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The role of plant growth regulators in preventing pre-harvest fruit dropping in plants

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Abstract
In horticulture, pre-harvest fruit dropping is a very serious problem and is a major cause of annual yield losses in several horticultural crops. There are several biotic and abiotic factors that lie behind fruit dropping, like weather, temperature, heavy rains, lack of pollination, failure of fertilization, attack of insects and diseases, lack of nutrition and embryo degeneration, etc. Plant growth regulators are signalling molecules that are synthesised by plants and regulate different physiological, growth, and developmental processes in plants. Plant growth regulators play a very significant role in the prevention of pre-harvest fruit dropping in various horticultural crops.
In the present review, we have discussed fruit drops, their causes, and the role of PGRs in prevention in different horticultural crops, including wax apple, citrus, litchi, gooseberry, etc.

Keywords: seed shattering, fruit dropping, PGRs, abscission, horticulture, pre-harvest etc

Introduction
Fruit dropping is the phenomenon due to which detachment or separation of premature fruits takes place from a plant. It may be natural, environmental or pest-mediated. Unfavourable weather circumstances, such as late frosts, extreme heat or cold, and rapid changes in humidity, are frequently associated with premature fruit drop. It could also be soil-related, as a result of insufficient hydration and nutrients. For example, boron-deficient green peppers exhibit some fruit drop. Nitrogen, phosphorus, potassium, and sulphur are of particular concern with respect to fruit production. Each nutrient has distinct insufficiency symptoms, and plant expression may differ depending on the species [Jones *et al*., 1984] [29].
Pathological or pest-related fruit drop is more likely to occur later in the growing season, as the fruit approaches maturity. The apple maggot (Rhagoletis pomonella) and plum curculio (Conotrachelus nenuphar) are two common insects that induce premature fruit drop. Common diseases responsible for immature fruit drop include apple scab (caused by the fungus Venturia inaequalis) and peach leaf curl (caused by the fungus *Taphrina deformans*). Insects and diseases have more visually discernible symptoms and are hence easier to diagnose than those produced by environmental or physiological abnormalities [Morton, 1987].
PGRs, or phytohormones, are chemical molecules produced naturally in higher plants. These PGRs regulate plant development and enable other physiological activities. Plant growth regulators also aid in the reduction of the fruit-drop problem in plants. PGRs, specifically gibberellic acid, NAA, AVG, and ethylene, have been reported to affect the fruit dropping mechanism in various plants [Bisht *et al*., 2018] [5].

1. Fruit drop in various fruit plants
1.1 Wax apple
The wax apple (Syzygium samarangense) is a species of perennial evergreen tree native to Malaysia, Papua New Guinea, Indonesia, and Thailand. [Morrison 1987]. Thailand, Cambodia, Laos, Vietnam, the Philippines, Taiwan, China (southern China), India, Tanzania (mostly in Zanzibar and Pemba), Surinam, and Jamaica are some of the countries where it is commercially cultivated. [Morton 1987]. The fruit pulp is a rich source of phenolics, flavonoids, and several antioxidant compounds, having high economic value and potential benefits for human health [Chen 2010; Moneruzzaman *et al*., 2011] [39]. It has become an increasingly popular fruit in the tropical region where it can fetch a price of up to 3$ per kilogramme, providing great benefits to local farmers and a prodigious boost to the national economy. The unexpected fruit drop just prior to harvest is a serious threat to several varieties of wax apple. The severe fruit-drop and low quality imitate the wax apple production, resulting in lower market prices.
The fruit pulp is enriched in phenolics, flavonoids, and other antioxidant compounds, and has a high economic value as well as possible health advantages [Chen 2010; Moneruzzaman *et al*., 2011] [39]. It has become a popular fruit in the tropical region, where it can cost up to $3 per kilogramme, profiting local farmers and

offering a significant boost to the national economy. Several wax apple varieties are threatened by an abrupt fruit drop soon before harvest. Because of the extreme fruit dropping and poor quality, the production of wax apples is imitated, resulting in reduced market pricing.

