliflower as foliar application and found that all the treatments showed a significant effect on yield, quality and economics therefore foliar application is better way to feed the cauliflower crop and enhance the arketable yield, quality and economics. Kumari (2013) [23] reveled among the different treatment of PGRs and thiourea higher net returns and B:C ratio were obtained under the application of ethereal 450 ppm. This was due to higher yield in treatents resulting higher net returns.

Conclusion

From the above review it has been concluded that PGRs had an immense potential to increase the production, quality, yield, modification of sex, fruit setting and tolerant to biotic and abiotic stress to meet requirements of food supply.

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