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Effect of plant growth regulators on fruit crops: A review

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Abstract
Plant growth regulators play key role in fruit production by influencing directly or indirectly various plant processes like germination, rooting, growth and productivity of fruits. These also can influence size, appearance and quality parameters of fruits by indirectly affecting the crop growth and development or directly by synchronizing flowering, improving fruit-set, decreasing pre-harvest fruit drop and thinning of excessive flowers or young fruits. These may also help in maintaining the desired tree growth and shape for high density orcharding. In this review article a detailed information on research work done in India on the use of various plant growth regulators in fruits production have been incorporated.

Keywords: Auxin, gibberellins, growth, quality and yield

Introduction
Growth regulator is- An organic compound can be natural or synthetic. It modifies or controls (capable of either increased or reduced the growth rate) one or more specific physiological processes within a plant but the sites of action and production are different. It required in low concentration, while plant growth retardants are synthetic compounds which reduce the growth of the plants. AMO-1618, Phosphon-D, CCC (Cycocel)-2 Chloro ethyl trimethyl ammonium Chloride, MH, B-995, jasmonic acid and paclobutrazol etc. are important growth retardants. Plant growth regulator which inhibits the physiological or biochemical process in the plant is called as growth inhibitors. Natural occurring Inhibitors– ABA, BA, Gallic acid and coumarin. Synthetic compounds-MH, 2, 3, 5-T or Triiodo benzoic acid (TIBA).
Relative effects of plant growth regulators-
Synergistic effect- Two or more growth regulators may be similar in their action, when the effect is more than the sum of their individual effects. Example- Auxin and gibberellins cause stem elongation by different mechanism while ABA and ethylene inhibits stem growth. Antagonistic effect-when the action of two growth regulators is opposite it is called antagonistic. Example- auxin promotes apical dominance but cytokinins oppose. Citrus fruit degreenig is done by the use of ethylene while re-greenig is done by the use of GA3.
Plant growth promoters are- Auxins, Gibberellins, Cytokinins and Brassinosteroids.
Plant growth inhibitors are- Abscisic acid and Ethylene.

Auxin
FW Went (1926) discovered the growth substances from the coleoptiles tip of oat seedling which he named Auxin. First time Kogal isolated it from human urine. These are generally produced by the growing apex of roots and stems (3:1) of the plant. Precursor-Tryptophen

Types of auxin
Natural- Indole 3-acetic acid (IAA)
Synthetic-2, 4-D, IBA, NAA

Role of auxin in plant health
Apical dominance, cell division and cell enlargement, shoot and root growth, flower initiation, tissue culture, plant growth, parthenocarpy, prevention of abscission layer etc.

Gibberellins
Second most important growth Hormone. Name given by Yabuta and Sumiki (1938). Gibberellins are named after the fungus *Gibberella fujikuroi*, which causes bakanae of foolish

seedling disease in rice plants to grow abnormally tall (Kurosawa *et al.*, 1926). It is produced in the shoot apex mainly in the leaf primordial (leaf bud) and root system, hence they translocate easily in the plant in both directions. Precusor-Kaurene.

Role of gibberellins in plant health
Prevention of genetic dwarfism, Bolting and flowering, Germination, Fruit setting, Breaking of dormancy and Flowering in long day plant.

Cytokinine
First isolated from coconut milk. Miller, Skoog and their coworkers isolated the growth factor responsible for cellular division from a DNA preparation calling it as Cytokinin (1951). It is synthesized in root apex, endosperm of seeds, young fruits, where cell division takes place continuously. Precusor-Isopetenyl adenine.

Role of cytokinine in plant health
Cell division, Cell and organ enlargement, Seed germination, Root initiation and growth, breaking dormancy and bud development and shoot growth.

Abscisic acid
It is also known as dormins, which acts as anti-Gibberellins. It is synthesized in leaves of wide variety of plants. Responsible for closing stomata during drought conditions, hence acts as plant stress hormone. Discovered by Addicott and his co-workers (1964). Precursor-Violaxanthin.

Role of Abscisic Acid in plant health
Abscission, dormancy, Inhibit seed development and germination, Stomatal closing and Antagonism.

