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Advances in Application of Unexploited Plant Bio-regulators for Fruit Production: A Review

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ABSTRACT

The term 'bio-regulator' has been used to encompass the natural and synthetic compounds that regulate various plant growth and developmental processes. Plant bio-regulators (PBRs) previously called plant growth regulators. Use of PBRs with a unique fact finding support assistance from biotechnology made a new approach of manipulating plant biological activities for enhancing growth, yield, quality, nutritive value and an important tool to reduce biotic and abiotic stress in plants. PBRs like jasmonic acid (JA) and its derivatives act as an omnipresent signaling molecules which mediate plant responses to biotic and abiotic stress. Salicylic acid (SA) and methyl salicylate are endogenous signal molecules, also playing pivotal roles in regulating stress responses. A polyamine is low-molecular weight organic compound having two or more primary amino groups, act as ethylene repressor. Prohexodione calcium is a new generation anti-gibberellin. Along with listed names several other bio-regulators are in vogue to improve plant growth, development, stress resistance, pathogenic defense and productivity. In this review, it's an attempt to portray existing advanced knowledge about under utilized bio-regulators role and utility in cultivation of fruit crops.

Key words: Jasmonic acid, Plant bio-regulators, Polyamine, Prohexodione calcium, Salicylicacid, Triacontanol.

Bio-regulators are synthetically or endogenous produced substances which controlone or more specific physiological and biochemical functions by their influence on gene and enzyme interactions in the plant system (Olaiya and Polomina 2013). Bio-regulators are of two types *viz.*, natural and synthetic. The uses of bio-regulators have developed into permanent features of agricultural and horticultural production techniques and have been used for more than 50 years. In case of fruit crops, it has been found beneficial for improving yield, quality, synchronization of flowering, earliness in flowering and fruiting, sex ratio modification, increase in post-harvest life, *etc.* (Lawes and Woolley, 2000; Chander *et al.,* 2019).

Plant bio-regulators (PBR's) previously called plant growth regulators. The name changed from plant growth regulators to plant bio-regulators in 1992 at Jerusalem in the 7th international symposium, which was conducted by ISHS (International Society for Horticultural Sciences). The unwrappingof hormones functions and their abilityto regulate all aspects of growth and development of plant were defining significancein horticulture. The 1960's emerged as the "Golden Decade" for plant hormones. New and thrilling things were being grasped about the gibberellins, the application of ethylene suddenly surfaced, cytokinins were discovered and ABA was identified. The 1970's did not result in the identification of any new classes of major hormones but pomologically it was a most active and important time. The use of daminozide was being fine-tuned, the plethora of uses of ethephon were being discovered. Amino-ethoxy vinyl glycine (AVG) was discovered, 6-benzyl amino purine (BA), GA alone and in combination were developed to improve fruit shape, fruit appearance and tree growth manipulation.

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The discovery or existence of brassinosteroids (Mitchell *et al.*, 1970) and jasmonates (Ueda and Kato, 1980) occurred and study regarding their functions continues till today. The commercial use of plant growth regulators to regulate fruit development was examined by Lawes and Woolley (2000). Fruit trees are known ashigh value crops and even small changein production efficiency, enhanced cosmetic value or product standard have the potential to highly increase product value. Use of PBR's is a distinctive fact in biotechnology and a brand new approach of handling plant biological activities for enhancing growth, yield, quality, nutritive value and also to reduce biotic and abiotic stress in plants. PBRs like jasmonic acid, its volatile ester methyl jasmonate (MJ) and other derivatives, collectively known as jasmonates (JA's), are ubiquitous signalling molecules which mediate plant responses to environmental stress such as wounding and insect and pathogen attack (Wasternack, 2018). Though bio-regulators are commonly used to improve plant growth, development, pathogenic defense and productivity, the molecular mechanisms of their effects still remain to be fully elucidated.

Overview of different plant bio-regulators and their effect on fruit crops

1-Methylcyclopropene (1-MCP)

1-Methylcyclopropene (1-MCP) is an ethylene action inhibitor (Blankenship and Dole, 2003) and cyclopropene derivative synthetic plant growth regulator (Khan and Ali, 2018). On exposure with climacteric fruits 1-MCP delay the natural increases in respiration and ethylene production rates during ripening; thereby delaying ripening related processes, such as softening, color change, starch breakdown.

