

Effective administration of plant growth regulators in Horticultural crops: A review

Abstract

Natural and synthetic plant growth regulators have been used with increasing frequency to modify crop plants by changing the rate or pattern, or both, of their responses to the internal and external factors that govern development from germination. The use of plant growth regulators (PGRs) in modern horticulture is well established, particularly in horticulture in industrially advanced countries, and their application is fast picking up in the developing nations as well. The research review indicated that use of plant growth regulators, regulation of plant metabolism, control of flowering, effects on fruit set and development, control of abscission, Breaking of Seed dormancy and seed germination, enhancing and regulation of flowering, controlling flower drop, fruit thinning, fruit setting, parthenocarpy, Post-harvest management and extending shelf life of horticultural crops.

Keywords: Plant growth regulators, Propagation, flowering and fruiting, Post-harvest in Horticultural crops

Introduction

“Plant growth regulators (PGRs) are organic compounds, other than nutrients, that modify plant physiological processes. PRGs, called biostimulants or bioinhibitors, act inside plant cells to stimulate or inhibit specific enzymes or enzyme systems and help regulate plant metabolism” (Bashir et al. 2021; Soni et al. 2022; Zahidet al. 2023). “Plant hormones, also known as phytohormones, are naturally occurring chemicals generated by plants that control growth. They are both flexible chemical regulators of plant development and in control of it. Plant growth regulators (PGRs) are the name given to these chemicals when they are synthesised” (Santner et al., 2009; Davies, 2010; Rademacher, 2015). They normally are active at very low concentrations in plants. The importance of PGRs was first recognized in the 1930s. Since that time, natural and synthetic compounds that alter function, shape, and size of crop plants have been discovered. Today, specific PGRs are used to modify crop growth rate and growth pattern during the various stages of development, from germination through harvest and post-harvest preservation.

Several environmental and endogenous signals must be integrated into the process of plant growth and development. These signals, along with the plant form is determined by an intrinsic genetic programme. Plant growth regulators are essential to this procedure. Classical groups or other chemicals are included in the main phytohormones and/or PGRs. Among these are indol-3-ylbutyric acid (IBC) and indol-3-ylacetic acid (IAA). abscisic acid (ABA),

(IBA), 1-naphthylacetic acid (NAA), 6- benzylaminopurine (BAP), benzyladenine (BA), gibberellic acid (GA₃), Chloromequat chloride (CCC), 2,4-dichlorophenoxyacetic acid (2,4-D), ethylene or ethephon (CEPA), jasmonate (JA, or yet, methyl jasmonates-MeJA), as well as brassinosteroids (BR), salicylic acid (SA), nitric oxide (NO), strigolactone (SL), and polyamines (like putrescine (Put), spermidine and spermine). Ascorbic acid (VC), alpha tocopherol (VE), thidiazuron (TDZ), phenylureas (CPPU), and triazoles (TR) are other compounds. The new family of plant growth regulators known as Karrikins was also discovered in smoke (Chiwocha et al., 2009; Davies, 2010; Ullah et al., 2012; Rademacher, 2015; Fahad et al., 2016). Plant growth regulators have become indispensable in the field of horticulture due to its potential in improvement of flower production and Shelf life, altering the growth, flowering and propagation of plants. Among the plant growth regulators gibberellins, auxin, ethylene, cytokinins, inhibitors and growth retardants are of immense use of the horticulturist (Janowska and Andrzejak, 2023).

The idea of the existence of auxins in plants was for the first time conceived by **Charles Darwin** in 1881. Subsequently, F.W. Went (1934) was able to collect the substance produced by the tip of the agar blocks by diffusion. The block was then cut into pieces and each piece was then cut end of coleoptiles which was responsible for curvature of tip towards light due to more growth of tissue on side which do not face direct light, Went named this substance as 'auxin' (Greek word Auxem means to grow) and concluded that no growth can occur without auxin'. Endogenous or exogenous Auxin is a requirement for initiation of adventitious roots in stems of cutting and air layering. It has been shown that the division of the first root initial cell are dependent upon either exogenous applied or endogenous auxin. Recent studies have substantially contributed to our understanding of the molecular mechanisms underlying the physiological role of auxin in plant development. Auxin is critical for the control of plant growth and also orchestrates many developmental processes, such as the formation of new roots.

Formation of performed root initials in stems is apparently dependent upon the native auxins in the plants plus an auxin synergist together, these had to synthesis of Ribonucleic acid (RNA) which is evolved in initial of the root primordial. Thimann and Went (1934) found that the relative amount of auxin present indigenous or applied was associated with the formation of root primordial. The synthetic root promoting auxin such as Indole Butyric Acid (IBA) and Naphthalene Acetic Acid (NAA) have been found effective for rooting of cuttings and air layering alone or in combination. (Hartmann *et al.* 1960) stated that in Pear 200 ppm of IBA was found very effective in promotion of rooting of hard wood cutting. Pathak and

Hariom (1982) observed that rooting potentiality of Jackfruit was improved by treatment of IBA + NAA (2500 ppm) or 2500 ppm IBA alone, while higher concentration of IBA proved supra optimal and their by reduced the rooting percentage.(Singh *et al.* 2001) reported that the application of IBA of 15000 ppm increased the survival percentage of Air layers in Mango.(Akwatuliralet *al.* 2011) investigated “the influence of different rooting media and indolebutryic acid (IBA) concentration on root and shoot development in stem cuttings of *Warburgiaugandensis*. Stem cuttings were treated with three different levels (0.3, 0.6 and 0.8% w/w) of IBA and one control i.e. no IBA and propagated in three rooting media (milled pine bark, top forest soil and sand) under non-misting propagators. Milled pine bark and 0.8% w/w IBA concentration gave the greatest number and longest shoots per stem cutting”.(Kishore *et al.* 2001) conducted “an experiment to observe the rooting of hardwood cuttings in sand and saw dust rooting substrate. Observation on the rooting behaviour of six Kiwi fruit varieties revealed that though, sawdust was a superior rooting medium for root initiation in Kiwi fruit hardwood cuttings, but subsequent root and shoot development was better in sand. The cultivars varied from each other only with respect to the magnitude of the rooting like IBA 3000 ppm was found to be suitable concentration for rooting”. (Nagarajaet *al.*1991) obtained “maximum survival percentage in IBA 4000 ppm in hardwood and semi-hardwood cuttings that was 90.00 per cent and 80.00 per cent, respectively”. In softwood cuttings, the maximum survival percentage was obtained in IBA 1000 ppm and NAA 3000 ppm that was 73.33 per cent.Response of hormone gibberellins was discovered by Kurosava, a Japanese scientist in 1926. The gibberellins together naturally occurring compound first isolated in Japan in 1829 from a fungus botanically known as *Gibberellafungikurai* (*Fusarium moniliforme*). It was first isolated from immature seeds of *Phaseolus cocineus* by Mac Millan and Suter (1958). These compounds display a remarkable diversity of physiological effects, including those on growth flowering, fruiting and dormancy (Bukavac and Wittwer, 1958; Brian, 1959; Stowe and Yamaki, 1957; Philney and West 1960). Comprehensive review of Published information on plant growth regulator was Compiled to determination the state of the art on the subject

