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Effect of plant growth regulators on fruit crops

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Abstract
The plant hormones are extremely important agent in the integration of developmental activities. Environmental factors often exert inductive effects by evoking changes in hormones in metabolism and distribution within the plant. Apart from it, they also regulate expression of intrinsic genetic potential of plants. Control of genetic expression has been demonstrated for the phytohormones at both transcriptional and translational levels. Also, hormones receptors and binding proteins have been identified on membrane surface that are specific for some hormones.The use of growth regulators has become an important component of agro-technical procedures for most of the cultivated plants and especially for fruit plants. So far in fruit crops, excessive fruit drop can be controlled by the exogenous application of plant growth regulators. The auxin and gibberellins are widely used to control the fruit drop and to improve the quality of fruit. Ontogenic development from fruit set to fruit ripening and final reach to customer, several agents are responsible for elimination of some fruits from fruit set to final maturity. In this review, we focus on the major functions of plant growth regulators in fruit production.

Keywords: Plant growth regulators, fruit, physiological, yield, growth

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. Thimmann proposed the term *Phyto hormone* as these hormones are synthesized in plants. *Plant growth regulators* include auxins, gibberellins, cytokinins, ethylene, growth retardants and growth inhibitors. Auxins are the hormones first discovered in plants and later gibberellins and cytokinins were also discovered. During the last 50 years considerable research work has been done in the country on various aspects such as varieties, propagation, irrigation, training and pruning etc. to increase the yield and quality of guava fruits. The production of poor quality fruits is a matter of common experience. It would be therefore worthwhile to improve the yield and quality of fruit crops by foliar application of plant growth regulators. The use of plant growth regulators has assumed an integral part of modern crop husbandry for increasing production of quality fruits. The plant hormones or regulators are the organic chemical compounds, which modify or regulate physiological processes in an appreciable measure in the plant when used in small concentration. They are readily absorbed and move rapidly through the tissues, when applied to different plant parts. These chemicals are specific in their action. In other words, plant growth regulators are organic substances (other than nutrients), which in small amount promote, inhibit or otherwise modify any physiological process in plants. Thus the use of plant growth regulators has resulted in some outstanding achievements in several fruit crops with respect to growth, yield and quality.

Essentiality of NAA

NAA is a synthetic auxin plant hormone that is routinely used for the vegetative propagation of plants from stem and cutting. The effect of NAA on plant growth is greatly dependent on the time of admission and concentration. NAA has been shown to greatly increase cellulose fiber formation in plants. In majority of fruit plants fruit drop is controlled by spraying of NAA in different fruit crops in different concentration. It is applied after blossom fertilization.

