International Journal of Plant & Soil Science

Volume 35, Issue 11, Page 36-46, 2023; Article no.IJPSS.99253
ISSN: 2320-7035

Effective Administration of Plant Growth Regulators in Horticultural Crops: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2023/v35i112943

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/99253

Review Article

Received: 21/02/2023
Accepted: 24/04/2023
Published: 01/05/2023

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 developing nations as well. The research review indicated that the 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 the shelf life of horticultural crops.

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Keywords: Plant growth regulators; propagation; flowering and fruiting; post-harvest in horticultural crops.

1. INTRODUCTION

"Plant growth regulators (PGRs) are organic compounds, other than nutrients, that modify plant physiological processes. PRGs, called bio-stimulants or bio-inhibitors, act inside plant cells to stimulate or inhibit specific enzymes or enzyme systems and help regulate plant metabolism" [3,65,82]. "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 synthesized" [55,16,52}. They normally a synthesized 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 are determined by an intrinsic genetic program. 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) [67], gibberellic acid (GA3), Chlormequat 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 [13,16,73,52,22]. plant growth regulators have become indispensable in the field of horticulture due to its potential in the improvement of flower production [17] 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 to the horticulturist [30].

The idea of the existence of auxins in plants was for the first time conceived by Charles Darwin. Subsequently, F.W. Went 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 the curvature of the tip towards light due to more growth of tissue on the side which do not face direct light, Went named this substance 'auxin' (Greek word Auxem means to grow) and concluded that no growth can occur without auxin'. Endogenous or exogenous Auxin is a requirement for the initiation of adventitious roots in stems of cutting and air layering. It has been shown that the division of the first root initial cell is 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 the synthesis of Ribonucleic acid (RNA) which evolved in the initial of the root primordial. [70] found that the relative amount of auxin present indigenous or applied was associated with the formation of root primordial. Synthetic root promoting auxin such as Indole Butyric Acid (IBA) and Naphthalene Acetic Acid (NAA) has been found effective for rooting cuttings and air layering alone or in combination [28] stated that in Pear 200 ppm of IBA was found very effective in the promotion of rooting of hardwood cutting [46] observed that the rooting potentiality of Jackfruit was improved by treatment of IBA + NAA (2500 ppm) or 2500 ppm IBA alone, while a higher concentration of IBA proved supra optimal and by reduced the rooting percentage [63] reported that the application of IBA of 15000 ppm increased the survival percentage of Air layers in Mangoes [1]. Investigated "the influence of different rooting media and indolebutryic acid

(IBA) concentration on root and shoot development in stem cuttings of *Warburgia ugandensis*. 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" [34]. 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" [40] 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 percent. Response of hormone gibberellins was discovered by Kurosava, a Japanese scientist. The gibberellins together naturally occurring compound first isolated in Japan in 1829 from a fungus botanically known as *Gibberella fungikurai* (*Fusarium moniliforme*). It was first isolated from immature seeds of *Phaseolus cocineus*. These compounds display a remarkable diversity of physiological effects, including those on growth flowering, fruiting and dormancy [11,10,68,49]. Comprehensive review of Published information on plant growth regulator was Compiled to determination the state of the art on the subject

2. MAJOR RESPONSE OF PLANT GROWTH REGULATORS IN HORTICULTURAL CROPS

2.1 Plant Propagation and Seed Germination

Hutchinson et al. [29] 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 *Alstroemeria aurantiaca*cv. 'Rosita' from shoots tip explants [47] found that the most efficient concentrations of hormones (IBA and NAA) which enhance rooting of layering and improve the rooting characteristics like root length, diameter, branching, hardness, and the relation of rooting with sprouting in water apples. [21] studied that "Shoot tips of 2-3 cm long of two pomegranate cultivars [21] 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 the best vegetative growth characteristics compared to MS and NN ones. BA at 1.0 mg/l induced a 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, while IBA generally proved to produce a higher number of roots per shoot. In addition, WPM at half-strength generally produced better plantlets compared to its full strength". A similar result was reported by [58] in apple rootstock.

[5] investigated that "the use of various plant growth regulators in *in-vitro* propagation in flowering ash, Shoot apices or nodal segments from aseptically grown seedings or shoot apices from adult trees were used as initial explants. The result reported that the highest shoot multiplication rates were obtained when the explants were cultured for 30 days in a 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".

2.2 Flowering and Fruiting

Many reviewers reviewed the effect of naphthalene acetic acid(NAA) as a plant growth regulator in reducing pre-harvest fruit drop and resulting in an increased number of fruits and yield in tomato crops [56] indicated that "aspirin and salicylic acid-induced multiple stress tolerance in bean and tomato plant" [71] 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 the 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" [74] studied "the regulation of flowering in African marigold (*Tageteserecta* L.) by the application of GA_3 100, 150 and 200 ppm etherel 250, 500 and 750 ppm, and MH 250, 500, 750 ppm and control. Among all treatments GA_3 200 ppm recorded maximum flower yield as compared to control".

The effect of foliar application of GA_3, NAA, Ethrel, and B-9 on chrysanthemum was studied by [24] and observed that GA_3 200 ppm and NAA 100 ppm increased growth of chrysanthemum flower; however, ethrel reduced vegetative growth in all concentrations.

2.3 Control Fruit Drop

Anthony et al. [4] reported that the use of several synthetic Auxin in the 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 [80] 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*) 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".

2.4 Post-harvest Management and Shelf Life

Cronjé et al. [15] 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". [79] 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*) 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) were more effective when used in combination than when used alone in reducing preharvest fruit drop and extending the harvest season while maintaining fruit quality.