Major Response of plant growth regulators in Horticultural crops

Plant Propagation and Seed germination

(Hutchinson et al 2014) reported that the use of TDZ at low concentrations was as effective as combined auxin (NAA)and cytokinin (BAP) in evoking shoot regeneration and elongation as well as the number of leaves formed per shoot during *in vitro* propagation of *Alstroemiaaurantiacav*. ‘Rosita’ from shoots tip explants.Paul andaditi,2009 found that

the most efficient concentrations of hormones (IBA and NAA) which enhance rooting of layering and improve the rooting characters like root length, diameter, branching, hardness and the relation of rooting with sprouting in water apple. Samir Z. (El-Agamy et al., 2009) studied that “Shoot tips of 2-3 cm long of two pomegranate cultivars (Manfalouty and Nab El-Gamal) were cultured on three different media at full strength, namely Murashige and Skoog; (MS), Nitsch&Nitsch; (NN) and Woody Plant Medium; (WPM). Woody Plant Medium (WPM) proved to produce best vegetative growth characteristics compared to MS and NN ones. BA at 1.0 mg/l induced high significant proliferation rate and shoot quality for two tested cultivars compared to kinetin. To induce rooting NAA at 0.25 mg/ (for Nab El-Gamal) and IBA at 0.25 mg/l (for Manfalouty) while IBA generally proved to produce higher number of roots per shoot. In addition, WPM at half-strength generally produced better plantlets compared to its full strength”. Similar result were reported by (Mamta Sharma *et al*, 2000) in apple rootstock.

(Arrillaga, I. *et al*.1990) investigated that “the use of Various plant growth regulators in invitro propagation in flowering ash, Shoot apices or nodal segments from aseptically grown seedlings or shoot apices from adult trees were used as initial explants. Result reported that the highest shoot multiplication rates were obtained when the explants were cultured for 30 days in liquid Rugini induction medium supplemented with BA followed by 30 days on solidified Rugini multiplication medium without growth regulators. Regenerated shoots were rooted on Heller medium containing auxins alone or in combination with BA. Rooting percentages up to 71% (juvenile material) or 50% (adult material) were obtained in the presence of NAA and BA, and were not improved by treating the basal end of the shoots with concentrated NAA solutions”.

Flowering and fruiting

Many reviewer had reviewed that the effect of naphthalene acetic acid(NAA) as a plant growth regulator in reducing pre-harvest fruit drop and resulting in increased number of fruits and yield in tomato crop. Seneratna *et al.*, (2000) indicated that “aspirin and salicylic acid induced multiple stress tolerance in bean and tomato plant”. Tiwari and Lal,2007 reported that “the effect of naphthalene acetic acid (NAA)all the treatments gave significantly higher yield than control. Maximum yield (88.00 kg/tree) was recorded with one leaf pair pruning during winter season. Overall yield during both the seasons was maximal in control (110 kg/tree) however, due to good quality fruit during winter season, higher income was obtained with the treated trees as compared to control”. Verma (2004) studied “the regulation of flowering in African marigold

(*Tagetes erecta* L.) by the application of GA₃ 100, 150 and 200 ppm etherel 250, 500 and 750 ppm, and MH 250, 500, 750 ppm and control. Among all treatment GA₃ 200 ppm recorded maximum flower yield as compared to control”.

Effect of foliar application of GA₃, NAA, Ethrel and B-9 on chrysanthemum was studied by (Gautam *et al.* 2006) and observed that GA₃ 200 ppm and NAA 100 ppm increased growth of chrysanthemum flower; however ethrel reduced vegetative growth in all concentration.

Control fruit drop

(Michael F. Anthony *et al.*, 2001) reported that the use of several synthetic Auxin in reducing abscission of mature citrus fruit in California, he found Both NAA and 3,5,6-TPA were effective in controlling preharvest fruit drop in citrus under CA conditions Both materials provided fruit holding late into the harvest season. Yuan and Jianguo (2008) studied “the effect of different plant growth regulators combination on fruit ethylene production, preharvest fruit drop, fruit quality, and fruit maturation were examined in ‘Delicious’ apples (*Malus domestica* Borkh.) results showed that 1-MCP or NAA + AVG was more effective than NAA or AVG alone in reducing preharvest fruit drop and extending the harvest season while maintaining fruit quality. 1-MCP applied 15 DBAH more effectively delayed preharvest fruit drop than when applied 7 DBAH in ‘Delicious’ apples. 1-MCP more effectively inhibited expression of MdPG2 in fruit abscission zones than AVG alone”.

Post-harvest management and Shelf life

(Cronjé, *et al.* 2005) reviewed “several plant growth regulators he found that complex plant mechanism is not so readily manipulated and 2,4-D remains the best product to inhibit calyx abscission of citrus fruit”. Yuan *et al.*, (2007) studied the effect of various plant growth regulators on fruit ethylene production, preharvest fruit drop, fruit quality, and fruit maturation were examined in ‘Golden Supreme’ and ‘Golden Delicious’ apples (*Malus domestica* Borkh.) our results showed that the combinations of NAA (a synthetic auxin) and AVG (an inhibitor of ethylene biosynthesis) or 1-MCP (an inhibitor of ethylene action) was more effective when used in combination than when used alone in reducing preharvest fruit drop and extending the harvest season while maintaining fruit quality.

