Artículo de revisión
Biotecnología Vegetal Vol. 19, No. 1: 3 - 14, enero - marzo, 2019
Instituto de Biotecnología de las Plantas. UCLV. MES.
eISSN 2074-8647, RNPS: 2154

Plant growth regulators in horticulture: practices and perspectives

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ABSTRACT
The plant growth regulators (PGRs) modulate plant growth and development and mediate responses to both biotic and abiotic stresses. This paper aims to expose, reflect and discuss about the practical use of PGRs in horticulture and their perspectives. The PGRs are used commercially in agriculture. Besides, in plant tissue culture is traditional practice and have relevant importance. The approach of the application of PGRs in horticulture shows good results. However, it needs more studies, discussions on the subject, which leads to conclude that it use in horticultural plants can be a challenge for all that act in the area, presenting practical advantages and favorable perspectives for future use.

Keywords: development, hormones, plant physiology, vegetables

Reguladores de crecimiento vegetal en horticultura: prácticas y perspectivas

RESUMEN
Los reguladores del crecimiento de las plantas (PGR) modulan el crecimiento y el desarrollo de las plantas y median las respuestas a los estreses bióticos y abióticos. Este documento pretende exponer, reflexionar y debatir sobre el uso práctico de los PGR en horticultura y sus perspectivas. Los PGR se utilizan comercialmente en la agricultura. Además, en el cultivo de tejidos vegetales es práctica tradicional y tienen importancia relevante. El enfoque de la aplicación de PGRs en horticultura muestra buenos resultados. Sin embargo, necesita más estudios, discusiones sobre el tema, lo que lleva a concluir que su uso en plantas hortícolas puede ser un desafío para todos los que actúan en el área, con ventajas prácticas y perspectivas favorables para el uso futuro.

Palabras clave: desarrollo, hormonas, fisiología vegetal, vegetales

INTRODUCTION

Horticulture is the generic term for various groups of plants such as olericulture, fruticulture, floriculture and landscaping, nursery, medicinal, spice and aromatic plants, mushrooms, among other groups of cultivated plants. The theoretical-historical of a given field of knowledge, especially of the uses of plant growth regulators in horticulture, is essential for a better understanding of its unfolding, trajectory and perspectives (Guedi *et al.,* 2011).

Growth regulating substances, plant hormones or simply phytohormones are compounds produced naturally by plants that participate in control of plant growth, as well as they are versatile chemical regulators of plant growth. When these substances are produced synthetically, they are called plant growth regulators (PGRs) (Santner *et al.*, 2009; Davies, 2010; Rademacher, 2015).

Plant growth and development require the integration of a variety of environmental and endogenous signals that, together with the intrinsic genetic program, determine plant form. Central to this process are plant growth regulators. The principal phytohormones and/ or PGRs include classical groups or others compounds. Among them are mentioned indol-3-ylacetic acid (IAA), indol-3-ylbutyric acid

(IBA), 2,4-dichlorophenoxyacetic acid (2,4-D), 1-naphthylacetic acid (NAA), 6-benzylaminopurine (BAP), benzyladenine (BA), gibberellic acid (GA_3), ethylene or ethephon (CEPA), abscisic acid (ABA), jasmonate (JA, or yet, methyl jasmonates-MeJA), Chlormequat chloride (CCC), as well as brassinosteroids (BR), salicylic acid (SA), nitric oxide (NO), strigolactone (SL), and polyamines (like putrescine (Put), spermidine and spermine). Besides, other molecules such as ascorbic acid (VC), alpha tocopherol (VE), thidiazuron (TDZ), phenylureas (CPPU), and triazoles (TR). In addition, Karrikins, the new family of plant growth regulators found in smoke (Chiwocha *et al.,* 2009; Davies, 2010; Ullah *et al.,* 2012; Rademacher, 2015; Fahad *et al.*, 2016). The nature, occurrence, transport and effects of each PGRs are different according to their characteristics.

In various areas of agriculture, plant growth regulators can become great allies in the search for increasing the productions with better phytotechnical, phytosanitary and commercial quality. Therefore, this paper aims to expose, reflect and discuss about the practical use of plant growth regulators in horticulture and their perspectives.