Effect of NAA on fruit crop

Maibangra and Ahmed (2000) [42] treated pineapple plant with 100 ppm NAA and it was found increased yield as compared to control. Choi and Minsoon (2001) [17] reported that application of NAA in “Fuji” apple significantly decreased shoot growth and re-growth rate. They further concluded that 2 or 3 application of NAA (60-70 days after full flowering) at the concentration of 10 to 40 mg / l can control the canopy size in high density orchard system. Ingle *et al*. (2001) [32] revealed that foliar application of NAA @ 30 ppm increased the fruit weight, acidity, juice per cent peel and yield over control in Nagpur mandarin. In an experiment effect of ambient temperature and defoliation on flower bud induction with chemicals in pineapple, Sawale *et al.* (2001) [59] found significant superior quality of fruits with respect to TSS, acidity and ascorbic acid content of juice. Yadav *et al.* (2001) [71] concluded that fruit weight, organoleptic rating, TSS, ascorbic acid and total sugar content of guava fruits increased significantly over control by the application of NAA @ 20 to 60 ppm and decreased fruit pressure (kg / cm^2) significantly to make it more acceptable. Yeshayahu *et al.* (2001) [72] stated that spray of 300 ppm NAA increased fruit size in 'Myovaze Satsuma' mandarin and NAA also thinned the fruit-lets and decreased total yield. Baghel and Tiwari (2003) [8] concluded that spray of 6 per cent urea and 150 ppm NAA in mango found superior for increasing the total number of flowers/panicle and percentage of hermaphrodite flowers. However, maximum flowering and fruiting and number of fruits/tree was recorded under combined application of 4 per cent urea and 150 ppm NAA. Greenberg *et al*. (2006) [26] observed the effect of spray of NAA 300 ppm on yield, fruit size, fruit quality, fruit splitting and the incidence of creasing in 'Nova' mandarin. The early NAA spray, thinned fruit lets, increased fruit size, decreased splitting to 30 per cent, decreased the incidence of creasing to 28 per cent compared to 36 per cent in the control, and had no effect on the yield. Harhash and Al-obeed (2007) [27] studiedeffect of different concentrations of NAA in Barhee and Shahi date palm cultivars on the bunch weight and both physical and chemical properties during two successive year 2005 and 2006. The observed that NAA (0, 50, 100, 150 and 200 ppm) applications on fruits of Barhee and Shahi cultivar.10 weeks after fruit set at depressed period resulted that application of 150 ppm NAA increased the yield and improve fruit quality. Stern *et al*. (2007) [65] reported that the application with 25 ppm 2,4-dichlorophenoxyacetic acid (2,4-D) plus 30 ppm naphthaleneacetic acid (NAA; 0.3% AmigoTM), at the beginning of pit-hardening when fruitlet diameter was ca. 13 mm caused appreciable and significant increases in fruit size and total yield, except when the crop load was heavy. Nawaz *et al*. (2008) [51] studied the effect of foliar sprays of NAA @ 10, 15 and 20 ppm in Kinnow mandarin and maximum Vitamin C contents (45.30 mg/100g) was found in 15 ppm NAA. Iqbal *et al.* (2009) [33] applied with 15, 30, 45, 60, 75 and 90 ppm NAA through foliar spray and reported that 45 ppm spray reduced pre-harvest fruit drop, increased yield, pulp/acid ratio (11.31), TSS (11%), total sugar (7.45%), acidity and ascorbic acid in guava. Asin *et al*. (2010) [7] observed that application of NAA @ 40 ppm in pear cv. 'Conference' and 'Blanquilla' and improved fruit retention per cent and fruit yield. Hasami and Abdi (2010) [28] found that of NAA @ 100 ppm increased bunch weight, improved physical properties (fruit weight, height, diameter and size), decreased TSS, total and reducing sugar in date palm. Kassem *et al*. (2010) [35] found that application of NAA at pea stage and marble stage in "Costata" persimmon significantly increased vegetative growth, fruit retention and fruit yield in both the seasons. Ghosh *et al*. (2012) [25] application of different doses of NAA @ 15, 20, 25 and 30ppm and observed that sprayed of NAA at 15 ppm was the most effective in reducing the fruit drop at different months after fruit set which resulted in doubling of fruit production as compared to control and improved fruit size in sweet orange. Kacha *et al*. (2012) [34] studied that application of NAA in phalsa and recorded that spray of 200 ppm NAA resulted maximum height of bush (177.33 cm) and length of shoot (99.17 cm).

Essentiality of GA_3

Gibberellins control fruit development in various ways and at different developmental stages. Fruit development is a complex and tightly regulated process. Growing fruits are very active metabolically and act as strong sinks for nutrients with hormones possibly modulating the process (Brenner and Cheikh, 1995) [10]. The development of a fruit can be separated into phases that include pre-pollination, pollination, fertilization and fruit set, post fruit set, ripening and senescence. The successful fertilization of the ovule is followed by cell division and cell expansion resulting in the growth of the fruit. Gibberellins are known to influence both cell division and cell enlargement (Adams *et al.,* 1975; Kamijima, 1981) [2, 37].