Relationships between the metabolic and ecophysiological processes

There are several interactions between various ecophysiological and metabolic processes and plant growth regulators that adversely affect the expansion and development of many agricultural crops. Plant biologists now have a much deeper understanding of how hormones influence growth and development because to the identification of receptors for numerous of

these hormones (Spartz and Grey, 2008; Pieterse *et al.*, 2009; Simon and Petrák, 2011). In this regard, Dharmasiri *et al.* (2013) describe the results pertaining to these hormonal signalling pathways, highlighting the mechanisms of hormone perception and subsequent signalling pathways that result in the regulation of gene expression. Various hormone groups that differ chemically and structurally control the growth and development of plants. Many strides have been made in the previous few decades towards understanding how these plant hormones are perceived and how they work. All of these hormones are involved in influencing gene expression by either regulating the amount of transcriptional factors or repressors, or their activity through posttranslational changes, even though some hormone responses are not always related to gene regulation. In light of this, ubiquitin-mediated protein degradation has emerged as a key component of numerous plant hormone signalling pathways. In addition, numerous unique signalling mechanisms past ten years have seen the discovery of numerous more plant hormones, including cell wall fragments and peptides (Yamaguchi and Huffaker, 2011; Dharmasiri *et al.*, 2013; Zahid *et al.* 2023).

“Salicylic acid (SA), jasmonates (JA), and ethylene (ET) are important players and their roles in understanding how plants react to biotic stressors have advanced significantly. A number of studies suggest that additional hormones, including auxin, gibberellic acid (GA₃), cytokinin, brassinosteroids, and peptide hormones, are also involved in the signalling pathways used by plants to defend themselves” (Bari and Jones, 2009). “Plant growth-promoting Rhizobacteria (PGPR) have received a lot of interest recently as a potential replacement for agrochemicals (fertilisers and pesticides) for the enhancement of plant growth through a variety of processes. It involves the development of soil structure, the breakdown of organic matter, the recycling of necessary elements, the solubilization of mineral nutrients, the production of numerous plant growth regulators, the degradation of organic pollutants, the stimulation of root growth, essential for soil fertility, the biocontrol of soil and seed-borne plant pathogens, and the promotion of changes in vegetation” (Sivasakthi *et al.*, 2014).

Table 1. Plant growth regulators used in horticulture crops for profit

Crops	PGRs	Impact	Reference Citation
Fruits			
Mandarin	2,4-D and NAA	Reduced pre-harvest fruit drop percentage increased fruit weight, juice percentage, total soluble solids, acidity, vitamin C content, and the quantity of fruits per plant.	Nawaz <i>et al.</i> (2008)
Sweetorange	NAA	Maximum improvement in fruit retention, fruit output per plant, fruit production per plant, and fruit drop	Sweet <i>et al.</i> (2018)

Sapota	GA3andNAA	Maximum fruit weight, length, diameter, volume, TSS, reducing and non-reducing sugar, yield per tree, yield per hectare, and prolonged shelf life	Sahu <i>et al.</i> (2018)
	Ethylene	shortened the ripening period and improved the physico-chemical characteristics	Vidhya <i>et al.</i> (2017)
Mango	GA3	Slowed down the overall weight loss, the concentration of chlorophyll and ascorbic acid, and the activity of amylase and peroxidase during ripening.	Sahu <i>et al.</i> (2018)
	ABA	Increasing total sugars and sucrose while reducing ruitripene consumption	Zaharah <i>et al.</i> (2012)
	Ethylene	Initiatingmangoripening	NguyenandMcConchie (2002)
Banana	Ethephon (1-MCP)	Delayedripeningprocess	Xiaoyan <i>et al.</i> (2015)
Guava	GA3	Maximumgrowth,yield,qualityattributeandhighestgermination	LalandDas(2017)
	BA	Effective in reducing shoot length, shooting response, number of shoots and explants, physiological loss of weight (PLW), decay, reduction in diameter, and juice content	Nagar <i>et al.</i> (2002)
	Ethylene	Increaseinthe rateofskinyellowingand softeningofimmature-green fruit	Reyes and Paull (1995)
Custardapple	BA	Enhanced shelf-life	Chouksey <i>et al.</i> (2013)
Pineapple	ABA	Reduced the intensity of internal browning, moisture loss and malic acid content in the crown leaves	Nanayakkara <i>et al.</i> (2005)
Citrus	ABA, Ethylene	Induced callus formation	Goren <i>et al.</i> (1979)
Phalsa	NAA	A higher rate of flowering, fruiting, fruit weight, fruit weight per shoot, fruit juice %, minimum seed percentage, and maximum yield per hectare.	Kacha <i>et al.</i> (2012)
	GA3	Increasing vegetative growth and yield	Singh <i>et al.</i> (2017)
Vegetables			
Bittergourd	NAA	Producedlowersexratiogave,maximum numberoffruitsperplant andfinallyyieldperhectarewiththe maximumBCR	Khatoon <i>et al.</i> (2019)
Capsicum	NAA	Increasedplantheight,earlyflowering,numberofbranches,plant spread,numberofflowersper plant,shelflifeandTSS	Singh <i>et al.</i> (2017)
Okra	ABA	Enhancinghealthpromotingcomponent	Prajapati <i>et al.</i> (2019)
	IAA	Maximumplantheightandintermodal length	Dhage <i>et al.</i> (2011)
	SAand ABA	Significantlyreducedtheharsheffects ofdroughtonokra germinationandgrowth parameters, enhancethe tolerant ability	Baghizadeh andHajmohammadrezaei(2011)
	CCC	Lowest number of days to first flowering, 50% blossoming, the position of the first flower's node, the maximum number of harvests overall, the number of fruits per plant, yield per plant and per hectare, the weight of a single fruit, the breadth of a fruit, the percentage of Vitamin "A" and crude fibre	Kumare <i>et al.</i> (2018)
	Brassinosteroid	Toincreaseinplant growthandbiomass,leafarea,chlorophyllcontent, photosynthesisrate,photochemicalefficiencyofPSII	WajidKhan <i>et al.</i> (2017)
Watermelon	TIBA	Bettergrowth,early flowering,minimumsexratio,highestfruityield andsuperiorquality	Chaudhary <i>et al.</i> (2016)
Tomato	2,4-DandIAA	Development of seedless parthenocarpic fruit with increased size,increasegrowthand yieldattributes	Gelmesa <i>et al.</i> (2013) Khaled <i>et al.</i> (2015)
	GA3	Foryieldattribute	Sharma <i>et al.</i> (2018)
	Ethylene	Promotionoffruitripening,floweringandoverallplantgrowth	SunidhiandGandhi, 2019

