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Transforming fruit production by plant growth regulators

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Abstract
Naturally occurring phytohormones, their chemical analogs, hormone-releasing agents, hormone sensitivity altering agents and hormone synthesis inhibitors collectively form plant growth regulators (Hajam *et al*, 2017). In order to increase the yield of monoecious crops, the increase female flowers are prerequisite for the same, Ethrel (250-1000 ppm) and CPPU (20-80 ppm) sprays work to induce female and intersexual flowers in male plants of papaya (Kumar, 1998). Fruit quality fulfillment comes to be a paramount concern of the researchers and fruit grower's important goal, particularly regarding optimising size, increasing firmness, TSS and protection against russeting, sunburn and other physiological disorders. Foliar sprays of PGRs (GA_3 at 20-40 ppm or NAA at 25-50 ppm) enhanced apple yield and fruit quality traits (Osama *et al.*, 2015). GA_3 increase fruit size, improves fruit firmness, increases vitamin-C, TSS, total sugars, sweetness index and overall sensory ratings of 'Red Delicious' apples (Hajam, 2017). Gibberellic acid and salicylic acid are also reported to increase yield, fruit acidity, reducing sugars, TSS, TSS/ acid ratio, fruit firmness and fruit chlorophyll a and b content peach trees (El-Shazly, 2013). Ethylene serves as a key ripening hormone of climacteric fruits and can influence ripening in many non-climacteric fruits (Giovannoni *et al.*, 2010). Treatment with high concentrations of ethylene stimulates respiration and increases the levels of fatty acids (FA) and volatiles and at the same time decreases firmness (Banday, 2006; Harb *et al.*, 2008). The combined spray of NAA 10 ppm and ethephon 150 ppm at full bloom can reduce fruit set up to 34 % in apple (Banday, 2006).

Keywords: Transforming fruit, plant growth regulators

Introduction
Plant hormones (also known as phytohormones) are naturally occurring organic substances that influence growth and development in very low concentrations and whose action may be involved in places remote from their origin. Hormones determine the formation of flowers, stems, leaves, the shedding of leaves and the development and ripening of fruit. Plants, unlike animals, lack glands that produce and secrete hormones; instead each cell is capable of producing hormones. Hormones are vital to plant growth and lacking them, plants would be mostly a mass of undifferentiated cells (Jain, 2013; Byers, 2000) [18, 6]. Plant Growth Regulators (PGR), on the other hand, include naturally occurring plant growth substances also called phytohormones, as well as synthetic compounds among which are chemical analogs, materials that alter hormone levels (hormone-releasing agents or synthesis inhibitors) and materials that alter hormone sensitivity (Hajam *et al.*, 2017) [15]. There are mainly five well-established categories of "classical" phytohormones, grouped together based on their structural similarities and on their effects on plant physiology. These five hormones include auxins, gibberellins, cytokinins, ethylene and abscisic acid. The other PGRs such as oligosaccharins, brassinosteroids, salicylic acid, jasmonates, polyamines, nitric oxide (NO), strigolactones, karrikins etc have been found recently. Their exogenous applications have shown the tremendous effect on fruit crops. In general plant hormones have major two effects and grouped accordingly as (1) Plant growth promoters:- substances which improve the overall health, growth and development of plants and (2) Growth retardants:- the group of chemicals which have common physiological effect of reducing stem growth by inhibiting cell division of subapical meristem. The influences on fruit production by the growth regulators are numerous and are employed in a wide range of circumstances varying from tissue culturally propagated plants to enhancing post-harvest storage life through almost all stages of plant life in between. It is not always the effect of single growth regulator but the interaction effect of different hormones in combination for instance; the ratio of cytokinin to auxin determines the fate of callus if it is high it promotes shoot proliferation while as low cytokinin: auxin ratio enhances root formation (Jain, 2013) [18].

Different uses of PGRs in fruit production

The different uses of plant growth regulators in fruit production can be summarized under following headings.