1-Methylcyclopropene (1-MCP) treatment inhibited ethylene production and ripening of durian fruit (Kesta, 2018). In addition, inhibitory effect of 1-MCP on ethylene production and ripening process was much higher at 25°C than at 15°C (Amornputti *et al.,* 2016). 1-MCP can be used to increase shelf life at ambient temperature and storage life at low temperature by delaying ripening processes of durian fruit (Amornputti *et al.,* 2014). Maninang *et al.* (2011) recorded that fumigation of durian with 1-MCP (1000-2000 ppb) depended on cultivar, temperature and time, can delay increase of TSS, softening, color and aroma development. Thai exporters have adopted 1-MCP fumigation for 6-h to delay ripening (Kesta, 2018). Care is needed to avoid high rate of 1-MCP fumigation that can lead to uneven ripening and hardening pulp (Kesta, 2018). Preharvest application of 1-MCP reduced the superficial scald incidence of "Law Rome" apple fruit and maintained firmness and showed better fruit appearance. In cold storage preharvest foliar spray of 1-MCP delayed soft scale development and soggy breakdown in "Honeycrisp" apple (DeEll and Ehsani-Moghaddam, 2010). 1-MCP extends storage life and also maintains fruit quality by binding to ethylene receptors and preserving membrane integrity under extended storage in apple (Elfving *et al.*, 2007). During fruit setting stage pre and postharvest application of 1-MCP reduce ethylene sensitivity of yellow pathia (*Selenicerus megalanthus* Haw). Serna *et al.* (2012) reported that 1-MCP treated fruit showed higher firmness, enriched color development and also reduced desiccation. In "Carabao" mango pre-harvest foliar application of 1-MCP (10 ppm) after 100 days of flowering delayed fruit ripening with development of better color and higher firmness in fruit during postharvest storage (Castilo-Israel *et al.,* 2014). Similarly, preharvest application of NAA in combination with1-MCP to "Bartlett" pears led to higher firmness, reduced ethylene production and internal browning index for 4 months during cold storage (Villalobos-Acuna *et al.,* 2010). Sugar apple fruits treated with 1-MCP at 810 ppb for 12 hours then stored at 25°C for 4 days were firmer than the control (Wongs-Aree and Noichinda, 2011). The fruits treated with 1-MCP at 30 or 90 ppb and the untreated fruits ripened faster than the fruits treated with 1-MCP at higher concentrations (Benassi *et al.*, 2003). Wongs-Aree and Noichinda (2011) reported thatatemoya fruits treated with ethylene generally ripened 50% faster than untreated fruit, while those treated with 1-MCP increased the number of days to ripening by 3-4 days. Applying 1-MCP to the fruit prior to ethylene production prevented fastripening, so that the ripening time was similar to fruit treated with 1-MCP. Atemoya fruits treated with1-MCP were slightly more prone to rotting and slightly higher severity of external blemishes in fruits observed compared to non-treated fruits (Hofman *et al.,* 2001). 'Nang','Fai' sugar apples and 'Pet Pakchong' atemoya were treated with 1-MCP at 500 ppb to study ripening behaviour of fruit (Noichinda *et al.*, 2009). Ethylene production were slightly decreased and delayed following all 1-MCP treatments while climacteric peaks for fruits treated with 1-MCP at 25°C were drastically reduced in 'Nang' and 'Pet Pakchong'. The ripening and softening of 1-MCP treated fruit was delayed for 2-3 days (Wongs-Aree and Noichinda, 2011).