	Cytokinin	Breaking dormancy after seed imbibition, also allowing germination and growth of dormant embryos.	Nawaz <i>et al.</i> (2012)
	PBZ	Improves the photosynthetic activity and water balance	Berova and Zlatev (2000)
	Thiourea	Increased plant dry weight and the tomato yield after inoculation	Nasr A. (1993)
Onion	NAA	Reduced physiological loss of weight, spoilage loss	Pate <i>et al.</i> (2010)
Brinjal	NAA	Long-styled flower percent, number of fruits/plant, and the highest fruit yield	Moniruzzaman <i>et al.</i> (2014)
Pea	GA ₃	Maximum number of pods per plant, seed yield, seed index and protein content in seeds	Bora and Sarma (2006)
Pumpkin	GA ₃	Enhancing growth and yield	Sure <i>et al.</i> (2012)
Bottle gourd	GA ₃	Maximum fruit length, fruits weight and fruits girth	Kumari <i>et al.</i> (2019)
Cucumber	GA ₃	maximum fruit set percentage, fruit retention and TSS	Kadi <i>et al.</i> (2018)
	Ethylene	Induce femaleness	Rudich <i>et al.</i> (1969)
Muskmelon	Potassium nitrate	TSS, carotene, ascorbic acid, thickness of the flesh, hardness of the fruit, skin colour, moisture content, and shelf life are examples of quality characteristics.	Sindhuja <i>et al.</i> (2017)
	CPPU	Increase number of fruits per vine, fruit weight and yield per vine	Sindhuja <i>et al.</i> (2017)
Lettuce	ABA	Minimize the effects of drought stress	Al Muhairi <i>et al.</i> (2016)
Cluster bean	SA and Thiourea	High yield parameters, yield and gum content	Meena and Meena (2017)
Flowers			
Calendula	NAA	Greater amount of carbohydrate accumulation and increased metabolic activities	Khudus <i>et al.</i> (2017)
	SA	Increased CO ₂ assimilation and photosynthetic rate and increased mineral uptake	Bayat <i>et al.</i> (2012)
<i>Clerodendrum splendens</i>	IBA	Increase in sprout length and root length	Jama <i>et al.</i> (2015)
Orchid	NAA	Enhanced the plant growth and development	Khandaker, M.M. <i>et al.</i> (2016)
Rose	IBA	Increase survival percentage, maximum number of roots and the longest roots	Susaj <i>et al.</i> (2012)
Marigold	NAA	Maximum weight and diameter of fully opened flower	Meshram <i>et al.</i> (2015)
	GA ₃	Increase vegetative growth and flowering	Mishra (2017)
	CCC	Increase flower yield and number of flowers/plant	Kumar <i>et al.</i> (2011)
	Triacetonol	Increase plant height, number of laterals, number of leaves and leaf area	Muruganandam (2014)
Chrysanthemum	GA ₃	Increase plant height, number of branches, suckers, leaves plant ⁻¹ , leaf area, days to flower and number of flowers	Sajid <i>et al.</i> (2016)
	GA ₃	Increase plant growth and flowering attributes	Reshma <i>et al.</i> (2017)
Gladiolus	ABA	As a hormonal trigger in ethylene insensitive senescence process	Kumar <i>et al.</i> (2014)
	Ethrel	Increase corm splitting, delayed flowering and slightly shortened flower stems	Halevy <i>et al.</i> (1970)
	SA	Improves vase life	Rahmani <i>et al.</i> (2015)
	BA	Sprouting of multiple buds and increase production of corms	Sajjad <i>et al.</i> (2015)
Tuberose	GA ₃	Beneficial for sprouting	Ganesh <i>et al.</i> (2013)
China aster	GA ₃	Increase number of primary branches, flowery yield per hectare, seed yield per plant and seed yield per hectare	Kumar <i>et al.</i> (2015)
	SA	Increase growth, flower and seed yield	Kumar <i>et al.</i> (2015)
Matthiola incana	Kinetin and NAA	Shoot length, greatest number of nodes and highest length of roots	Hesar <i>et al.</i> (2011) Kaviani <i>et al.</i> , 2013
Cactus	ABA	Increase in calli fresh weight and colour	Lema-Ruminska <i>et al.</i> (2013)
Petunia	Ethylene	Induced adventitious root formation	Dimasi-Theriou <i>et al.</i> (1993)
Gerbera	BA and GA ₃	Increase vase life, fresh weight, solution uptake, membrane stability and TSS	Danae <i>et al.</i> (2011)
Dahlia	MH	Highest number of flowers and diameter of bud	Malik <i>et al.</i> , (2017)

In the context of 'green' biotechnologies for tree fruits, such as plant breeding, the new technologies have lately emerged as potent instruments. Use of plant regulators and hormonal plant regulation are two further examples of innovative technologies. In salt-stressed and control *Arabidopsis thaliana* seedlings Costa *et al.* (2017). Simura *et al.* (2018) established “the validity of and made a hormonal approach (including quantification of the main phytohormone classes or groups: cytokinins, auxins, brassinosteroids, gibberellins, jasmonates, salicylates, and abscisates)”.

In vitro plant tissue culture

Regardless of the plant species, PGR usage is a crucial procedure in plant tissue culture.