At the ripening stage, fruits release a considerable amount of ethylene (ripening hormone), which drives fruit softening and the production of an abscission layer in the stem [Burg *et al*., 1965] [9]. Furthermore, ethylene increases the synthesis of enzymes that break down cell walls and complex carbohydrates that hold cell walls together in the stem's abscission zone. Later, these glue-like compounds degrade, leaving only the vascular strands connecting the fruit to the plant. These strands are easily split, allowing the fruit to fall through [Abeles *et al*., 1969].

1.2 Citrus

In India, citrus is the third largest fruit crop after bananas and mangoes. The average yield of citrus fruits in India is frighteningly low (8.8 t ha-1) compared to other established countries like Turkey, Indonesia, Brazil, and the USA (22-35 t ha-1). As for mandarin (Citrus reticulata), Kinnow mandarin (North-West India), Nagpur mandarin (Central India), Khasi mandarin (North-East India) and Coorg mandarin (South India) are the commercial mandarin cultivars of India. Cultivars of sweet orange, a hybrid-citrus (Citrus maxima × Citrus reticulata), are consistently grown in various states of India, viz. Andhra Pradesh (Sathgudi), Maharashtra (Mosambi), and Punjab (Malta and Jaffa) [Patel *et al*., 2017] [43]

Citrus is an economically important crop in India, grown for its high nutritive and commercial values. Citrus fruits are beneficial for human health because they are natural sources of vitamin C (ascorbic acid), vitamin A, fibre, nutrition, and antioxidant content. Besides, citrus fruits contribute to high economic productivity compared to other fruits. Hence, the production of citrus fruits proves to be a blessing for farmers. In general, citrus trees bloom profusely in spring, but only a limited number of flowers turn into fruits that remain on the tree till harvest and reach maturity. [(*Timmer & Brown,* 2000;] [51]

In Kinnow, less than 1% of blooms grow into harvestable ripe fruits. Excessive fruit drop, which can be caused by malnutrition, high or low temperature stress, high rainfall, and pests and diseases, is a serious problem in citrus fruit-crops that begins with blooming (flowering) and continues until the final fruit-harvesting, it leads to a reduction in crop yield and low profit for arable farmers [Kumar *et al*., 2018].

1.3 Gooseberry

Ribes uva-crispa (European gooseberry) and Ribes hirtellum (American gooseberry) are the most common types of gooseberry. The Indian gooseberry (Phyllanthus emblica L., syn. Emblica officinalis Gaertn.), local name Amla or Aonla, is one of the most significant indigenous fruits of India with a long history of cultivation[(*Papp & Porpáczy***,** 1999)] [42].

Amla is now widely grown in India, Sri Lanka, Cuba, Puerto Rico, Hawaii, Florida, Iran, Iraq, Java, the West Indies, Trinidad, Singapore, Malaysia, China, and the Panama Canal region. Aonla is grown in several Indian states, including Uttar Pradesh, Haryana, Rajasthan, Maharashtra, Gujarat, Andhra Pradesh, and Tamil Nadu. Its cultivation is spread over numerous districts in Uttar Pradesh, including Pratapgarh, Rae Bareli, Jaipur, Sultanpur, Banda, Kanpur, Agra, and Mathura [Wali *et al*. 2015] [54].

Aonla fruits are high in vitamin C and a good source of minerals, fibre, and phenolic compounds. Fruit-bearing Aonla trees frequently suffer from severe fruit-drop, which reduces fruit yield significantly and ultimately causes economic loss. Inadequate pollination, self-incompatibility,poor fruit set, water stress, nutritional deficiency, insect plague, hormonal imbalances, and disease infestations are the major causes considered for Aonla fruit-drop [Allemullah and Ram., 1990] [2].

1.4 Fruit drop in Lychee

Lychee (*Litchi chinensis*), a non-climatic fruit with good taste, pleasant flavour and high nutritional and commercial values, is found in Australia, Brazil, China subtropical parts of India, Indonesia, South Africa, Thailand, Pakistan and Vietnam [Menzel; 2001] [37].

Orchards are usually planted at a much higher density and then thinned in order to high fruit-yield. The average yield is between 10-80 kg per branch. A six-year old tree can yield 0.9-1.4 kg of fruit, while a 12-year-old tree can produce 140 kg of fruit. 60-70 kg fruit-yield per tree is typically considered to be reasonable, while 120-130 kg per tree is considered excellent fruit-yield. As normal, such good and excellent yields correspond to a productivity level of 12-13 tonnes per hectare. Yields and quality of lychee are affected by many physiological disorders, such as fruit cracking, flower drops, fruit drops, sunburn, delayed fruit growth, irregular bearing, black spots, etc. [Singh *et al*; 2016].