1. Flowering response

The first requirement for fruit setting and ultimately yield is the presence of flowers. Growth retardants generally enhance flowering while as GAs (gibberellins), ethylene and auxins inhibit it. By postponing flowering help the plants to avoid harsh environmental conditions. Hence many scientists worked on plant growth regulators as potent substances for induction and inhibition of flowering in fruit crops. The summarization of the work reveals that flowering can be delayed by 1 to 2 weeks by NAA at 200 to 800 ppm application in apple, cherries, pears, peaches and plums (Dennis *et al.,* 1970; Guerriero *et al.,* 1970; Maksymiuk *et al.,* 1986; Mclaughin and Greene 1991; Wani *et al.,* 2017) [8, 12, 25, 26, 35] whereas, benzyl adenine (BA) enhances flower induction and flower bud formation (Buban, 2000) [4]. Plant growth regulators like acetylene (20-70 ppm), NAA at 10 to 50 ppm and 2, 4-D at 6 to 10 ppm induces early flowering in pineapple. NAA application is also employed to bring uniform flowering and fruit set by inducing ethylene formation in pineapple which eases the harvesting in it. In litchi, NAA replaces girdling for improved flowering. SADH (Succinic acid-2.2-dimethyl hydrazide) promotes flowering in apple, pear, peach, and blueberry, whereas grapes and lemon respond to CCC (cycocil) with increased flowering but in strawberry, peach, plum and cherry the application of GA increases fruit set.

2. Flower and fruit thinning

Optimising yield is helpful for better quality and better returns. The yield optimisation and prediction are done based on the presence of flowers on the fruit trees. Higher yields are not always good for orchardists as these may reduce the next year crop and compel the plants for biennial behavior. Thus thinning is done to optimise flower density that means the flower count is lowered to the number required as per the kind of fruit trees, age of the tree, tree growth, rainfall pattern, soil type, soil fertility, vigor of rootstocks, pruning and training system used and other prevailing environmental factors. Fruit set is more affected by temperatures after application of chemical thinners than temperatures before application (Kviklys and Robinson, 2010) [2]. High temperatures for 5 days after chemical treatment had a large negative effect on fruit set whereas cool temperatures for 5 days post chemical treatment had a positive effect on fruit set compared to the set at in-between temperatures. Many of the plant growth regulators have been employed as flower and fruit thinning agents in which auxins especially NAA is very effective and is mostly used in fruit crops. DNOC (4, 6-dinitro-ortho-crysylate) also works as a better thinner in stone fruits.

Pre-bloom application of GA is very effective for optimum fruit set and loose and attractive clusters of grapes. Spraying NAA at 5 to 10 ppm helps to thin peaches and grapes whereas in mango soil application of paclobutrazol (Cultar) @ 5g per tree is employed for regulating fruiting. BA is suggested to be applied when fruitlets have a diameter of 7 to 12 mm at a concentration range of 25 to 200 ppm (Rademacher, 2000) [30]. Promalin (GA_{4+7} + BA) is also employed as an effective fruit thinner (Buban and Lakatos 2000) [5]. In most of the fruit crops, GA_3 inhibits flower bud differentiation in deciduous fruit so reducing the level of gibberellins in the vegetative buds to compel their transformation to flower buds. Gibberellin sprays reduce next year flowering whereas late sprays are less effective in this regard (Hajam, 2017) [15].

Fruit Thinning Chemicals in Apple and Stone Fruits (Khalil, *et al.,* 2010) [21]

Crop	Dosage (ppm)	Time of application
Apple		
NAA	10-15	Full bloom to 4 weeks after Petal Fall
2,4- D	2-10	Full bloom to Petal Fall
2,4,5- T	2-25	Full bloom to Petal Fall
Stone Fruits		
NAA	10-50	Petal Fall to Pit Hardening
2,4- D	2-15	Full bloom to Petal Fall
2,4,5- T	2-25	Full bloom to Petal Fall
Ethephon	100-500	Petal Fall to Pit Hardening

3. Fruit size and yield

Fruit size and yield improvement is an important aspect of fruit production. Auxins have successfully improved fruit size in plums, cherries, and apricots (Stern *et al.,* 2007) [33]. Post-bloom application of CPPU increases size in kiwi and other fruits. Dipping bunches of grapes in GA_3 (75 ppm) for 10 seconds are beneficial for size improvement. Application of 50- 100 ppm GA in grapes also increases the berry size. BA produces bigger sized fruits of elongated shape. GAs enhance flowering, and fruit set and growth in various species. Auxins have successfully improved fruit size in plums, cherries, and apricots. Dipping bunches in CPPU, BA and BR (Brassinolide) is also helpful for size improvement in grapes (Bhat *et al.,* 2011) [2]. Foliar sprays of PGRs (GA_3 at 20-40 ppm or NAA at 25-50 ppm) are reported to enhance apple fruit set and fruit retention percentage (Osama *et al.,* 2015) [29]. Prohexadione-Ca (growth retardant) and NAA (auxin) on apricot trees trigger a considerable increase in fruit mass, yield and yield efficiency (Mesa *et al.,* 2012) [27].