According to Perera *et al.* (2009), consistent callogenesis was produced by cultivating unfertilized ovaries at the -4 stage in CRI 72 medium containing 100 M 2,4-D and 0.1% activated charcoal. They also examined the impact of plant growth regulators on the ovarian culture of the coconut (*Cocos nucifera* L.). Application of 9 M TDZ improved callus development. On somatic embryogenesis induction media containing 66 M 2,4-D, embryogenic calli were subcultured. The somatic embryos' growth was stunted after being subcultured onto CRI 72 media containing ABA. In Y3 medium, somatic embryo maturation was possible without the use of growth regulators. While 2-isopentyl adenine (2iP) improved the frequency of plant regeneration, adding GA3 to conversion solution containing 5 M BA stimulated the conversion of somatic embryos. Garcia *et al.* (2011) found that “the direct organogenesis in this species was obtained through shoot development from internodal segments in the presence of BA in an in vitro study examining the effects of explant type, plant growth regulators (NAA, picloram - PIC, and 2,4-D), salt composition of basal medium, and light on callogenesis and regeneration in *Passiflora suberosa* L. (passion fruit - Passifloraceae). On media containing BA as a supplemental ingredient, either by itself or in combination with NAA, indirect organogenesis was accomplished from all explant types”.

Conclusion

With the help of reviews mentioned above it is concluded that the application of several plant growth regulators in horticultural crops will continue to increase in the near future, depending primarily upon the economic benefits of this technique in comparison to other production Methods. It will continue to have applications as horticultural crops as well as many Agricultural crops on established plant propagation, Breaking of Seed dormancy and seed germination, enhancing and regulation of flowering, controlling flower drop, Fruit thinning, Fruit Setting and Parthenocarpy, Post-harvest management and extending shelf life of

horticultural crops. A growing trend in horticulture with many benefits is the use of plant regulators. The method used to apply plant growth regulators exhibits good outcomes in horticulture. The conclusion that the application of plant growth regulators in horticulture plants can be a challenge for all those who act in the sector, presenting practical advantages and favourable possibilities for future use, leads to additional studies, weights, and conversations on the subject. The integration and coordination of several signalling events during plant growth is necessary for the regulation of complicated growth and developmental processes. PGRs would be advantageous as an excellent method for producing the variety of horticulture plants in nurseries, fields, and greenhouses. Today's world requires a high output yield, improved crop production, and the incorporation of new technologies. In order to further our understanding of plant physiology, future horticultural research will be dependent on the development of molecular and biotechnological methodologies. This is especially true for research on the use of plant growth regulators in horticultural plants. The use of plant growth regulators for additional high value crops, such as vegetables, fruits, and flowers, should be investigated for novel options. Applying these substances might be a good strategy to lessen the damaging effects of stress on plant growth. The crops of several horticultural plants can also benefit from the alteration of the hormonal balance. In the context of biotechnologies, the new technologies have recently come into their own as potent tools.

Future perspectives

Future prospects for plant growth regulator use and application in agriculture look bright, particularly when it comes to horticultural crops. Understanding how the information transmitted by these straightforward chemicals is incorporated throughout plant growth would be a significant task (Santner et al., 2009). In addition, during the past few years, it has become clearer the molecular mechanisms governing hormone synthesis, signalling, and action, as well as the functions of plant hormones in adapting to environmental changes. The alteration of hormone biosynthesis pathways to produce transgenic plants with improved biotic stress tolerance will be made easier by these discoveries. It has been discovered that either synthetic or natural crop growth controllers are more effective and thorough at boosting crop production.

References

1. Akwatulira¹, F., Gwali, S., Okullo, J.B.L., Ssegawa, P., Tumwebaze, S.B., Mbwambo, J.R. and Muchugi, A. 2011. Influence of rooting media and indole-3-butyric acid (IBA) concentration on

- rooting and shoot formation of *Warburgiaugandensis* stem cuttings. *African J. Pl. Sci.* **5**(8): 421-429.
2. Al Muhairi MA, Cheruth AJ, Kurup SS, Rabert GA, Al- Yafei MS. Abscisic acid-induced modifications in growth and pigment composition of lettuce (*Lactuca sativa* L.) under different irrigation regimes. *Genetics and Plant Physiology.* 2016; 6(1-2):72-84.
 3. Amjad Bashir, M., Rehim, A., Raza, Q.-U.-A., Muhammad Ali Raza, H., Zhai, L., Liu, H., & Wang, H. (2021). Biostimulants as Plant Growth Stimulators in Modernized Agriculture and Environmental Sustainability. *IntechOpen.* doi: 10.5772/intechopen.98295
 4. Anthony, Michael F., and Charles W., Coggins, Jr., (2001)NAA and 3,5,6-TPA Control Mature Fruit Drop in California Citrus.*HORTSCIENCE* 36(7):1296–1299.
 5. Arrillaga, I., Lerma, V., and Segura, J.(1992)Micropropagation of Juvenile and Adult Flowering Ash.*J. AMER. SOC. HORT. SCI.* 117(2):346-350.
 6. Baghizadeh A, Hajmohammadrezaei M. Effect of drought stress and its interaction with ascorbate and salicylic acid on okra (*Hibiscus esculents* L.) germination and seedling growth. *Journal of Stress Physiology & Biochemistry.* 2011;7(1):55-65.
 7. Bari R, Jones JD (2009) Role of plant hormones in plant defence responses. *Plant molecularbiology* 69(4): 473-488; doi: 10.1007/s11103-008-9435-0
 8. Bayat H, Alirezaie M, Neamati H. Impact of exogenous salicylic acid on growth and ornamental characteristics of calendula (*Calendula officinalis* L.) under salinity stress. *Journal of Stress Physiology & Biochemistry.* 2012;8(1):258-267.
 9. Berova M and Zlatev Z. (2000) Physiological response and yield of paclobutrazol treated tomato plants (*Solanum lycopersicum*) *Plant Growth Regulation.* 30:117–123.
 10. Brain, I. (1959). Gibberellic acid plant tall, spindly and high energetic. *Sci. Fmr.* 3(5): 14-15.
 11. Bukovac, J. W. (1958). Gibberellic acid makes plant tall, spindly. *Sci. Fmr.*7(3): 10.
 12. Chaudhary DC, Patel NM, Rathva VD, Nurbhanej MH. Effect of growth substances on growth, flowering, yield and quality attributes of watermelon (*Citrulluslanatus*Thunbmans f.) cv. DurgapuraLal (RW-177-3). *International Journal of Agriculture Sciences,* 2016;8(40):1825-1828. Chouksey S, Singh A, Thakur RS, Deshmukh R. Influence of gamma irradiation and benzyl adenine on keeping quality of custard apple fruits during storage. *Journal of Food Science and Technology.* 2013;50(5):934-941.
 13. Chiwocha SD, Dixon KW, Flematti GR, Ghisalberti EL, Merritt DJ, Nelson DC, Riseborough JAM, Smith SM, Stevens JC (2009) Karrikins: a new family of plant growth regulators in smoke. *Plant science* 177(4): 252-256; doi: 10.1016/j.plantsci.2009.06.007