Severe drop of flowers and fruits of is a major concern in lychee, even after a prolific flowering. Flower and fruit drop in litchi may be due to (a) fertilisation failure, embryo abortion, auxin nutrition (especially) and hormonal imbalance; and (b) external biotic (fruit borer and heavy mite attack) and abiotic factors (west winds, low humidity and high temperatures). The young tree has a less long-lasting decline than the older trees. The overall amount of fruit decreases after the fruit has been established for the first fortnight and begins to mature. [Racsk *et al*; 2007]

2. Various factors contribute to fruit drop in plants

Fruit drop is most common in plants that produce multiple seeds each harvest, such as milkweeds, walnuts, oranges, cranberries, apples, pears, peaches, cherries, almonds, blackberries, raspberries, strawberries, red currants, gooseberries, high bush blueberries, and so forth. It is believed that embryo abortion and fruit drop are two sides of the same coin, caused by a number of interconnected causal events. The causal factors of the fruit drop are broadly categorised into endogenous factors (such as plant genetic composition, physiological deficiencies and hormonal disorders) as well as exogenous factors (such as poor soil fertility and nutrient deficiency, low or high soil humidity, excessive drought heat, excessive rainfall, plant disease, insect pests, resource constraint due to excessive fruit competitiveness, etc. [Bangerth, 2000] [4].

2.1 Exogenous factors

Exogenous elements like as environmental calamities, mineral nutrition, and diseases caused by pests and pathogens all have an impact on the fruit's life and untimely dropping. Late frost causes fruit drop before and after fruit setting by severely damaging buds, flowers, and early fruits, mostly by killing essential conducting tissues. Drought is a major contributor to decreased fruit yield. High temperatures produce more fruit drops than chill and water stress in the soil. As a result, cold-climate acclimated fruit varieties are more prone to pre-harvesting fruit drop; substantial fruit drop in sweet cherries appears during fruit set after a period of sudden dry and hot weather, followed by a period of cool and rainy weather in the spring. Poor lighting (e.g., shade) increases the occurrence of sweet cherry fruit drops and other fruit species; [Grappadelli *et al*., 1993]. Applying nocturnal red-light for varying lengths of time also resulted in a moderate quantity of fruit drop [Greene *et al*., 1986] [21].

2.1 (a) Mineral nutrition.

Fruit drop among orchards is variable, indicating that fruit drop can be influenced by cultural management. [Hoying and Robinson 2010] [46] indicated that a nutrient imbalance is a stress factor that may lead to apple PFD (Preharvest fruit drop). A boron deficiency, for example, is believed to cause cell degradation and decrease carbohydrate transport, which is likely to cause abscission. Excessive decline in pome fruit production occurs during severe deficiencies of boron [Wooldridge, 2002] [28, 55].

There has been no comprehensive research on the impact of nutrient concentrations on apple PFD, but changes in fruit retention and quality have been shown by the influence of nutrient supplementation at different developmental phases. The 'Tydeman's Late Orange' apple cultivar decreased PFD when magnesium was applied as foliar sprays in the form of magnesium sulphate (i.e., Epsom salts). It was also assumed that high nitrogen nutrient status of the trees was also thought to be correlated with a higher pre-harvest drop.Apparently, the conditions that result in a high nitrate supply near harvest time cause an increased drop in 'McIntosh.' The same pattern has been observed in the case of phosphorus. If addressing nutrient deficiencies does indeed prevent fruit drop, nutrients should be included along with PBRs in the management of PFD [Hoffman, 1940].

2.1 (b) Diseases

In plants, the fruit drop is also caused by several plant pathogens such as virus, bacteria, fungi, and pests that damage tissues and cause many diseases that lead to drops in the fruit before the harvest. Pathogens affect the metabolism of plants and alter their characteristics. [Hoffman, 1978].The affected tissues show physiological changes close to symptoms of senescence in healthy tissues, which sometimes lead to fruit drop. Here we address important diseases involving premature flowering or fruit drop.