The effects of brassinosteroid and CPPU (N-(2-chloro-4-pyridyl)-N –phenylurea) either alone or in combination with benzyladenine on bunch parameters viz. bunch weight, berry weight, berry volume, and number of berries per bunch were evaluated by Bhat *et al.* (2011) [2] on seedless grape variety ‘Tas-A-Ganesh’ (a clone of ‘Thompson Seedless’). The growth regulator treatments were applied by dipping bunches at either at 7 or 15 or both 7 and 15 days after fruit set. The results showed that two dips, i.e., (7th + 15th) days after fruit set were more effective than single dips. The treatments having a combination of either higher or lower concentration of both BR (0.4 ppm) and CPPU (4 ppm) along with brassinosteroid 20 ppm produced maximum bunch weight which was nearly 30 percent more than that of control.

4. Fruit quality

Fruit quality fulfillment is a paramount concern of the researchers and fruit grower’s important goal, particularly regarding optimising size, increasing sweetness, firmness, TSS, overall organoleptic ratings and protection against biotic and abiotic stresses. Foliar sprays of PGRs (GA_3 at 20-40 ppm or NAA at 25-50 ppm) are reported to enhance yield and fruit quality traits of apple (Osama *et al.,* 2015) [29]. GA_3 increase fruit size, improve fruit firmness and delay maturity of sweet cherries and apples (Kappel and MacDonald, 2007; Hajam, 2017) [15]. Enhancement of total sugars by sole as well as combined applications of hormones and nutrients has been also reported in different fruit crops by Kirmani *et al.* (2015) [22], Gurung *et al.* (2016) [33], Wani *et al.* (2017) [35] and Hajam

(2017) [15]. Different fruits respond differently to PGRs for parthenocarpic (without pollination) fruit development. Parthenocarpic fruits are seedless, at the same time they are larger and sweetish. For this GAs form, parthenocarpic fruits in pears, citrus, apples; auxin spray in strawberry and cytokinins in grapes. GA_3 (50-100 ppm) and NAA (25-50 ppm) form loose clusters, decrease fruit set, reduce the number of berries per cluster increase size of remaining berries and improvement of berry size in grapes. The other parameters like fruit acidity, reducing sugars, total soluble solids (TSS), TSS/ acid ratio and fruit firmness which determine the quality of fruits like peach are improved by gibberellic acid and salicylic acid sprays (El-Shazly, 2013) [9]. Growth hormones especially GA_3 causes formation of firmer fruits with higher anthocyanin content and lower fungal infection in sweet cherry, apple, pear etc. which is evident from the work of Katiyar *et al.* (2009) [20]; Hajam (2017) [15] and Wani *et al.* (2017) [35] who reported enhancement of physicochemical characters and yield fruits like apple and guava by spray GA_3, CPPU, BA, Ethrel and NAA whereas, GA_3 reduce russeting in apple and pear and application of AVG increased the fruit size and fruit mass.

Triacontanol and Octacosanol (natural plant growth regulators) are also reported to improve quality and maintain firmer fruits (Naeem *et al.,* 2012) [28]. Use of brassinosteroids seems to hold promise in regulating the grape cultivation *cv.* Flame Seedless (Harindra *et al.,* 2014) [17]. Methyl Jasmonates increase fruit firmness, SSC (Emine and Burhan, 2014) [10]. Salicylic acid treated fruits exhibit significantly higher total phenols flavonoids as compared to control fruits (Razavi *et al.,* 2014) [32]. The overall antioxidant content in ripening fruits was increased by prohexadione-Ca (P-Ca). This growth retardant also promoted an increase in vitamin C (Ramirez *et al.,* 2014) [31].

Chitu *et al.* in 2010 [7] revealed that the foliar clays application increased the percentage of russeting free fruit from 17% (controls) to 23-28%. Carbosulf performed better than the clays (average 38% fruits russeting free), but worse than Promalin, which averaged close to 59% russeted free fruits. Kaolin treatments reduced significantly the losses in sunburned fruits from 24-28% in the controls to 12-15%. Because the tested products are containing only ecological components, their application may be extended to the organic crops protection, even though the results seem to be moderate in strength.