14. Costa LD, Malnoy M, Gribaudo I (2017) Breeding next generation tree fruits: technical and legal challenges. *Horticulture Research* 4: 17067; doi: 10.1038/hortres.2017.67
15. Cronjé, P.J.R., Crouch, E.M., and Huysamer, M.(2005) Postharvest Calyx Retention Of Citrus Fruit, *ISHS Acta Horticulturae* 682: V International Postharvest Symposium.
16. Davies PJ (2010) The Plant Hormones: Their Nature, Occurrence, and Functions. In: Davies PJ (eds). *Plant Hormones*, pp. 1-15. Springer, Dordrecht; doi: 10.1007/978-1-4020-2686-7_1
17. Devi, D.U.; Sekhar, R.C. and Baba, J.D. (2007). Effect of growth regulators on flowering and corn production gladiolus. *J. Research ANGRAU*. 35(1): 6-14.
18. Dhage AA, Nagre PK, Bhangre KK, Pappu AK. Effect of plant growth regulators on growth and yield parameters of okra. *The Asian Journal of Horticulture*. 2011;6(1):170-172.
19. Dharmasiri S, Jayaweera T, Dharmasiri N (2013) Plant hormone signalling: current perspectives
20. Dimasi-Theriou K, Economou AS, Fakiotakis SEM. Promotion of petunia (*Petunia hybrida* L.) regeneration in vitro by ethylene. *Plant Cell, Tissue and Organ Culture*. 1993;32:219-225.
21. El-Agamy, Samir Z., Mostafa, Rafat A.A ., Shaaban, Mokhtar M. and El-Mahdy, Marwa T.(2009) *In vitro* Propagation of Manfalouty and Nab El-gamal Pomegranate Cultivars *Research Journal of Agriculture and Biological Sciences*, 5(6): 1169
22. Fahad S, Hussain S, Saud S, Khan F, Hassan S, Nasim W, Arif M, Wang F, Huang J (2016) Exogenously applied plant growth regulators affect heat stressed rice pollens. *Journal of agronomy and crop science* 202(2): 139-150; doi: 10.1111/jac.12148
23. Garcia R, Pacheco G, Falcão E, Borges G, Mansur E (2011) Influence of type of explant, plant growth regulators, salt composition of basal medium, and light on callogenesis and regeneration in *Passiflora suberosa* L. (Passifloraceae). *Plant Cell, Tissue and Organ Culture (PCTOC)* 106(1): 47-54; doi: 10.1007/s11240-010-9892-4
24. Gautam, S. K.; Sen, N. L.; Jain, M. C. and Dashora L. K. (2006). Effect of plant growth regulators on growth, flowering and yield of chrysanthemum cv. Nilima. *Orissa J. Hort.* 34(1): 36-40.
25. Gelmessa D, Abebie B, Desalegn L. Effects of gibberellic acid and 2,4 dichlorophenoxy acetic acid spray on vegetative growth, fruit anatomy and seed setting of tomato (*Solanum lycopersicum*). *Science, Technology and Arts Research Journal*. 2013;2(3):25-34.
26. Gill, K., Kumar, P., Negi, S., Sharma, R., Joshi, A. K., Suprun, I. I., & Al-Nakib, E. A. (2023). Physiological perspective of plant growth regulators in flowering, fruit setting and ripening process in citrus. *Scientia Horticulturae*, 309, 111628.
27. Goren R, Altman A, Giladi I. (1979) Role of Ethylene in Abscisic Acid-induced Callus Formation in Citrus Bud Cultures. *Plant Physiology*, 63:280-282.

28. Hartmann, H.T.; Griggs, W.N. and Hansen, C.J. 91960). Old Home pear rootstock propagated by hardwood cuttings. *Calif. Agric.*, 14 9-10.
29. Hutchinson, M. J., Onamu, R. , Kipkosgei, L. and Obukosia, S. D.(2014)Effect of thidiazuron, naa and bap on in vitro propagation of *alstroemeriaaurantiacacv.* ‘rosita’ from shoot tip explants *JAGST Vol. 16(2) 2014*
30. Janowska, B., &Andrzejak, R. (2023). Plant Growth Regulators for the Cultivation and Vase Life of Geophyte Flowers and Leaves. *Agriculture*, 13(4), 855.
<https://doi.org/10.3390/agriculture13040855>
31. Kacha HL, Viradia RR, Leua HN, Jat G, Tank AK. (2012) Effect of NAA, GA3 and ethrel on yield and quality of phalsa (*Grewiaasiatica* L.) under South-Saurashtra condition. *The Asian Journal of Horticulture.* 7(2):242-245.
32. Khaled AM, Sikder S, Islam MR, Hasan MA, Bahadur MM. (2015) Growth yield and yield attributes of tomato (*Solanum lycopersicum.*) as influenced by Indole Acetic Acid. *Journal of Environmental Sciences & Natural Resources*,8(1):139-145.
33. Khatoon R, Moniruzzaman M, Moniruzzaman M. (2019) Effect of foliar spray of GA3 and NAA on sex expression and yield of bitter gourd Bangladesh Journal of Agricultural Research. 44(2):281-290.
34. Kishore, D.K., Pramanickk, K. and Sharma,Y.P. (2001) Standardization of kiwi fruit (*Actinidia chinensisvarDelicosa*)propagation through hardwood cutting, *J. Appl. Hort.* 3(2): 113-114.
35. Kumar P, Haldankar PM, Haldavaneka PC (2018) Study on effect of plant growth regulators on flowering, yield and quality aspects of summer okra (*Abelmoschus esculentus*L. Moench) Var. Varsha Uphar. *The Pharma Innovation Journal*, 7(6):180-184.
36. Lal N and Das RP (2019) Effect of Plant Growth Regulators on Yield and Quality of Guava (*Psidiumguajava* L.) cv. Allahabad Safeda. *International Journal of Current Microbiology and Applied Sciences.* 6(5):857-863.
37. Lema-Ruminska J, Goncerzewicz K, Gabriel M. Influence of abscisic acid and sucrose on somatic embryogenesis in Cactus CopiapoatenuissimaRitt. Forma mostruosa. *The Scientific World Journal.* 2013, pp.1-7.
38. Malik SA, Rather ZA, Wani MA, Din A, Nazki IT (2017). Effect of growth regulators on plant growth and flowering in dahlia (*Dahlia variabilis*) cv. Charmit. *Journal of Experimental Agriculture International*,15(3):1-7.
39. Nagar BL, Dashora LK, Yadava LP (2002). Effect of ultra-violet radiation, cytokinin and vapor gard on postharvest shelf life of kagzi lime (*Citrus aurantifolia*Swingle). *Journal of Applied Horticulture*, 4(1):21-24.