Effect of GA_3 on fruit crop

Ingle *et al*. (2001) [32] revealed that foliar application of GA_3 @ 25 ppm increased the fruit weight, volume, TSS, ascorbic acid, peel and yield over control in 'Nagpur' mandarin. Eel Kim *et al.* (2003) [19] application in Satsuma mandarin with GA_3 at 0, 25, 50 and 100 ppm and reported considerably decreased the number of flowers and increased the number of vegetative shoots. Fruit set rate showed an increasing tendency as the GA_3 level increased and increase fruit size. El-Sabagh and Ahmed (2004) [20] reported that application of GA_3 at 90ppm in 'Anna' apple was found in the highest total soluble solid percentage and yield. Studied in citrus fruit plant spray with 100 ppm GA_3 was found delayed chlorophyll degradation, inhibited carotenoid beta-cryptoxanthin biosynthesis and accumulation, which inhibited the development of fruit colour and lustre. Chao and Lovatt (2006) [16] found that application of 10 ppm GA_3 at 60 per cent full bloom, 75 per cent petal fall and in early July or 25 ppm at 60 per cent and 90 per cent full bloom, 75 per cent petal fall and 10 days after 75 per cent petal fall reduced total yield relative to the untreated control and application of GA_3 (15 or 25 ppm) at 60 per cent and 90 per cent full bloom, 75 per cent petal fall and 10 days after 75 per cent petal fall resulted in retention of significantly more fruit and increased yield. Modesto *et al.* (2006) [46] studied the effect of foliar sprays of GA_3 at 0, 5, 10, 15 and 20ppm in 'Ponkan' mandarin and reported, delay in fruit harvesting, which was induced by the physiological effect of GA_3. Saleem *et al.* (2008) [56] observed that application of GA_3 in 'Blood Red' sweet orange has reduced fruit weight, diameter, peel thickness and peel quality, improved juice content (%), pulp (%), reducing sugar, non-reducing sugar, total sugar, TSS (%) and Vitamin C. Sharma and Singh (2008) [60] observed that application of GA_3 at 10 ppm in plum, proved more effective in promoting tree growth and fruit weight and volume and increased yield. Garner *et al*. (2011) [22] working in 'Hass' avocado reported that foliar application of GA_3 at 25ppm increased yield and fruit size. Moneruzzaman *et al*. (2011) [47] found that application of GA_3 in red jambu air madu fruits (*Syzygium samarangense*) increased fruit length and diameter. Furthermore, it enhanced faster fruit growth and colour development in addition to increasing fruit number, weight and yield. It also decreased premature fruit dropping. However, spraying with 20 ppm GA_3 increased the number of buds and fruit setting and reduced bud dropping before anthesis. With regard to fruit quality, the application of GA_3 at 50 ppm increased total soluble solids (TSS), total sugar, total biomass and total flavonoids content in the fruits by 112, 97, 45 and 92 per cent compared with the control treatment. Bhujbal *et al*. (2012) [11] found that application of GA_3 at 50, 100 and 150 ppm was showed that spray of 150 ppm GA_3 earliness in sprouting of new shoot, increased shoot length and maximum number of leaves per shoot in sapota. Kumar *et al.* (2012) [38] observed that the application of GA_3 in strawberry at 80 ppm improved vegetative growth, runner production, ascorbic acid and acidity. Reddy and Prasad (2012) [55] reported that the spray with GA_3 75ppm has increased fruit size and yield in pomegranate cv. Ganesh. Khalid *et al*. (2012) [36] working in young 'Kinnow' mandarin found that the spray of gibberellic acid 10 ppm at fruit setting stage and their effect on fruit quality was evaluated immediately after harvest. The PGRs alone had significant influence on juice mass (%), rag mass (%), ascorbic acid (mg 100 mL-1) and reducing sugars (%) whereas, rind mass (%), TSS, titratable acidity (TA), TSS:TA and total sugars (%) were not affected by PGRs applications.

Essentiality of 2,4-D

Endogenous hormones and their balance play a modulating role in the mobilization of nutrients to the developing organs and can influence the longevity of a bud. The dependence of abscission relative to the endogenous content of auxins has been proven by exogeneous application of 2,4-D or NAA, as the transportation of auxins by the plant lasts for a long time without ethylene appearing to affect it.