Avocado fruits treated with 1-MCP showed delayed ripening. Fruits remained unripened and hard for weeks at room temperature when treated with 1-MCP at 10 µL L^{-1} (Feng *et al.*, 2000). In different cultivars of avocado ('Hass', Ettinger','Reed' and 'Fuerte') , application of 1-MCP (30 to 70 nL L^{-1}) on fruits at 20°C for over 10 days, resulted into reduction cell wall softening enzymes (Polygalacturonase and Cellulase) in ethylene production which delayed ripening without softening. Similarly, Jeong *et al.* (2003) found that avocado fruits stored at 20°C applied with 1-MCP and wax resulted into delayed ripening and had better green colour and firmness over the control. Treated fruits had lower ethylene production and respiration rate than other treatments. Fruit firmness in control condition decreased from >100 to 20 N over a 7-day period at 20°C, while fruit treated with 1-MCP and wax required more than 11 days at 20°C to soften to 20 N. Avocado fruits at different times during ripening were exposed to ethylene (100 µL L^{-1}) for 1 day at 20°C followed by application of 1-MCP resulted in delayed in ripening by 3.3 days compared with non 1-MCP treated fruit, as soon as the fruit started to soften, there was minimum effect of 1-MCP. There is limited potential to control ripening process using ethylene after treatment with 500 nL L^{-1} 1-MCP but higher concentrations could be more effective. In avocado, resuming of the ripening process seems to be much difficult to achieve over the other fruit crops. Dauny *et al.* (2003). found a possible cause for the apparent relative 'irreversibility' of 1-MCP that 1-MCP was absorbed faster and in higher amounts by avocado and avocado oil than by apple fruit and water, respectively. Thus, ripening and 1-MCP efficacy in avocado could be due to the production of 1-MCP from the oil fraction andre-binding to ethylene receptors.

Brassinosteroid

Brassinosteroid is a group of steroidal substances that occurs naturally, which are first isolated from the pollen of rape plants (*Brassica napus* L.), considered as the sixth group of phyto hormones. In India, Godrej Agrovet Ltd. of Mumbai introduced 28-homobrassinolide (Double) and Cadila Pharmaceuticals Ltd. of Nasik introduced Brassinolide (Cadmore) in the market. Increased resistance to unfavourable environmental factors, stress and diseases, growth promotion, success of fertilization and fruit-set, shortening the period of vegetative growth, fruit quality and nutritional value, no. of fruits, size and fruit yield. Brassinosteroid is very effective on the yield of yellow passion fruit plants and produced the highest number of fruits per plant. It is also improve quality of grapes by increase cluster weight, berry weight, length and breadth and reduced the rate of berry softening, maintained external colour, stabilized anthocyanins of grape cultivar.

Brassinosteroids (BRs) are polyhydroxy steroid phytohormones (Clouse, 2011). They play important roles in cell division and elongation, vascular differentiation, flowering, photomorphogenesis and pollen development (Clouse 2011). BRs have been reported to be involved in growth, development and ripening of grape and strawberry (Chai *et al.,* 2013; Symons *et al.,* 2006). According to Clouse *et al.* (1996). Arabidopsis mutants deficient in brassinosteroids biosynthesis or perception presented numerous deficiencies in developmental pathways that could not be rescued by brassinosteroids application. The application of brassinosteroids (as epibrassinolide, BL) increased colouring of berry and enhanced ripening in grape berries. Conversely, the application of a brassinazole (BZ) a BR biosynthesis inhibitor showed a contrary effect (Symons *et al.,* 2006). Conversion of 6-deoxocastasterone to the bioactive BR castasterone catalyzed by BR 6-oxidase enzyme (Symons *et al.,* 2006). BL application promoted ripening and the accumulation of FaBRI1 receptor transcript of strawberry fruit (Chai *et al.,* 2013; Clouse, 2011). Moreover, the receptacle remains white through the transient silencing of the FaBRI1 gene caused a delay in fruit ripening (Chai *et al.,* 2013). BR signaling could play an important role in ripening of non-climacteric fruit. Possibly through modulation of ethylene content BRs have been proposed to be the first signal for ripening of the grape berry (Ziliotto *et al.,* 2012). In early developmental stages of *F. vesca* and *F. chiloensis* the gene encoding for the late embryogenesis abundant domain protein (LDP1) has been expressed (Espinoza *et al.,* 2016). Multiple BRs and ABA response motifs have been found in promoter region of LDP1 gene. Espinoza *et al.* (2016) reported that the transiently expressed FcLDP1 promoter-GFP fusion was regulated by ABA and BRs which shows that these hormones regulate FcLDP1 expression during fruit development of *F. chiloensis.*