3. RELATIONSHIPS BETWEEN THE METABOLIC AND ECO-PHYSIOLOGICAL PROCESSES

There are several interactions between various eco-physiological 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 of the identification of receptors for numerous of these hormones [66,50,59] In this regard, [19] describe the results pertaining to these hormonal signaling pathways, highlighting the mechanisms of hormone perception and subsequent signaling 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 toward 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 number 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 signaling pathways. In addition, numerous unique signaling mechanisms past ten years have seen the discovery of numerous more plant hormones, including cell wall fragments and peptides [78,19,82].

"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" [7]. "Plant growth-promoting Rhizobacteria (PGPR) have received a lot of interest recently as a potential replacement for agrochemicals (fertilizers 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,

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 number of fruits per plant.	[44]
Sweet orange	NAA	Maximum improvement in fruit retention, fruit output per plant, fruit production per plant, and fruit drop	[69]
Sapota	GA3 and NAA	Maximum fruit weight, length, diameter, volume, TSS, reducing and non-reducing sugar, yield per tree, yield per hectare, and prolonged shelf life	[53]
	Ethylene	shortened the ripening period and improved the physico-chemical characteristics	[75]
Mango	GA3	Slowed down the overall weight loss, the concentration of chlorophyll and ascorbic acid, and the activity of amylase and peroxidase during ripening.	[54]
	ABA	Increasing total sugars and sucrose while reducing ruitripene consumption	[81]
	Ethylene	Initiating mango ripening	[45]
Banana	Ethephon (1-MCP)	Delayed ripening process	[26]
Guava	GA3	Maximum growth, yield, quality attribute and highest germination	[14]
	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	[39]
	Ethylene	Increase in the rate of skin yellowing and softening of immature-green fruit	[75]
Pineapple	ABA	Reduced the intensity of internal browning, moisture loss and malic acid content in the crown leaves	[41]
Citrus	ABA, Ethylene	Induced callus formation	[27]
Phalsa	NAA	A higher rate of flowering, fruiting, fruit weight, fruit weight per shoot, fruit juice %, minimum seed percentage, and maximum yield per hectare.	[31]
	GA3	Increasing vegetative growth and yield	[62]
Vegetables			
Bittergourd	NAA	Produced lower sex ratio gave, the maximum number of fruits per plant and finally yield per hectare with the maximum BCR	[33]
Capsicum	NAA	Increased plant height, early flowering, number of branches, plant spread, number of flowers per plant, shelf life and TSS	[61]
Okra	ABA	Enhancing health-promoting component	[51]
	IAA	Maximum plant height and intermodal length	[18]
	SA and ABA	Significantly reduced the harsh effects of drought on okra germination and growth parameters, enhance the tolerant ability	[6]
	CCC	The 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 fiber	[35]
	Brassinosteroid	To increase in plant growth and biomass, leaf area, chlorophyll content, photosynthesis rate, and photochemical efficiency of PSII	[76]
Watermelon	TIBA	Better growth, early flowering, minimum sex ratio, highest fruit yield and superior quality	[12]
Tomato	2,4-DandIAA	Development of seedless parthenocarpic fruit with increased size, increase growth, and yield attributes	[25] [32]
	GA3	For yield attribute	[57]
	Ethylene	Promotion of fruit ripening, flowering, and overall plant growth	[83]
	Cytokinin	Breaking dormancy after seed imbibition, also allows germination and growth of dormant embryos.	[43]
	PBZ	Improves the photosynthetic activity and water balance	[9]
	Thiourea	Increased plant dry weight and the tomato yield after inoculation	[42]

Crops	PGRs	Impact	Reference Citation
Vegetables			
Pea	GA3	Maximum number of pods per plant, seed yield, seed index and protein content in seeds	[72]
Bottle gourd	GA3	Maximum fruit length, fruits weight and fruits girth	[35]
Lettuce	ABA	Minimize the effects of drought stress	[2]
Flowers			
		area, days to flower and number of flowers	
	ABA	As a hormonal trigger in ethylene in sensitive senescence process	[62]
	GA3	Increase number of primary branches, flower yield per hectare, seed yield per plant and seed yield per hectare	[62]
Chinaaster			
	SA	Increased growth, flower and seed yield	[35]
Cactus	ABA	Increase In calli fresh weight and colour	[37]
Petunia	Ethylene	Induced adventitious root formation	[20]
Dahalia	MH	Highest number of flowers and diameter of bud	[38]

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" [64].

In the context of 'green' biotechnologies for tree fruits, such as plant breeding, the new technologies have lately emerged as potent instruments The use of plant regulators and hormonal plant regulation are two further examples of innovative technologies. In salt-stressed and controlled *Arabidopsis thaliana* seedlings [60] established "the validity of and made a hormonomic approach (including quantification of the main phytohormone classes or groups: cytokinins, auxins, brassinosteroids, gibberellins, jasmonates, salicylates and abscisates)".

4. *In vitro* PLANT TISSUE CULTURE

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

According to [48] 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.) [77]. Application of 9 M TDZ improved callus development. On somatic embryogenesis induction media containing 66 M 2,4-D, embryogenic calli were sub-cultured. The somatic embryos' growth was stunted after being sub-cultured 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 a conversion solution containing 5 M BA stimulated the conversion of somatic embryos [23] 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), the 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".

5. 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 regulator 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 favorable possibilities for future use, leads to additional studies, weights, and conversations on the subject. The integration and coordination of several signaling 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 a 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 [36], 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.

6. 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 [55]. In addition, during the past few years, it has become clearer the molecular mechanisms governing hormone synthesis, signaling, 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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