Effect of 2,4-D on fruit crop

Medeiros *et al.* (2000) [45] found that application of 2,4-D @ 10 ppm has given the best pre-harvest fruit drop control in 'Hamlin' orange. Ingle *et al.* (2001) [32] revealed that foliar application of 2,4-D @ 10 ppm increased the fruit weight, volume, TSS, ascorbic acid, peel and yield over control in Nagpur mandarin. Greenberg *et al*. (2006) [26] observed the effect of spray with 2,4-D, 40 ppm on yield, fruit size, fruit quality, fruit splitting and the incidence of creasing in ‘Nova’ mandarin and found that early spray of 2,4-D decreased fruit splitting to 25 per cent, increased yield to 50 kg/tree compared to 37 kg/tree in the control, increased fruit size and had no effect on the incidence of creasing. Stern *et al.* (2007) [65] observed that application of 25 ppm 2,4-D plus 30 ppm NAA at the beginning of pit-hardening in cherry caused appreciable and significant increases in fruit size, total yield and fruit quality. Nawaz *et al*. (2008) [51] studied the effect of foliar sprays of 2,4-D at 10, 20 and 30 ppm in Kinnow mandarin and found lowest fruit drop of 12.95 per cent, increased number of fruits/plant and fruit weight/plant. In this case maximum TSS (12.03%), Reducing sugars (3.44%), Non-reducing sugars (5.75) and Total sugars (8.86%) were found in 30ppm 2, 4-D and minimum acidity (0.78%) was found in 10ppm 2, 4-D. Amiri *et al.* (2012) [4] applied 0, 10, 30 and 60 ppm 2,4-D through foliar spray and found that 60 ppmspray reduced pre harvest drop compare to control, significantly decreased percent of small, very small fruit size and increase large and marketable fruit size in Satsuma mandarin. Reddy and Prasad (2012) [55] reported that application of 2,4-D at 20, 30 and 40 ppm three times starting at full bloom and, subsequently, at 45 and 90 days after fruit set in pomegranate cv. Ganesh, has resulted significantly increased fruit size in length, breadth and volume and higher fruit weight (262.23g), higher aril percent and maximum number of fruits (64.00) which resulted in highest fruit yield of 16.78 kg/plant. Ashraf *et al*. (2013) [5] conducted an experiment to see the influence of 2,4-D in Kinnow and observed improved fruit weight, more number of fruits per plant, juice percentage, total soluble solids (TSS), ascorbic acid content, acidity, TSS/acid ratio, and reduced the fruit drop.

Essentiality of Triacontanol

Triacontanol is a natural plant growth regulator found in epicuticular waxes. It is used to enhance the fruit production. Quite a number of researchers have reported the TRIA-mediated improvement in growth, yield, photosynthesis, protein synthesis, uptake of water and nutrients, nitrogen-fixation, enzymes activities and contents of free amino acids, reducing sugars and soluble protein. Expectedly, TRIA enhances the physiological efficiency of the cells and, thus, exploits the genetic potential of plant to a large extent.

Effect of Triacontanol on fruit crop

Mandal and Kumar (1989) [43] found that foliar spray of triacontanol in the form of mixtalol @ 6 ml/10 l water was found to be effective with respect to length of terminal shoot, number of leaves and increase in leaf area. Further, plants sprayed three weeks before fruit set was better than those sprayed three weeks after fruit set and control. Nagalaxmi and Gunasekaran (1989) [49] reported that the total number of leaves and growth of ‘Poovan’ banana was maximum, when triacontanol was applied three times at the rate of 5 g / plant in vermiculture medium. Similarly, Mahajan and Sharma (1999) [41] observed that application of triacontanol at 10 and 20 ppm in plum significantly increased fruit size, weight and TSS content of fruit. Power *et al.* (2000) [53] found that spray of 0.5 per cent triacontanol resulted in the highest value for vine length, number of leaves and 100 leaf weights in betel vine. Similar beneficial effect of triaontanol on vegetative growth of betelvine was also recorded by Arulmozhiyan (2000) [6]. Application of 3 ppm triacontanol in tea plant increased leaf area, leaf : shoot ratio and dry matter content (Barua and Das, 2000) [9]. Power *et al.* (2000) [53] found that spray with 0.5 per cent triacontanol resulted in the highest value for vine length, number of leaves and 100 leaf weights in betelvine. Ghawade *et al*. (2002) [23] studied of physico chemical characters of the fruits in Nagpur mandarin located at different sides of trees and found that, fruits located inside the tree contain less TSS and acid whereas, those exposed in the sun had more total soluble solids, ascorbic acid and rapid colour development resulting in early ripening. Sprayed triacontanol on temperate fruits and highlighted its effect on plant growth characteristics, fruit set, yield and quality. Studied the influence of foliar application of nutrients and bioregulators on growth, fruit set, yield and nut quality in walnut cv. Local Selection. Sharma *et al.* (2008) [60, 61] found that application of triacontanol at 2.5, 5.0, 7.5 and 10.0 ppm thrice, viz., 7 days before full bloom, 15 days after full bloom and one month after second application in apple cv. Red Delicious and recorded that spray of 7.5ppm triacontanol increased shoot extension growth, fruit set, fruit quality and fruit yield significantly in comparison to other triacontanol treatments. Sharma and Singh (2008) [60] observed that application of triacontanol at 5 ppm in plum proved more effective in promoting tree growth, fruit weight, volume and increased yield. Shinde *et al.* (2008) [64] reported that application of triacontanol at 300, 500, and 700 ppm at flowering, pea and marble stage of fruit development in mango cv. Parbhani