2.1 (b1).Thefungus *Monilinia fructicola,* which causes fruit-rot, is polyphagous and is responsible for the immediate Preharvestdrop-in of several fruit species (apple, pear, apricot, peach, sweet and sour cherry, plum) [Holb, 2003,] [26]. At first around the point of penetration, a brown spot emerges, which slowly rises and covers the entire fruit. The softened fruit is abscised without any abscission layer at the top end of the fruit stem. 'Liberty,' 'Golden Sweet,' 'Independence,' 'Rome Elegance,' 'Jonathan' and 'Sir Award' are the most susceptible apple varieties to monilia fruit rot [Holb, 2005] [25].

2.1 (b2).Fungus *Taphrina deformans* causes leaf-curl disease of peach; symptoms can also appear on the fruit in the form of protuberances and discoloration, and the vigorous infection can cause drop in fruit. The most vulnerable varieties are Elberta June, Elberta Bronzos and Elberta New July. In apricot and peach, premature drop in fruit, caused by scab (*Venturia carpphyla*), is particularly dangerous during an extended period of drought, especially when water stress (EPPO) is experienced. The symptom occurs initially as light yellowish-green spots on the green fruits after the 10–14th week of petals-falling; dark brown conidia appear on the flecks. The flecks subsequently get increased and became corky, shrivelling the fruits subsequently. The late maturing apricot and nectarine varieties with the highest fruit-drop rate (EPPO) are most susceptible [***Kovács*** (1993)] [32].

2.1 (b3).Fungus *Gnomonia leptostyla* causes fruit drop in walnuts, the symptoms occur only on the fruit surface (epicarp). The spots are initially small, slightly depressed, dark brown, and later they grey and spread over the surface of the fruit; the kernel may rot and the fruit gets dropped prematurely [Maria *et al*., 1997) [36].

2.1 (b4) Fungus *Colletotrichum acutatum* cases fruit drop in citrus species; its symptoms occur on the petals, then the flowers turn brown,causing the flowers as well as the young fruits to shed [Li *et al*., 2003]. Post-blooming fruit drop seen in the orange 'Temple' variety. Large losses are due to this outbreak, which is reaching 100% without sanitary intervention The pathogen can attack all cultivated species except *Citrus aurantifolia* (key lime) and *Citrus lemon* (Limon).

2.1 (b5) Fungus *Colletotrichum gloeosporioides* (powdery mildew and anthracnose diseases;powdery mildew covers fruit, foliage and twig with a white powdery substance, while anthracnose makes up dark spots on plant leaves and sunken lesions, both contributing to stem growth, branch dieback and premature fruit-falling in the mango tree [(***Timmer & Brown,*** 2000;] [51] Mango scab is caused by fungus *Elsinoe mangiferae*. It affects the leaves, stems and young fruits and causes various lesions on stems and leaves.

2.1.3 Pests: Agricultural and horticultural crops are targeted by a wide variety of pests, including insects, mites, nematodes, and gastropod molluscs. They damage the plants both directly (plant cause) and indirectly (through fungal infections, bacteria or viruses. [(*Singh et al*., 2005).]

2.1.3 (a) Beetle *Omophlusproteus*: Itlives on sweet cherry (*Prunus avium*) preferably and feeds mainly on stigma and stamen (part of flower). This beetle kills the primordial pistil or the young fruit and soon decreases the flowers and fruit [***Czencz*** (2002)] [14].

2.1.3 (b) Beetle *Coenorrhynchus aequatus*:It affects a wide variety of fruit crops, including apples, peach, quinces, plums, almonds, hawthorns and rowanberries, starts, which feed on flower buds and continues like other beets**.** The terrified flowers and fruitlets are destined to be shed. After petal shedding, it occurs around the fruit stem in small holes and the larvae penetrate into the fruit and feed on the seeds; the fruits stop growing and get dropped. Another proboscides beetle *Rhynchites bacchus* attacks on various varieties of fruit such as apple, pear, plum, peach, apricot and almond, feed on blossom buds, flower parts, and fruits.[(***Glits et al***., 1997)] [19]

2.1.3. (c) Peach moth (*Anarsia lineatella*)**:** Peach twig borer, *Anarsia lineatella* larvae are first attracted to the growth of new tree and second to the growth of preharvested fruit. The process of ripening is accelerated by the scare, and a drop in pre-harvest is initiated. On developed fruits gum used to appear. The door is also opened to the monilia by the caterpillars. In the related literature, peach, apricot, plum and almond were indicated as host plants in decreasing order of frequency [Webster 1902]. Potential hosts include the Prunus genus peach, apricot, plum and almond, apple, pear and various cultivated species.