The article begins with an explanation about the conceptual dimensions of plant growth regulators. Later, it addresses with a discussion about the ways of use and application in the field, especially in horticultural crops. The text highlights the importance of plant growth regulators and their interrelations between the different ecophysiological and metabolic processes. Finally, it presents the general context of the current use of plant growth regulators in horticulture and its future perspectives.

PLANT GROWTH REGULATORS

Since 1930, PGRs have been a systematic use in different agriculture practices. For instance, control of vegetative growth, decreased susceptibility towards biotic and abiotic stress, reduce the risk of lodging in field crops, breaking of bud dormancy, control of fruit set, improvement of fruit quality, acceleration or delay of fruit ripening for optimal harvesting, optimization of fruit storage and ripening, improved morphological structure, increases in yield, and modification of plant constituents (Alcázar *et al*., 2010; Choudhury *et al*., 2013; Rademacher, 2015; Fahad *et al.,* 2016; Bergstrand, 2017).

The concept of plant growth regulators are refer to artificially produced substances which in very low quantities normally act at sites other than the place of production and control different physiological processes that modulate plant growth and development. It is a structurally unrelated collection of small molecules derived from various essential metabolic pathways (Santner *et al.*, 2009; Davies, 2010).

These compounds are important regulators of plant growth and mediate responses to both biotic and abiotic stresses. Peleg and Blumwald (2011) expressed that the plant hormones play central roles in the ability of plants to adapt to changing environments, by mediating growth, development, nutrient allocation, and source/sink transitions. Although, abscisic acid (ABA) is the most studied stress-responsive hormone, the role of cytokinins, brassinosteroids, and auxins during environmental stress is less studied. Recent evidence indicated that plant hormones are involved in multiple processes. Crosstalk between the different plant hormones results in synergetic or antagonist interactions that play crucial roles in response of plants to abiotic stress. The characterization of the molecular mechanisms regulating hormone synthesis, signaling, and action are facilitating the modification of hormone biosynthetic pathways for the generation of transgenic crop plants with enhanced abiotic stress tolerance in field (Alcázar *et al*., 2010; Peleg and Blumwald, 2011; Verma *et al.*, 2016).

USE, APPLICATION AND IMPORTANCE OF PLANT GROWTH REGULATORS

The use and application of plant growth regulators in agriculture have several practical examples. The PGRs in this context are employed commercially. Besides, in plant tissue culture is traditional practice and have relevant importance.

Plant growth and development

The commercial uses of auxins include prevention of fruit and leaf drop, promotion of flowering, thinning of fruit, induction of parthenocarpic fruit development, and rooting of cuttings for plant propagation, among others (Taiz and Zeiger, 2010).

Considerable success had been obtained in the application of PGRs in some process of plant development such as flowering and fruit development as well as ripening, harvesting and post-harvesting of fruits and vegetables. In this sense, Sajid *et al*. (2009) revealed effects of foliar application of PGRs and nutrients for improvement of lily flowers (*Lilium* sp.). Tropical trees are generally induced to flower through environmental cues, whereas floral initiation of temperate deciduous trees is often autonomous. In the tropical evergreen tree mango, (*Mangifera indica* L.), cool temperature is the only factor known to induce flowering, but does not ensure floral initiation will occur because there are important interactions with vegetative growth involvement of plant hormones (Bangerth, 2009). In horticultural trees are discussed four major pathways to flowering. Those have been characterized in *Arabidopsis*, including environmental induction through photoperiod and temperature, autonomous floral initiation, and regulation by gibberellins and nitrate used (Marín *et al.*, 2011).

The temperate deciduous tree apple (*Malus domestica* Borkh.), flowers autonomously, with floral initiation dependent on aspects of vegetative development in the growing season before anthesis. Although with respect to the floral initiation of trees in general the effect of the environment, interactions with vegetative growth, the roles of plant growth regulators and carbohydrates, and the advances in molecular biology (Wilkie *et al*., 2008). The environmental interactions in vegetative and reproductive growth were also the subject of Tang *et al.* (2009) observed effects of exogenous application of plant growth regulators on the development of ovule and subsequent embryo rescue of stenospermic grape (*Vitis vinifera* L.) cv. Centennial Seedless, Thompson Seedless and Crimson Seedless sprayed by CCC, BA, CEPA and Put.