Bhusan and showed that spray of 700 ppm triacontanol significantly given maximum length (10.91 cm), breath (8.91 cm), volume (336.58 cm3), weight (330.41 g), mesocarp (69.92%) and lowest proportion of endocarp (12.00%). Chowdhary *et al*. (2009) [18] found that spray with triacontanol 0.05 per cent in two cultivars of water chestnut and observed increased the volume of individual fruit by 45.32 per cent in Haldipada green and 47.11 per cent in Haldipada red cultivars and the fresh fruit yield also increased 32 per cent in green and 31.25 per cent in red cultivars, But the soluble carbohydrate content in fresh fruits decreased by 25.46 per cent to 29.61 per cent in triacontanol treated green and red fruit cultivars.

Essentiality of Paclobutrazol

Paclobutrazol is probably the most widely used PGR in the production of fruit crops because of its wide range of efficacy and moderate- to long-lasting response. Applications of paclobutrazol, particularly when delivered as a spray, delay flower development and reduce flower size. Paclobutrazol is absorbed by roots and stems, and to a lesser extent, by leaves. Therefore, it can be applied as a spray, sprench, drench, or bulb or young-plant dip. Sprays are more effective when they penetrate plant canopies so that there is contact with stems. The post-harvest application of a small amount of paclobutrazol to the soil significantly promotes flowering and fruiting in the following year. Therefore, early and proactive applications are strongly recommended, and late applications should generally be used as a last resort.

Effect of Paclobutrazol on fruit crop

Application of paclobutrazol @ 1000 ppm in 'Fuji' apple reduced the shoot growth significantly over control. Paclobutrazol significantly suppressed the increase in tree height and canopy volume in mango. Kurian and Iyear (1993) [39]. Sarkar *et al.* (1998) [58] summarized that Although suppression of increase in the girth, spread and number of leaves were recorded and found statistically non significant. Similarly in grape the spray of paclobutrazol increased berry set, bunch size, yield and quality in respect to T.S.S and acidity of fruit (Sherawat *et al.,* 1998) [62]. Hussein *et al.* (1998) [30] observed that application of paclobutrazol @ 150 ppm as foliar spray and 6 g / tree as soil drench reduced vegetative vigour like shoot length, shoot thickness, internode numbers etc. in order to improve tree productivity and fruit quality and also had significant positive effect on yield/tree in fig cv. 'Sultania'. Early flowering and fruiting was also recorded by application of paclobutrazol in mango (Sao Jose and Rebounces, 2000) [57]. Similarly, Lichev *et al.* (2001) [40] found that application of cultar (25% paclobutrazol) significantly inhibited the annual shoot growth and improves photosynthetic activity which may increase yield in cherry. Application of paclobutrazol 10 g / tree in mango resulted reduced tree height (21.20%), tree volume (33.1%) and mean shoot length (48.2%). This response was attributed to GA – inhibitory activity of paclobutrazol (Murti *et al.,* 2001) [48].

Essentiality of CCC

Chlorocholine Chloride (CCC) is gibberellins biosynthesis inhibitor involved in the inhibition of cyclization of geranyl-geranyl pyrophosphate to copyallyl pyrophosphate. The chemical control of the plant growth to reduce the size through the use of plant growth regulators is a common practice to make a plant more compact and commercially more acceptable. A number of synthetic compounds are known to manage shoot growth in higher plants without being phytotoxic or causing malformation or damage.