2.1.3. (d) Moth (*Spilonota ocellana*)**:** Itmay cause falling of flowers and premature fruit-drop in apples, quinces, sweet cherry, peaches, apricot and hazel .Its larvae start feeding on flowers, consuming stamina and pistils; then larger caterpillars hide under the web and feed on the increasing fruit.[*Kadocsa,* 1938.]

2.1.3. (e) Oriental fruit moth (*Grapholitha molesta*)**:**It causes peach and apricot fruit drop. The caterpillars choose relatively smaller fruit, then they begin feeding on it. They strike fruit near fruit stem and penetrate the fruit skin and create holes on fruit surface from which exudation of gum oozes out on fruit surface; the fruits are either dropped or start rotting due to fungal infection [(*Bodor & Reichart,* 1969)] [6].

2.1.3. (f) Apple moth (*Cydia pomonella*):It causes high fruit drop levels (30–40%) in many types of fruits such as apples, pears, quinces, medlars and walnuts. The larvae of the first-generation harm 2 or 3 fruitlets, while 1 or 2 fruits are sufficient for the production of second generation. As a rule, the frightened fruits fall in June or July [(***Garai,*** 2005).] [18]

g) Mediterranean fruit fly (*Ceratitis capitata*): It is a polyphagous with wide range of hosts. The larvae usually prefer *Citrus* species but also feed on apricot, peach, pear, apple, and plum, cherry and other fruits that are not grown juicy. The fruits continue to tan, soften, fleshy, creamy and mucilaginous and begins to rot when fallen on the soil [(*Rasztik,* 2003)].

2.2 Endogenous factors

2.2.1 Fertilisation and pollination conditions

The time of pollination and fertilisation is critical in terms of fruit drop; it is more common in almonds when pollination is observed at the end of a good pollination cycle (EPP). According to Ortega *et al*. (2004), there is a strong link between fruit set and fruit drop, but found that pre-harvest fruit drop occurs only in varieties.

2.2.2 Seed content in fruit

Several researchers (Luckwill, 1953 & Tydemann, 1943) [35] have expressed an interest in seed generation during the earliest phase of fruit growth. Some researchers hypothesised a link between the number of seeds per fruit and the size of the berry in currants, as well as the size of the berry and the occurrence of the drop. As a result,

cultivars that grow from fewer seeds are more susceptible to environmental disasters such as low nutrition, water stress, and fruit dropping [Stösser, 2002].

2.3 Competition for nutrients between different plant organs

2.3.1 Vegetative and generative organs compete

The young primordial fruit actively generates green chloroplasts for photosynthesis and synthesises its own food. As a consequence, it loses its ability to synthesise food and operates as a sink for food from other plant organs (Atkinson *et al*., 2001) [3]. However, if the source and hence transport are restricted (for example, when the leaves of the short shoots are eliminated), the fruit will drop. On the contrary, Atkinson *et al*. (2001) [3] reported a decrease in fruit size rather than a drop in fruit size. The weak link between leaf area and fruit number produces a decline in fruit during the two-week transmission of approaching harvest time.

The price of peaches is determined by the volume of fruit rather than the quantity of fruit. The competition of the tree's vegetative organs (leaves and fruit proportion) has a profound influence on the growth of the stone endocarp [Timon, 1992; Brunner, 1982] [7].

Fruit drop varies on the same tree based on the arrangement of separate branches [Soltész, 2002]. In apples, there is a reasonable link between shoot growth and susceptibility to fruit-falling. Slow-growing trees were employed by trees with high shoot growth to drop more fruit, which could also hold supernumerary fruit primordia (mummies) on the fruiting structures. Healthy (water-) shoots in fallen fruit perform their function. Efficient shoot growth also contributes significantly to the decline in blueberry fruit.