Jasmonic acid (JA)

Jasmonic acid (JA) is plant immune hormone derived from Linolenic acid which can convert into variety of derivatives including Methyl jasmonate (MeJA), initially MeJA was discovered as a secondary metabolite in essential oils of jasmine and its role in plant defence was first shown by Farmer and Ryan (1990). Regulated plant growth and development processes include growth inhibition, senescence, flower development and leaf abscission also helps in tuber formation in potatoes, yams and onions, response to wounding of plants, also helps in transcription of many genes involved in plant defence. N-propyl dihydrojasmonate (PDJ) a JA derivative has been used to improve apple fruit quality and colour. It also regulates ethylene biosynthesis and influence aroma volatiles. Jasmonate have a role in plant defense against environmental stress. The application of PDJ decreased low-temperature injuries such as splitting and spotting in apple fruit.

Jasmonic acid (JA) and its bioactive isoleucine conjugate (JA-Ile) more active in root development, seed germination, stamen development or senescence and they are involved in signaling for both abiotic and biotic stress responses in plants (Wasternack *et al.,* 2018). Application of methyl jasmonates (MeJA) can reduce fruit detachment force; promote the development of dry stem scars in grapes, avoiding post harvest infections (Fidelibus and Cathline, 2010). In early developing grape berries a higher levels of jasmonic acidand JA-Ile have been foundfollowed by aimmediate decrease during progression to ripe stages (Bottcher *et al.,* 2015). Thus, in both strawberry and grape berry JA-Ile could be involved with early fruit development. Asynchronized down regulation of the JAs including JA-Ile and their biosynthetic genes takes place from flowering to ripening stages of fruit in strawberry (Garrido-Bigotes *et al.,* 2018). Bogs *et al.* (2005) and Almeida *et al.* (2007) found that proanthocyanidin accumulation in developing grape berry and strawberry exhibited a close pattern to JA-Ile, leading to early fruit development and decreasing as the fruit ripens. JA pathway related to PAs biosynthesis in strawberry fruit an increase in proanthocyanidin content by the application of a chemical inhibitor for the key JA-Ile biosynthetic enzyme JAR1 (Delgado *et al.,* 2018). Exogenous application of methyl jasmonates in *F. chiloensis* fruit, MeJA (methyl ester of JA) changed the expression profiles of ripening-related genes including those related to jasmonic acid and biosynthesis of ethylene (Concha *et al.,* 2013). It is also responsible for upregulation of genes related to the anthocyanin biosynthesis pathway and chalcone synthase (FcCHS), flavanone 3-hydroxylase (FcF3H), chalcone-flavononeisomerase (FcCHI), dihydroflavonol 4-reductase (FcDFR) anthocyanin synthase (FcANS) and anthocyanidin 3-O-glucosyltransferase (FcUFGT) which results in increased anthocyanin accumulation (Concha *et al.,* 2013). Garrido-Bigotes *et al.* (2018) reported that application of MeJA to strawberry fruit generated a higher anthocyanin increase along with the accumulation in JA, JA-Ile and MeJA levels. Similarly, MeJA application increased PA content in two wine grape varieties (Gil-Muńoz *et al.,* 2018) and in grape cell suspensions JA increases anthocyanin production (Belhadj *et al.,* 2008). It was reported that phenylalanine ammonia lyase (PAL) activity enhanced by the application of jasmonates and enhanced a significant increase in polyphenol compounds (quercetin, ellagic acid and myricetin) (Moro *et al.,* 2017). Chini *et al.* (2007); Thines *et al.* (2007) and Sheard *et al.* (2010) reported that in JA signaling pathway F-box coronatine insensitive1 protein (COI1) associated with jasmonatezim-domain (JAZ) form the JA-Ile co-receptor and the biological processes mediated by JA-Ile requirethe activation of the JA signaling pathway. AsJA-Ile level rises, COI1 binds to JAZs that are subsequently degraded by the 26S proteasome after ubiquitination by ubiquitin ligase complex SCFCOI1 (Chini *et al.,* 2016) but in case of lower JA-Ile, JAZ repressors bind to MYC2 and other transcription factors suppressing the expression of early JA-responsive genes.11 JAZ members have been described in grape, which respond to abiotic andbiotic stresses and hormone treatments (Zhang *et al.,* 2012). Garrido-Bigotes *et al.* (2018) demonstrated that two MYC TFs encoding genes and 12 putative strawberry JAZ proteins exhibited high expression in flowers and at early fruit stages of strawberry that matched with the down regulated pattern of JA-Ile observed during the development of this fruit.