Effect of CCC on fruit crop

Application of 3000 ppm CCC at 15 leaf stage in grape was found to be highly effective in increasing the yield / vine. Yield increased on account of growth retardant was mediated through increased number of cluster / vine (Shikhamany and Reddy, 1989) [63]. Brahmachari *et al.* (1995) [12] studied effect of foliar spray (one before flowering and one a month after fruit set) of NAA, PCPA, 2,4,5-T,GA_3, Kinetin and CCC in 6 years old guava cv. Sardar and observed that spray of 250 and 500 ppm CCC has enhanced fruit set as well as improved weight and quality of fruit. Brahmachari *et al.* (1996) [13] reported that all the growth substances increased flowering, fruit yield and quality compared with no treatment. However, CCC @ 500 ppm induced the earliest flowering and highest number of flowers, fruit set, retention and yield. Cycocel spray at 1500 ppm increased bunch size and yield in grape (Sherawat *et al.,* 1998) [62]. Similarly in mango Sarkar *et al.* (1998) [58] found that application of CCC @ 750 to 3000 ppm increased the yield significantly over control in mango by improving the number of fruits / tree and weight of fruit. The foliar application of 100 and 200 ppm cycocel in grape increased per cent bud burst and advanced the peak on set of bud burst to an earlier date than control (water sprayed) and GA_3 treated plants (Marizouk *et al*., 1998) [44]. Nath and Baruah (1999) [50] conducted an experiment on regulation of flowering time, plant growth and yield in 'Assam' lemon with the help of pruning and growth regulators. They reported that spray of 3000 ppm CCC in lemon gave the highest yield. Which resulted the maximum net returns and benefit cost ratio. Albuquerque *et al.* (2000) [3] found that application of 1500 ppm CCC increased the number of fruiting buds in grape. In red raspberries cv. 'Autumn Bliss' Ghora *et al.* (2000) [24] conducted an experiment on effect of growth retardants (CCC, daminozide and paclobutrazol) on growth and development under plastic green house condition and found that application of 500 ppm CCC enhanced anthesis and fruit ripening by about 10 days. In an experiment on effect of growth substances on flowering and fruiting characters of 'Sardar' guava.

Essentiality of Etheral:

Ethylene is a naturally occurring plant growth substance that has numerous effects on the growth, development and storage life of many fruits crops. Harvested fruits may be intentionally or unintentionally exposed to biologically active levels of ethylene and both endogenous and exogenous sources of ethylene contribute to its biological activity. Ethylene synthesis and sensitivity are enhanced during certain stages of plant development, as well as by a number of biotic and abiotic stresses. Ethylene production is promoted by stresses such as chilling (Wang, 1990) [70] and wounding (Abeles *et al*., 1992) [1], and this stress-induced C_2H_4 can enhance fruit ripening. However, these stresses also induce other physiological changes and it is difficult at time to reduce whether it is the stress or one of the stress-induced changes that is producing the effect. Phenylpropanoid metabolism is enhanced by ethylene, and certain phenolic compounds have been associated with a reduction in certain diseases (Hertog *et al*., 1992; Frankel *et al*., 1995) [29, 21].

Effect of Ethrel on fruit crop

Brahmachari *et al.* (1995) [12] reported that application of ethrel at 25 or 50 ppm in guava enhanced fruit set percentage, weight, quality of fruit while, reduced number and weight of seeds thereby increased pulp / seed ratio. In a study on induction flowering in off year mango cv. "Alphonso" as influenced by chemicals and growth regulators, the foliar spray of ethrel @ 200 ppm has increased number of flowers / panical. (Vijaylakshmi and Srinivasan, 1998) [69]. Turn bull *et al.* (1999) [68] studied routes of ethephon uptake in pineapple and reasons for failure of flower induction and found that ethylene releasing agents such as ethephon are used widely to induce flowering in pineapple. Likewise, Similarly, Ramburn (2001) [54] reported that foliar application of 0.5 gm PBZ + 0.4 gm ethephon / l promoted flowering in litchi with erratic fruiting. Onaha *et al.* (2001) [52] found higher percentage of flower bud induction in pineapple by application of ethephon.

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