In the case of pecan fruit drop, shoot growth and fruit drop are linked. The fact that leaves can trigger fruit abscission is remarkable. It has to do with ABA translocation from the leaves to the fruits. Mature leaves are sufficient to prevent apical buds from growing under the influence of GS3 spray. Young leaves promote ripe fruit abscission, while mature leaves encourage fruit abscission by promoting ABA transfer [Cooper *et al*., 1969].

2.3.1 Competition between generative organs

It is widely accepted that the deposition of organic matter in generative organs (flowers or fruit primordia) is not sustainable in the long term, resulting in a vigorous drop of fruit (Racskó, 2005). Excess bloom has typically resulted in a low fruit set rate. The physiological assumption for this is that the flower or fruit set that began developing earlier is dominant in comparison to other flowers or fruits that started developing later. Primogenous dominance refers to this form of dominance. Its supremacy in this situation is attributable to its early arrival rather than its position.

The majority of pear varieties [Dibuz, 1996] and gooseberry varieties (Bubán, 1996) [8] grow basipetally, with the first basal flower in the inflorescence corresponding to the apple's apical flower. Those flowers are the most mature, have the best chance to produce fruit, and are less likely to fall. Excision of this first bloom, on the other hand, transfers the same likelihood of dropping on to the subsequent inflorescence flowers [Miranda *et al*., 2005] [38].

4 Role of PGRs in the prevention of fruits dropping

Plant Growth Regulators (PGRs) are naturally occurring organic compounds in higher plants that act as messenger molecules and regulate various physiological and other developmental processes in plants at very low concentrations, including improved fruit quality, fruit retention, and crop productivity [Khandaker *et al*., 2013] [30]. It has been found that the exogenous application of various PGRs has been effective in improving the endogenous levels of phytohormones and mineral nutrients, and reducing pre-harvest fruit drop and promoting fruit growth and maturity in various plants, including mangoes, citrus, and apples. [Wahdan *et al*., 2011] [53].

4.1 Role of auxin in preventing of fruit dropping

Auxins were discovered in the 1920s by the Dutch biologist Frits Warmolt Went, who described their significance in plant development. Auxins influence numerous processes of growth and behaviour in the plant's life. The auxins and their analogues such as naphthalene acetic acid (NAA) and naphthalene acetamide (NAAM) play a vital role in the prevention of pre-harvest fruit dropping in plants through the delaying of abscission and the development of hydrolytic enzymes like cellulase [Monselise and Goren, 1978] [40].

The chemicals 2, 4-D (2, 4-dichlorophenoxyactic acid), Fen prop (2-[2, 4, 5-trichlorophenoxy]) and Daminozide (2, 2-dimethylhydrazide) also have auxin activities and play an important role in the prevention of pre-harvest fruit drop. Application of 2, 4-dichlorophenoxyactic acid and 2, 4-D + GA3 delayed fruit ripening, reduced production of ethylene, increased fruit size and reduced fruit drop [El-Otmani (1992)] [17].

4.1.2 Gibberellic acid (GA)

Gibberellic acid (GA) is a tetracyclic di-terpene that stimulates plant growth and development processes such as seed germination, mesoderm-to-shoot transition, converting juvenile leaf to adult, and vegetative shoot to flowering (Gupta *et al*., 2013) [22]. Gibberellic acid is commonly used in horticulture to improve blooming (Khandaker *et al*; 2015), fruit setting, to prevent pomegranate cracking and to inhibit apple rusting. Gibberellic acid increased fruit productivity in oranges by decreasing the dropping of buds and reducing fruit drop in wax apple fruit. The exogenous application of GA_3 might decrease the fruit drop by up to 32% According to [Singh

and Lal, 1980] [48], applying GA_3 at 50mg/L after five weeks of flowering increases fruit retention time and fruit size in Indian litchi.

4.1.3 Naphthalene acetic acid (NAA)

NAA is a synthetic plant growth regulator and analogue of auxin that, in high quantities, is harmful to plants. It reduces the pre-harvest fruit drop in apples [Yuan and Carbaugh 2007]. The applications of NAA might delay apple fruit dropping in apples after 10–14 days of treatment, and repeated applications of NAA are more effective than one operation. NAA treatments increased fruit production, fruit size, total yield per tree, and ripening while having no negative effects on the nutritional and organoleptic properties of a loquat. NAA has been found to dramatically enhance fruit collection, fruit length, diameter, and weight, TSS, total sugar, and vitamin C content, and reduce fruit drop in guava [Iqbal *et al*., 2009] [27].