40. Nagaraja, U.S. Muthappa, B.C. Rai and Guruprasad, T.R. (1991) Effect of intermittent mist and growth regulators on propagation of *Jasminum grandiflorum* by different types of cuttings. *Haryana J.Hort.Sci.* 20(3-4): 183-188.
41. Nanayakkara KPGA, Herath HMW, Senanayake YDA. Effects of Pre-harvest Treatments of Potassium, Post- harvest Treatments of Calcium, Potassium, Abscisic Acid and Light on Reducing Internal Browning in Pineapple (*Ananas comosus* (L.) Merr. cv Mauritius) under Cold-storage. *Acta Horticulture*, 2005, pp. 321-327.
42. Nasr AA (2019) The effect of cytokinin and thidiazuron on tomato inoculated with endomycorrhiza. *Mycorrhiza*, 3:179-182.
43. Nawaz A, Amjad M, Khan SM, Afzal I, Ahmed T, Iqbal Q (2012) Tomato seed invigoration with cytokinins. *Journal of Animal and Plant Science*, 22(4):121- 128.
44. Nawaz MA, Ahmad W, Ahmad S, Khan MM (2008) Role of growth regulators on preharvest fruit drop, yield and quality in kinnow mandarin. *Pakistan Journal of Botany*, 40(5):1971-1981.
45. Nguyen H, Mc Conchie R (2002) Effect of Ethylene and Ripening Temperatures on the Skin Colour and Flesh Characteristics of Ripe 'Kensington Pride' Mango Fruit. *Acta Hort*, 635-642.
46. Pathak, R.K. and Hariom (1982). Propagation of Jachfruit (*Artocarpus heterophyllus*) by stool layering. *National Seminar of plant propagation* (27-29): 65-68 at B.C.K.V. Kalyani, (W.B.).
47. Paul, R., and aditi ,Ch.,(2009) IBA and NAA of 1000 ppm induce more improved rooting Characters in air-layers of waterapple (*Syzygium javanica* L) *Bulg. J. Agric. Sci.*, 15 (2) 123-128
48. Perera PI, Vidhanaarachchi VRM, Gunathilake TR, Yakandawala DMD, Hocher V, Verdeil JL,
49. Philney, S. and J. West (1960). Gibberellic acid makes plants bigger size and Tall, Spindly. *Sci. Hort.* 7(3): 7.
50. Pieterse CM, Leon-Reyes A, VanderEnt S, VanWees SC (2009) Networking by smallmolecule hormones in plant immunity. *Nature chemical biology* 5(5): 308-316; doi: 10.1038/nchembio.164
51. Prajapati U, Asrey R, Arora A, Singh AK, Hasan M. (2019) Differential effects of abscisic acid and fluridone on postharvest quality parameters of detached capsicum (*Capsicum annum* L.) fruits. *Journal of Scientific and Industrial Research*, 78:242-247.
52. Rademacher W (2015) Plant growth regulators: backgrounds and uses in plant production. *Journal of plant growth regulation* 34(4): 845-872; doi: 10.1007/s00344-015-9541-6
53. Sahu CK, Patel MK, Panda CM. (2018) Effect of pruning and plant growth regulator on plant growth and fruit yield of sapota (*Manilkara zapota* L.) cv. Cricket Ball. *International Journal of Current Microbiology and Applied Sciences*, 7(9):1352-1357.