Ethylene
First observed by Neljubow (1901). Ethylene is a colorless gaseous hormone found in ripening fruits, flowers, leaves and nodes of stem. Synthesis of ethylene is inhibited by carbon dioxide and requires oxygen. Precursor-Methionine.

Role of ethylene in plant health
Fruit ripening, seedling growth and emergence, growth inhibition, epinasty, thinning in apple, flowering and sex expression.

PGRs used for fruit retention/drop
The minimum percentage of fruit drop (23.00%) was observed in 0.2 percent boron + NAA 150 ppm, reported by Rajput *et al*., (2015) [56]. Similar results were found by Singh *et al*. (1996) and Rajput *et al.* (1977) they reported that the spray of NAA (200ppm) resulted in reduced flower or fruit drop in guava cv Allahabad Safeda. Lal *et al*., (2013) [32] reported that It was minimum (38.80%) under 50 ppm GA_3.
Almeida *et al*., (2004) [2] and Davies & Zalman (2006) [13] reported that application of 2, 4-D, GA_3 & some other plant growth regulators significantly reduced the pre-harvest fruit drop in citrus species. Nagargoje *et al*., (2007) [39] reported that foliar application of 100 ppm NAA at 50% flowering and at pea stage of fruit reducing flowers and fruit drop as well as in increasing fruit set and fruit retention. Gill and Bal (2013) [17] recorded the minimum fruit drop (58.52%) in case of ber cv Umran as compared to control (89.44%) with the application of NAA @ 30 ppm during the second fortnight of October and again superimposed during second fortnight of November.
The effect of NAA (20 ppm) and GA_3 (15 ppm) on fruit retention in ber cv. Banarasi Karaka was studied by Pandey (1999) [44]. They reported that both the treatments resulted in higher fruit retention i.e. 10.30% and 10.18% respectively as compared to control. Similarly, application of urea 2% along with NAA@20 ppm resulted in higher fruit retention in ber cv. Gola (Bhati and Yadav, 2004) [5]. Tripathi *et al*., (2009) [71] noted that, among the various treatment GA_3 40 ppm decreased the fruit drop (74.25%) in ber cv. Banarasi karaka.

PGRs used for fruit set
Rajput *et al*., (2015) [56] observed that maximum percentage of fruit set (76.33%) was observed with 0.2 percent boron + NAA 150 ppm. Kaur and Kaur (2016) studied the effect of different concentrations of NAA (5, 10 and 15 ppm) and GA_3 (10, 15 and 20 ppm) when applied at fruit set in case of cape gooseberry cv. Aligarh. Among all the treatments, the maximum fruit set was recorded in NAA (15 ppm) concentration i.e. 71.40 percent more than that of control.
The effectiveness of plant growth regulators on tissue cultured papaya cv. Red lady was observed by Hazarika *et al*., (2016) [20]. Different concentration of growth regulators i.e. BA (100, 150 and 200 ppm), GA_3 (100, 150 and 200 ppm), NAA (100,150 and 200 ppm), CCC (500, 750 and 1000 ppm) and etherel (200, 300 and 400 ppm) sprayed at 30, 45 and 60 days after planting. They found that the growth regulators significantly increased the fruit set of papaya. Application of GA_3 (200 ppm) resulted in highest fruit set percent (76.46%) and lowest fruit set was recorded in control (47.72%).
Bhujbal *et al*., (2012) [7] studied the effect of plant growth regulators like CCC (250, 350 and 450 ppm), NAA (100, 150 and 200 ppm) and GA_3 (50, 100 and 150 ppm) in sapota cv. Kalipatti. Spraying of growth regulators was done one month before flowering and again at pea stage. Among all the treatments CCC (450 ppm) led to better flowering and fruit set followed by NAA (200 ppm). Agarwal and Dikshit (2008) [1] reported that cycocel (400 ppm) application superimposed with NAA (100 ppm) during different fruit developmental stages in sapota cv. Cricket Ball resulted in higher number of flowers and more fruit set as compared to control.
Revar (2010) [58] noted that, the maximum fruit set was recorded with the foliar spray of GA_3 50 ppm in custard apple. Rajput *et al*., (2015) [56] revealed that, the maximum fruit set (73.33%) was recorded with the foliar spray of 0.2% boron + NAA 150 ppm in guava cv. Lucknow-49. Rao and Livingstone (1984) [54] also recorded more number of fruits with CCC treatment in mango.