Polyamine

Polyamineis low-molecular weight organic compound having two or more primary amino groups, linear polyamines perform essential functions in all living cells, examples are putrescine, cadaverine, spermidine and spermine. Their effects are similar than those of auxins, CKs, GAs, ABA and ethylene (Yahia*,* 2019). Signal transduction pathways of PAs and JAs by interfering with ethylene biosynthesis and perception, lead to a less ripe fruit quality control in the postharvest handling chain. Polyamine helps in cell division, embryo development, regulate fruit ripening, flower development, reduce physiological weight loss, hypersensitive response to microbial infection, defense mechanism against abiotic stress.

Polyamines have an important role during fruit set, early development and fruit ripening, as well as in the regulation of quality attributes of fruits. During ripening, the content of polyamine decreases in both climacteric and non-climacteric fruits. These natural polycations are used to control ripening and postharvest decay, as well as to improve fruit quality (Yahia*,* 2019). Polyamines and ethylene show contrasting effects in relation to fruit ripening. Polyamines delay the fruit senescence and increase the shelf life (Kakkar and Rai, 1993). As they share a common precursor S-adenosylmethionine, polyamines may compete directly with the synthesis of ethylene (Bagni and Torrigiani, 1992). Researchers reported that polyamines extend the shelf life of fruits. In litchi, polyamines (putrescine, spermidine and spermine) delayed the changes associated with senescence such as browning, peroxide level, ethylene production and cell leakage (Jiang and Chen, 1995). Preharvest spray of putrescine on mango cv. ‘Kensington Pride’ reduced ethylene production, increased fruit firmness and sugars as compared to the control. After 20 days storage, the putrescine sprayed fruits showed higher firmness, TSS and lower fruit rot (Malik and Singh, 2003). In pomegranate increasing salinity level increased tissue concentration of Na^+ and Cl^-, while the K/Na ratio decreased. Using polyamine, increased concentrations of potassium and proline content can increase plant resistance to salinity levels (Naeini *et al.*, 2006).

Prohexodione calcium

Prohexodione calcium is a chemical compound of carboxylic group, Prohexodione Ca is a new generation anti-gibberellin. It is a mimic of 2-oxoglutaric acid and ascorbic acid. Reduces longitudinal shoot growth by blocking dioxygenases involved in biosynthesis of gibberellin also reduces ethylene formation and delays abscission of young fruits and senescence it can also reduce alternate bearing. Prohexadione Ca has been reported to be absorbed completely within eight hours and to degrade in plants with a half-life of a few weeks and in soil with a half-life of less than one week, without producing toxic metabolites (Ilias and Rajapakse, 2005).

The study reported that grape berries treated with Pro Ca (Prohexadione Ca) showed reduced average weight and 25% reduction in crop yield and 90% reduction in presence of shoulders in bunches. The average sizes of individual berries from treated vines were different from those of control. Clusters of grapes from treated vines had a higher number of small berries (10-14 mm diameter) and a lower number of berries (14 to 18 mm) than control. Wine obtained from these berries had a higher alcoholic degree. Wines obtained from treated grapes contain higher color intensity, hue, titratable acidity and tannins. There was early dryness and quick fermentation of treated grapes. For both control and ProCa wines, malolactic fermentation took 23 days of duration. Different color was recordedin ProCa treated wine. The wine was considered with purple, biguerrau cherry and blackish colors than the control one, while the shades found in the control wine were cherry red and deep red. Among different treatments differences were observed in terms of odourand aroma perceptions. Aromas and intensity were similar for both control and ProCa wines. In both wines, fruity aromas were present. ProCa wine also had spicy aromas and was globally considered more complex than the control wine. Wine obtained from treated grapes had more balanced taste than control. It was light and mild mouthfeel for the control wine. In contrast, ProCa wine presented higher stickiness and astringency. For both control and ProCa wines after taste was very fruity; the latter also presented spicy and balsamic attributes. Wine obtained from ProCa treated grapes had more persistence than the control (Vaquero-Fernandez *et al.,* 2009).