4.1.3 AVG (Aminoethoxyvinylglycine)

AVG is a natural substance that inhibits ACC synthesis in the ethylene biosynthesis pathway [Kim *et al*., 2004], and hence suppresses the production of ethylene in a variety of climatic fruits. This results in less pre-harvest fruit drop and a delay in fruit ripening but the results vary depending on the cultivar and concentrations used. ReTain® is a plant growth regulator with a 15% w-1 AVG. ReTain TM application retards ripening and reduces pre-harvest drop in apples, peaches, nectarines, and other climate-sensitive fruits, 10 days before harvest has been shown to be more effective in increasing the firmness and consistency of late-maturing peach cultivars than application 15 days before harvest.

Aminoethoxyvinylglycine (AVG) and naphthalene acetic acid (NAA) combinations in apple trees showed excellent premature drop prevention while not reducing fruit firmness following controlled atmospheric storage [Sazo and Robinson, 2013] [47]. AVG decreased ethylene production in 'Golden Delicious' apples, reducing premature drop and delaying fruit maturation on the tree, as well as fruit ripening and softening during storage.

4.1.4 Role of AVG, NAA& ethylenein fruit dropping-

NAA plays a number of roles in fruit dropping like fruit abscission and fruit softening, reduces the pre-harvest fruit drop whereas AVG decreased the drop in ethephon fruit (Byers; 1997) [10]. The combined action of AVG and NAA delayed the decline of Preharvest fruits more effectively than AVG or NAA alone (Li and yuan; 2008) [33]. Together NAA and AVG enhances ethylene development in fruits by increasing the expression of *MdACS1* and *MdACO1* genes in the fruit cortex region (Li and Yuan; 2008) [33]. However combined action of AVG and 1-MCP inhibited the expression of *MdACS5A* and *MdACO1* genes but not MdACS1 in the fruit abscission region. These findings underline our widespread record in 'Golden Fantastic' and 'Golden Supreme' apples (Yuan and Carbaugh, 2007).

Both AVG/MCP1 inhibit falling of apple fruit by inhibiting the expression of genes in the abscission zone (MdACS5A and MdACO1) in apple. The result suggested that NAA increases apple-fruit ethylene production. On the other hand, NAA increased expression of *MdPG1* gene (Zhu *et al*; 2008) [57], which is a fruit softening gene but reduces the expression of *MdPG2* (Abscission zone formation gene) in the fruit cortex (Li *et al*; 2008) [33]. Above theory indicates that MdPG1 participates in fruit softening but not MdPG2. However, these results also showed that expression of *MdPG2* plays a key role in the fruit abscission zone (Li and Yuan; 2008) [33, 57]. Combined application of NAA and AVG might inhibits the expression of genes responsible for abscission in fruits.

Conclusion

This review was concerned with the significant effects of various PGRs on improving fruit growth, fruit production, fruit quality and fruit yield and focused primarily on the prevention of premature fruit dropping by applying these phytohormones. Fruit dropping is a serious problem in horticultural practices which adversely affects plant quality, yield and productivity. For e.g. several living organisms like *Heteroptera edessa* sp., *Conotrachellus dubiae* are mainly responsible for fruit drop up to 9.27% and 9.15% respectively. Whereas the remaining 90.73% fruit drop are mainly caused by abiotic factors like wind, rain, temperature which leads to physiological and biochemical changes inside plant. The temperature has a directly proportional influence to the flowers and fruits dropping; it means that as the temperature decreases, the fruit drop decreases as well. The precipitation might show inversely proportional influences on fruit dropping, because at the time of lower rainfall, there is greater fruit drop.

Many of the commercially available plant growth regulators are used in stone fruit production. Auxins are used to enhance the size of stone fruits. Gibberellins are used for increasing fruit size and firmness of peaches and cherries. Gibberellins can delay storage disorders such as internal browning and woolliness development. The application of AVG delays maturation of fruit and improve fruit colouring, might increases the period of fruit drop.Application of PGRs results in better output as it improves the internal physiology of developing fruits to improve fruit set, reduce fruit drop.

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Conflicts of Interest

The authors declare that they have no conflict of interest regarding the publication of this manuscript.

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