Whale *et al.* in 2008 [36] sprayed ‘Cripp’s Pink’ apple fruit on trees with aminoethoxyvinylglycine (AVG) alone, ethephon alone, or AVG followed by ethephon at two different locations in Western Australia. Fruit sprayed with AVG alone had retarded colour development at harvest. However, ethephon applied after AVG enhanced percent red blush, anthocyanin concentration and reduced chlorophyll concentration in the fruit skin in both locations. These fruit had similar colour to those treated with ethephon alone. Internal ethylene concentration and fruit firmness were unaffected by the different treatments in 2002. However, in 2003 AVG with or without ethephon reduced internal ethylene concentration and maintained firmness compared to ethephon alone. In concluded, AVG treatment alone delayed colour development and ripening of ‘Cripp’s Pink’, while AVG application 5 weeks before harvest followed by an ethephon application 2 weeks later enhanced red colour at commercial harvest. This is, therefore found as an effective tool for improving colour of ‘Cripp’s Pink’ apples at commercial harvest without adversely affecting other fruit quality attributes.

Effect of preharvest applications of AVG and ethephon on respiration rate, IEC, SSC, TA, fruit firmness of Cripp’s Pink Apple (Whale *et al.* 2008) [36]

Treatment	Resp. Rate (mmol co_2 $kg^{-1}h^{-1}$)	Internal ethylene (nL L^{-1})	SSC (%)	TA (%)	Fruit firmness (N)
Control	0.51 b	61.1 b	13.3 b	0.78 a	83.1 c
AVG	0.43 c	17.3 c	13.1 b	0.80 a	92.4 a
Ethephon	0.65 a	499.1 a	14.1 a	0.76 a	82.9 c
AVG + Ethephon	0.47 bc	124.8 b	13.9 a	0.75 a	88.9 b

6. Harvesting & post harvesting

Chemical harvesting and dehulling with ethephon is well known in fruit crops. Ethrel sprays are used for induced harvesting in walnut, pecan, olive, apricot, cherry, date, and grapes (Khalil *et al.,* 2010; Yaloni *et al.*, 2014) [21, 37]. Maintenance of quality and inhibition of softening is done by removal of ethylene produced by fruit in storage rooms. An alternative to ethylene removal is lowering the sensitivity of the fruit to its effect. A new inhibitor of ethylene action, diazocyclopentadiene (DCAP), has been found to inhibit ripening in tomatoes and apples (Blankenship and Sisler, 1993) [3]. Paclobutrazol treatments in apple orchards reduced bitter pit, cork spot and senescent breakdown (Mclaughin and Greene, 1991) [26]. A combination of ethephon plus auxin (2, 4, 5-TP or NAA) on ‘McIntosh’ apples also advances ripening without any loss of storage life. Walnut can be easily dehulled by Ethephon. Postharvest treatment with GA_3 at 200 ppm has been found highly effective in retarding ripening mangoes. GA_3 is a well-known substance to delay rind-aging of oranges. Dipping of fruit in 2,4-D, 2,4- 5- T or MH- 40 extends the storage life of fruits. Auxins enhance the postharvest life of the fruit and bloom intensity for the following season (Stern *et al.,* 2007) [33]. Salicylic acid (SA) enhances the postharvest life of the fruits and maintains their overall quality. MCP treated fruit maintained higher fruit firmness, acidity and color in plum whereas, ReTain® delayed maturity allowing for later harvest, maintained fruit firmness during storage in apples (Stover *et al.,* 2003) [34].

Conclusion and suggestion

PGRs play a very important role in commercial fruit production regulating various physiological processes. Detailed information and understanding of hormone biosynthesis, transport, mechanism of action, rate, time, a method of application etc. are required to predict any specific response in any specific fruit crop. New and improved products for better thinning agents to better storage life enhancers seem to be most urgently needed for use in fruit trees, while most other indications appear to be relatively well covered with existing products. PGRs like Promalin, AVG and 1-MCP, that have multiple uses and least toxic are proving to be very successful in fruit crop production. New introductions are only possible if there is a strong partnership between fruit growers, research scientists and companies of crop protection industry.

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