PGRs used for yield increment
Prajapati and Singh (2018) [53] reported that maximum fruit was reported with application of foliar spray of NAA@200ppm. Kher *et al*., (2005) [27] and Yadav *et al*., (2001) [72] also reported application of NAA (20, 40, 60 and 80 ppm) sprayed 15 days before harvest increased the fruit weight in guava due to accumulation of sugars and high pulp percentage in sprayed fruits. The highest yield (37.13kg/plant) was found in 50 ppm GA_3 treatment, reported by Lal *et al*., (2013) [32]. The application of NAA@150 ppm at flower initiation, fruit set and then again during the fruit development stage in sapota cv. Kalipatti resulted in the highest fruit number (2633 per tree) and yield i.e. 215.51 kg per tree followed by NAA (100 ppm) and the lowest fruit number (1520.34 per tree) and yield (115.02 kg per tree) was recorded in control Chavan *et al*., (2009) [10]. Gill and Bal (2013) [17] observed that application of GA_3 in ber cultivar Umran during

the second fortnight of October and again during second fortnight of November recorded the highest fruit yield (47.89 kg/tree) as compared to control (14.56 kg/tree). Ghosh *et al*., (2009) [16] observed that, the maximum yield per plant (7.8 kg) was recorded with the foliar application of NAA@25 ppm in pomegranate cv. Ruby. Iqbal *et al*., (2009) [22] revealed that, the maximum yield per plant (44.80 kg) was recorded with the foliar spray of NAA@45 ppm in guava cv. Red flesh. Pawar *et al*., (2005) [50] recorded highest yield in cv. Mridula of pomegranate in Maharashtra with 75 ppm GA_3, while Mohamed (2004) [37] from Asyut (Egypt) recommended 150 ppm of GA_3 for getting heaviest fruit with lowest fruit-splitting in cv. Manfalouti of pomegranate.

PGRs used for fruit ripening

Srivastava and Dwivedi (2000) [69] reported that Salicylic acid treatment delayed the ripening of banana fruits (*Musa acuminata*). Nagaraj *et al*., (1984) [40] reported that calcium carbide treated fruits reduced the number of days required for fruit ripening. Fruits dipped with 500 ppm ethrel, at 52^0C for 5 min. in hot water, observed early and uniform ripening with good colour of fruits compared to other treatments in cv. Alphanso (Das *et al*., 2011) [12]. The ethephon treated fruits improves the peel color and accelerates the mango fruit ripening (Lakshminarayana *et al*., 1975) [71]. The rate of ripening in mangoes can accelerate by treating the fruit with ethylene (Kader and Mitcham, 2008) [25]. Siddiqui and Dhua (2009) [68] also reported that fruit treated with ethrel-500 ppm enhance uniform ripening with comparatively more appealing colour development and increase the organoleptic qualities of the fruits, facilitating the marketability through widening consumers acceptance as a whole. Kulkarni *et al*., (2011) [28] also noted that ethrel @ 500 ppm induced uniform ripening without impairing taste and flavour of banana. Similarly, Mahajan *et al*., (2010) [33] observed that treatment of bananas with ethylene gas (100 ppm) or ethephon (500 ppm) resulted in adequate ripening of fruits after 4 days with uniform colour, pleasant flavour, desirable firmness and acceptable quality and better shelf-life.

PGRs used for fruit storage

The shelf life of aonla fruits was extended up to 16 days at room temperature when the treatment was given in combination of plant growth regulators and boron i.e. NAA 40 mg/l+ GA3 50 mg/l+ Boron 0.50% at pin head and pea stage (Patel *et al.*, 2017).