Post bloom (PB) application of Prohexadione Ca, reduced the vegetative growth in apple. Trees sprayed with Prohexadione Ca at post bloom, had the highest percentage of branches. Application of ProCa in apple at PB stage has been reported to inhibit the biosynthesis of active gibberellins (Davies, 2004) and reduce the vegetative growth (Cline *et al.,* 2008; Silveira *et al.,* 2012; Hawerroth *et al.,* 2012). Prohexadione Ca PB delayed the loss of functionality of primary cortical vascular bundles in the proximal part of the fruit until 81 DAFB in comparison to the control and GA4+7 PB. Treatment with Prohexadione Ca at post bloom found to reduce the biosynthesis of GAs and inhibit cell expansion in the fruit (Davies, 2004). Application of prohexadione Ca, at post bloom reduced the Mg/Ca, K/Ca, N/Ca, (K + Mg + N)/Ca and (Mg + K)/Ca ratios in the fruit flesh at the distal portion compared to GA4+7 PB, but without differing from the control. Prohexadione Ca applied fruit possessed higher total water-soluble Ca content and lower electrolyte leakage compared to trees treated with GA4+7. While, higher incidence and severity index for fruit was recorded from trees treated with GA4+7 than fruits from trees treated with Prohexadione Ca, regardless of the application period (PB or Pre-harvest).

Salicylic acid

Salicylic acid is ortho-hydroxybenzoic acid and is a secondary metabolite acting as analogues of growth regulating substances. For the first time saliciline was extracted from white willow (*Salix alba*) and hence the name salicylic acid. Salicylic acid (SA) and methyl salicylate (MeSA) are endogenous signal molecules, playing pivotal roles in regulating stress responses and plant developmental processes including heat production or thermogenesis, photosynthesis, stomatal transpiration, conductance, ion uptake and transport, disease resistance, seed germination, sex polarization, crop yield and glycolysis. Salicylic acid (SA) and acetyl salicylic acid (ASA) provide multiple stress tolerance in plants and its derivatives regulate the expression of stress tolerance. Chitinase β-1, 3-glucanase, Phenylalanine ammonia-lyase and Polyphenoloxidase enzymes increased total phenolic compounds and lignin in mango fruit. However, SA treatment successfully maintained fruit firmness by suppressing conversion of insoluble protopectin into water soluble pectin (He *et al.,* 2017).

Salicyclic acid (SA) affects the number of fruits, yield, vitamin C concentration and anthocyanin content of 'Pajaro' cultivar of strawberry (Eshghi *et al.,* 2014). The study reported that all characteristics increased significantly after SA application. (Eshghi *et al.,* 2014) recorded that the highest amount of yield and number of fruits obtained when plants were treated with 2 mM of SA. (Eshghi *et al.,* 2014) found that higher concentration of vitamin C in treated fruits might be due to the protective role of SA on fragile structure of ascorbic acid. The study reported that fresh cut Chinese water chestnut dipped in 2 or 4 mM of SA solution had higher vitamin C after a couple of hours in comparison to control samples (Peng and Jiang, 2006).

Triacontanol

Triacontanol (TRIA) found in epicuticular waxes and is a natural plant growth regulator (PGR). It is used to intensify the fruit production. Many 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 exploits the genetic potential of plant to a large extent through enhancing the physiological efficiency of the cells (Naeem *et al.,* 2012).