54. Sahu CK, Patel MK, Panda CM (2018) Effect of pruning and plant growth regulator on physico-chemical quality of sapota (*Manilkara zapota* L.) cv. cricket ball. *The Pharma Innovation Journal*. 7(8):335-338.
55. Santner A, Calderon-Villalobos LIA, Estelle M (2009) Plant hormones are versatile chemical regulators of plant growth. *Nature chemical biology* 5(5): 301-307; doi: 10.1038/nchembio.165
56. Senaratna, T., D. Touchell, E. Bunn and K. Dixon (2000) Acetyl salicylic acid (Aspirin) and salicylic acid induce multiple stress tolerance in bean and tomato plants. *Plant Growth Regul.*, 30: 157-161.
57. Sharma A, Khanal A, Dhital B. (2018) Effect of gibberellic acid on postharvest shelf-life and quality of tomato. *Journal of Postharvest Technology*. 6(4):82-90.
58. Sharma, M., Dogil, M., and Sharma, D.R. (2000) Success full propagation in vitro of Apple rootstock MM106 and influence of phloroglucinol, *Indian journal of experimental biology* 38:1236-1240
59. Simon S, Petrášek J (2011) Why plants need more than one type of auxin. *Plant Science* 180(3): 454-460; doi: 10.1016/j.plantsci.2010.12.007
60. Simura J, Antoniadi I, Siroká J, Tarkowská D, Strnad M, Ljung K, Novák O (2018) Plant Hormonomics: Multiple Phytohormone Profiling by Targeted Metabolomics. *Plant Physiology* 177: 476-489; doi: 10.1104/pp.18.00293
61. Singh B, Yadav AL, Meena AK. (2017) A study on foliar feeding of GA3 and NAA on vegetative growth and yield of phalsa (*Grewia subinaequalis* D.C.). *International Journal of Current Microbiology and Applied Sciences*, 6(6).
62. Singh P, Singh D, Bahadur V, Jaiswa DK. (2017) Study on naphthalene acetic acid and gibberellic acid on growth and quality of capsicum (*Capsicum annum* L.) cv. Indra under shade net conditions. *International Journal of Current Microbiology and Applied Sciences*. 6(6):2582-2585.
63. Singh, M. Baghel, K.S. and Singh, M. (2001) influence of plant growth regulator and colour of wrapper on air layering in mango varieties. 2(1): 37-40.
64. Sivasakthi S, Usharani G, Saranraj P (2014) Biocontrol potentiality of plant growth promoting bacteria (pgpr)- *Pseudomonas fluorescens* and *Bacillus subtilis*: a review. *African journal of agricultural research* 9:1265-1277
65. Soni, S., Vishwakarma, G., Singh, S. C., Kumar, S., Singh, R. K., Awasthi, P., & Gangwar, V. (2022). Commercial use of plant growth regulators in horticultural crops: An overview. *The Pharma Innovation Journal*, 11(6), 112-119.

66. Spartz AK, Gray WM (2008) Plant hormone receptors: new perceptions. *Genes and development* 22(16): 2139-2148; doi:10.1101/gad.1693208
67. Stover L., Ed., Mike., F., Risio, R., Yang, X., and Robinson, T. (2001) Fruit Weight, Cropload, and Return Bloom of 'Empire' Apple Following Thinning with 6-Benzyladenine and NAA at Several Phenological Stages. *HORTSCIENCE* 36(6):1077–1081.
68. Stowe, T.J. and Yamaki, S. (1957). Gibberellic acid make plant Tall. Spindly and high energetic. *Sci. Fmr.* 8(1): 10-11.
69. Sweety Rana GS, Reddy GC. (2018) Impact of growth regulators on fruit drop and yield parameters of sweet orange (*Citrus sinensis* Osbeck) cv. Jaffa. *Journal of Pharmacognosy and Phytochemistry*, 7(4):3417- 3419.
70. Thimann, K.V. and Went, F.W. (1934). On the chemical nature of root forming hormone. *Proc. K. Led. Akad.*, 37:436-439.
71. Tiwari, J.P., and Lal, S. (2007) Effect of NAA, flower bud thinning and pruning on crop regulation in guava (*psidium guajava* l.) cv. Sardar, International Guava Symposium, ISHS Acta Horticulturae, 735.
72. Tyagi, A.K. and Singh, C.N. (2006). Effect of GA₃ and IBA on flowering and pulp production in tuberose (*Polianthes tuberosa* Linn.) cultivar pear double. *J. Orna. Hort.* 9(2): 152.
73. Ullah F, Bano A, Nosheen A (2012) Effects of plant growth regulators on growth and oil quality of canola (*Brassica napus* L.) under drought stress. *Pak J Bot*, 44(6): 1873-1880
74. Varma, L. R. (2004). Regulation of flowering in African marigold (*Tagetes erecta* L.) by the application of GA₃ ethrel and MH. *Journal of Ornamental Horticulture*, 7(3and4), 168-170.
75. Verma, L.R. and Arha (2004). Studies on regulation of flowering in African marigold (*Tagetes erecta* L.) by the application of GA₃ ethrel and MH. *J. Orna Hort.* 7(3-4):168-170.
76. Vidhya M, Pandiarajan T, Pandiselvam R, Amirtham D, Balakrishnan M, Haseena R. (2017) Effect of ethylene concentration and exposure time on physico chemical quality and colour value of sapota fruit (*Manilkara zapota*). *Asian Journal of Chemistry*. 29(5):970- 974.
77. Wajid Khan M, Shahid MA, Balal RM. (2017) Determination of critical level of brassinosteroid (24-epibrassinoloid) for heat-tolerance in okra (*Abelmoschus esculentus* L.). *Life and Environmental Sciences*, 54(3):207-217.
78. Weerakoon LK (2009) Effect of plant growth regulators on ovary culture of coconut (*Cocos nucifera* L.). *Plant Cell, Tissue and Organ Culture (PCTOC)* 99(1): 73-81; doi: 10.1007/s11240-009-9577
79. Yamaguchi Y and Huffaker A (2011) Endogenous peptide elicitors in higher plants. *Current opinion in plant biology* 14(4): 351-357; doi:10.1016/j.pbi.2011.05.001

80. Yuan, R and Carbaugh, David H. (2007) Effects of NAA, AVG, and 1-MCP on Ethylene Biosynthesis, Preharvest Fruit Drop, Fruit Maturity, and Quality of ‘Golden Supreme’ and ‘Golden Delicious’ Apples *HORTSCIENCE* 42(1):101–105.
81. Yuan, R., and Jianguo Li (2008) Effect of Sprayable 1-MCP, AVG and NAA on Ethylene Biosynthesis, Preharvest Fruit Drop, Fruit Maturity, and Quality of ‘Delicious’ Apples *Hort Science* 43(5):1454–1460.
82. Zaharah SS, Singh Z, Symons GM, Reid JB. (2012) Mode of action of abscisic acid in triggering ethylene bio- synthesis and softening during ripening in mango fruit. *Postharvest Biology and Technology*, 75:37-44.
83. Zahid, G., Iftikhar, S., Shimira, F., Ahmad, H. M., &Kaçar, Y. A. (2023). An overview and recent progress of plant growth regulators (PGRs) in the mitigation of abiotic stresses in fruits: A review. *Scientia Horticulturae*, 309, 111621.
84. Tadeu Dias JP. Plant growth regulators in horticulture: practices and perspectives. *Vegetal biotechnology*. 2019 Mar;19(1):3-14.