PGRs used for flower induction

The maximum number of flowers per plant with treatment T_3 [Naphthalene acetic acid (NAA) @ 200ppm] followed by treatment T_2 [Gibberellic acid (GA_3) @ 100ppm] reported by Prajapati and Singh (2018) [53]. Lal *et al*., (2013) [32] reported that maximum number of flowers (16) per shoot was found in 1000 ppm CCC treatment. Bhoye (2010) [6] found that, the maximum number of flowers per shoot (34.00) was recorded with the foliar spray of GA_3 50 ppm in custard apple cv. Balanagar. The maximum number of flowers per shoot (151.21) was recorded with the foliar spray of NAA@150 ppm in phalsa, observed by Kacha *et al*., (2012) [24].

PGRs used for fruit quality improvement

Prajapati and Singh (2018) [53] reported that maximum TSS and total sugars were reported with application of foliar spray of NAA @ 200ppm. Biswas *et al*., (1988) [9] also reported that the TSS increased due to its action on converting complex substances into simple ones, which enhances the metabolic activity in fruits. In case of total sugar, application of ethrel (ethephon) at 0.250 ml/lt. resulted in higher total sugar content in guava, further Sandhu and Bal (1989) [59] also found similar trend in ber, due to the ethrel promoted hydrolysis of starch into sugars. Mango fruit ripened with 600 ppm of ethrel had the higher TSS, ascorbic acid content and carotenoids but the least reducing sugars (Mann, 1974) [35]. Yadav *et al*., (2001) [72] find out that foliar spray of GA_3 increased total sugar content in guava. Kumar and Singh (1993) [30] found that GA_3 at 30 ppm pre-harvest sprays in mango significantly improved fruit quality. Anawal *et al*., (2015) [3] reported that NAA application @ 40 ppm at full bloom stage in pomegranate cultivar Bhagwa resulted in maximum fruit length (8.65 cm), fruit diameter (8.71cm), fruit volume (255.44 ml), fruit weight (262.23 g), TSS (16.76 °B), total sugars (15.58%), non-reducing (1.75%) and reducing sugars (13.83%) as compared to control. Garhwal (2015) [15] studied the effect of GA_3 application @ 100 ppm on fruit quality of sapota cv. Kalipatti during the full boom and pea stage. He reported the maximum TSS, reducing sugars, non-reducing sugar, total sugar and ascorbic acid content (19.28°Brix, 8.45%, 3.89%, 12.34% and 9.81 mg/100g pulp respectively) as compared to control (15.99 °Brix, 6.78%, 2.80%, 9.59% and 6.25 mg/100g pulp respectively). Patil (2006) [49] reported that reducing, non-reducing and total sugars were more in GA_3 as compared to NAA. The treatment GA_3 (150 ppm) recorded highest percentage of reducing sugar (10.28 percent) and non-reducing sugar (5.96 percent).While the treatment GA_3 (100 ppm) recorded 9.95 percent reducing sugar (5.78 percent), non-reducing sugar. The treatment control recorded least percent of reducing sugar (9.02 percent) and non-reducing sugar (4.25 percent). Nawaz *et al*., (2008) [42] observed that, the maximum fruit size (72.80 mm) was recorded with the foliar spray of GA_3 10 ppm in kinnow mandarin. Arora and Singh (2014) observed that, the maximum fruit volume (24.42 cc) was recorded with the foliar spray of NAA@30 ppm in ber cv. Umaran. Chandra *et al*., (2015) [11] observed that, the maximum fruit volume (40.33 cc) was recorded with the foliar spray of GA_3@25 ppm in aonla cv. NA-7.

PGRs used for seed treatment

Treatments of guava seeds with 5,000 ppm ethephon resulted in 72 percent germination and yielded plants with longer shoots and more laterals (Sinha *et al*., 1973) [67]. Effect of different water and acid soaking periods on seed germination were studied in guava cv. Allahabad Safeda. Seeds soaked in water for 36 hours exhibited an increased percentage germination (90%) and a reduced time for seedling emergence in comparison to seeds soaked in H_2SO_4, HCl and HNO_3 (Pandey and Singh, 2000) [45]. Singh *et al*., 2002 [62] reported that treated seeds of jackfruit viz., 100ppm GA_3 gave highest germination percentage with fastest germination. The effect of seed treatments with growth regulators (250 and 500 ppm GA_3, 250 and 500 ppm thiourea), chemicals (sulphuric acid) and distilled water on seed germination of wild ber (*Zizyphus nummularia*) were studied and the highest percentage of seed germination was recorded with 500 ppm GA_3 (Rajwar *et al*., 2007) [57].