The study reported that foliar spray of triacontanol in the form of mixtalol (6 ml/10 L) was found to be effective with respect to number of leaves, length of terminal shoot and leaf area in guava (Mandal and Kumar, 1989). They further reported that application of triacontanol sprayed three weeks before fruit set was better than those sprayed three weeks after fruit set and control (Suman *et al.,* 2017). Nagalakshmi and Gunasekaran (1989) reported that when triacontanol was applied three times at the rate of 5 g per plant in vermiculture medium the total number of leaves and growth of 'Poovan' banana was maximum, similarly, (Mahajan and Sharma, 1999) observed that in plum significant increase in fruit size, weight and TSS content of fruit through the application of triacontanol at 10 and 20 ppm. Pawar *et al.* (2000) found that spray of triacontanol @ 0.5 per cent resulted in the highest value for vine length, number of leaves and 100 leaf weights in betel vine. (Arulmozhiyan, 2000) also recorded similar beneficial effect of triaontanol on vegetative growth of betelvine. (Barua and Das, 2000) found that application of triacontanol @ 3 ppm in tea plant increased leaf area, leaf: shoot ratio and dry matter content. Ghawade *et al.* (2002) studied the influence of foliar application of nutrients and bio-regulators on growth, fruit set, yield and nut quality in walnut cv. Local selection and also sprayed triacontanol on other temperate fruits and highlighted its effect on plant growth characteristics, fruit set, yield and quality. Sharma *et al.* (2008) recorded that spray of 7.5 ppm triacontanol increased shoot extension growth, fruit set, fruit quality and fruit yield significantly in comparison to other triacontanol treatments after the application of triacontanol thrice, *viz.*, 7 days before full bloom, 15 days after full bloom and one month after second application at 2.5, 5.0, 7.5 and 10.0 ppm in apple cv. Red Delicious. Sharma and Singh (2008) observed that application of 5 ppm triacontanolin plum proved more effective in promoting tree growth, fruit weight, volume and increased yield. Shinde *et al.* (2008) reported that application triacontanol at the concentration of 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, breath, volume, weight, mesocarp and lowest proportion of endocarp. Chowdhary *et al.* (2009) reported that application of 0.05 per cent triacontanol in two cultivars of water chestnut increased the volume of individual fruit by 45.32% and 47.11% in Haldipada green and Haldipada red cultivars respectively and the fresh fruit yield also increased 32% in Haldipada green and 31.25% in Haldipada red cultivars.

However, the soluble carbohydrate content in fresh fruits decreased by 25.46% to 29.61% in triacontanol treated green and red fruit cultivars

Some of the unique applications of PBR's in fruit crops

Lime sulphur, fish emulsion, fish oil, potassium bicarbonate and sodium chloride are potential blossom thinners for reduction of crop load in apple (Close and Bound, 2017). AVG has been developed to increase fruit set in walnut trees by controlling pistillate flower abscission (PFA) (Retamales and Petracel, 2010). Treatment with 1-MCP along with MAP significantly increases the shelf life of fruit, maintain firmness and reduce chilling injury in nectarine fruit (Ozkaya *et al*., 2014). Use of a soybean oil adjuvant plus ethephon reduces peach flower bud survival, acting as potential thinning agent (Reighard *et al*., 2017).

Conclusion

The application of plant bio-regulators in horticulture particularly in fruit crops is a trend with great advantages. Most of the fruit crops show good results with the application of plant bio-regulators. However, alongwith the use of traditional growth regulators, the new generation plant bio-regulators (PBRs) would act in favorable manner in production of the diverse fruit plants in nursery, field and greenhouse. The need of modern world is higher yield and enhanced quality production of the crop through incorporating recent technologies. Future research in horticulture and especially, the use of plant bio-regulators in different fruit crops will rely on development of biotechnological and molecular understanding of plant's physiological response. Fresh alternatives situations should be explored for the use of plant bio regulators for high value fruit crops. The use of these valuable molecules of biological origin can be an fruitful approach for mitigating the adverse impact of stress on plant growth. In addition, the manipulation of the hormonal balance can bring gains to the different fruit plants. The new growth enhancing products have recently emerged as powerful tools in the context of supportive biotechnological studies.

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