PGRs used for root enhancement

Stoutemeyer (1942) [70] studied and reported that IBA is a strong auxin, used for rooting in cuttings. Hassing (1972) [19] reported that the division of the first root initial cells depends

upon either applied or endogenous auxin. Singh and Singh (1964) reported that the IBA at 2000 ppm gave 90% rooting and success with Sweet lime and Lemon cuttings. Singh and Sandhu (1981) studied the rooting and sprouting of stem cutting of peach and reported that the IBA at 500 ppm resulted in higher rooting and maximum root and shoot length. Pande and Das (1990) [43] obtained highest percentage of rooting of cuttings (76.10%) with hard wood stem cuttings of pomegranate treated with 500 ppm IBA. Panwar *et al*., (2001) [46] suggested that the basal end of cuttings of pomegranate cv. Ganesh dipped in IBA (750 ppm) solution for one minute, gave the highest value for almost all root and shoot parameters. Gupta and Brahmachari (2004) [18] reported that IBA + NAA at 5000 ppm exhibited the best result by recording 88.87% rooting and 70.79% of survivality of layers in nursery after 180 days with stool layers in custard apple. Singh and Pathak (2012) [63] reported that IBM@1500 ppm is the best treatment in respect of percent rooted air layers, number of primary roots, number of secondary roots, root quality and percent establishment on air layering of Barbados cherry. Manga *at el*., (2017) [34] reported that the minimum days for root initiation (84 days), maximum number of roots, higher rooting and survival percentage in layers prepared in the month August applied with IBA-4000 ppm. Growth of these layers was vigorous as depicted by maximum number of sprouts, number of leaves and shoot length at 90 days after separation from mother plant layers placed under shade house for hardening. Patel *et al*., (2007) [48] reported that the highest budding success, maximum length of sprouts, number of leaves/plant, leaf width and minimum number of days taken for sprouting was recorded in cultivar Allahabad Safeda. While, sprouts girth and leaf length was recorded under cultivar Hybrid-1. Seed treatments, soaking in GA_3@3000 ppm for 24 hours resulted in significantly higher seed germination, co-efficient of germination velocity, shoot length, seedling girth, vigour index, maximum number of leaves per seedling, leaf area, fresh weight and dry weight of seedlings (Munthaj, 2014) [38].

PGRs used for canopy management

Phawa *et al*., (2017) [51] reported that with the application of 75ppm GA_3 maximum canopy volume is obtain in pomegranate cv. Kandhari. Same findings also observed by Eelkim *et al.* (2003) [14] in mandarin, Sharma (2004) [61] in apple, Saleem *et al.* (2007) [60] in sweet orange and Kumar *et al*., (2012) [29] in strawberry.

PGRs used for others

Nalawadi *et al*., (1977) [41] revealed that the pollen viability of local cultivar was 96.3 percent, but in case of Kalipatti, Cricket Ball and Calcutta Round it was 97.7, 97.7 and 97.6 percent respectively. Similarly, Piatos and Knight (1975) [52] also observed that pollen viability was more than 95 percent in all the three different sapota cultivars. The pollen viability in cricket ball, kallipatti and chhattri was 84.0, 97.6 and 92.9 percent respectively (Minhas, 1982) [36]. Jain *et al*., (2007) [23] observed that, the minimum days required for harvesting (115.50 days) was recorded with the foliar spray of ethrel 500 ppm in guava cv. Sardar. Bhoye (2010) [6] observed that, the minimum days required for harvesting (113.00 days) was recorded with the foliar spray of NAA@30 ppm in custard apple cv. Balanagar. Bhujbal *et al*., (2013) [8] revealed that, the minimum number of seeds per fruit (1.420) was recorded with the foliar spray of GA_3 150 ppm in sapota. Hoda *et al*., 2013 [21] reported that the extent of fruit cracking was reduced significantly with application of 300 ppm pacloputrazol, while grain%, fruit juice%, TSS% and acidity% were increased.

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