In the case of cotton (*Gossypium hirsutum* L.), is a perennial woody shrub with an indeterminate growth habit, evolved in tropical, relatively dry areas of the world. Through adaptive changes, accomplished through breeding and selection, cotton is now widely grown under both semi-arid and humid conditions. However, despite these adaptive changes, cotton continues to exhibit many attributes of its tropical origin. The crop grows best under warm temperatures and high light intensity, is somewhat drought tolerant, and often continues or resumes growth late in the season. Because of these growth habits, alterations in growth and development of the crop are often agronomical desirable. These alterations may be accomplished with PGRs (Cothren and Oosterhuis, 2010).

In seedless grapes (*Vitis* spp.), Bhat *et al*. (2011) found that the application of CPPU and BR along with GA_3 increase the leaf number, leaf area and leaf dry matter and indirectly influencing the fruit yield and quality.

The effects of nitrogen fertilization and plant growth regulators (chlormequat -CCC or ethephon) has been studied in other culture such us wheat (*Triticum aestivum* L.) by Shekoofa and Emam (2008). Besides, Tiwari *et al.* (2011) informed about the effect of gibberellic acid and other plant growth regulators as naphthalene acid on hybrid rice (*Oryza sativa* L.) seed production.

The influence of exogenous applications of plant growth regulators on fruit quality of young 'Kinnow' mandarin (*Citrus nobilis* × *Citrus deliciosa*) trees was assayed by Khalid *et al.* (2012). BA and kinetin at 20 mg l^{-1} were applied at flowering stage and, BA, kinetin at 10, 20 and 30 mg l^{-1} and GA_3 at 10 mg l^{-1} were applied at fruit setting stage. This study revealed that irrespective of shelf duration the fruit harvested from young trees treated with 10 mg l^{-1} GA_3, 30 mg l^{-1} BA and kinetin at fruit setting stage, showed significantly higher juice contents (50.53%, 49.8% and 51.64%) and lower rag contents (26.5, 26.6 and 25.83%), respectively in comparison with control, without application of plant growth regulators. Maximum reducing sugars (1.62%) was observed with 20 mg l^{-1} kinetin at flowering and maximum ascorbic acid contents (58.45 mg 100 m l^{-1}) of juice were observed with control. Interaction of plant growth regulators and shelf duration had significant effect on reducing sugars (%), non-reducing sugars (%) and ascorbic acid (mg 100 m l^{-1}) contents. The authors showed that the results validated that fruit quality parameters except ascorbic acid contents of young ‘Kinnow’ mandarin trees could be improved by the exogenous application of kinetin.

Others PGRs also have an important role in plant growth as shown Fahad *et al.* (2016). The authors demonstrated that the exogenously application of plant growth regulators (VC, VE, BR, MeJA and TR) in four different combinations increase thermal stability and better rice performance under high-temperature stress. The PGRs increased the biosynthesis of metabolites as evidence of stress tolerance.

Besides, chemical PGRs are used in the production of ornamental potted and bedding plants. Growth control is needed for maximizing production per unit area, reducing transportation costs and to obtain a desired visual quality. However, the use of plant growth regulators is associated with toxicity risks to humans and the environment. In many countries, the availability of plant growth regulators is restricted and few substances are registered for use. A number of alternative methods have been suggested. The methods include breeding (genetic methods) and crop cultivation practices such as fertigation, temperature and light management. A lot of research into ´alternative´ growth regulation was performed during the years of the 1980 until 1990, revealing several possible ways of using different climatic factors to optimize plant growth with respect to plant height. In recent years, the interest in climatic growth regulation has been resurrected, not least due to the coming phase-out of the PGR, chlormequat chloride. Currently, authorities in many countries are aiming towards reducing the use of agrochemicals. At the same time, there is a strong demand from consumers for products produced without chemicals. Global environmental change presents both old and new challenges as immediate challenge is to adapt plant, animal and food systems to changing temperature, nutrient and water conditions (Fresco, 2009; Bergstrand, 2017).

The effect of different plant growth regulators (30 mg l^{-1} of NAA, 30 mg l^{-1} of GA_3 and 30 mg l^{-1} of 2,4-D) on growth and yield of tomato (*Solanum lycopersicum* L.) was studied by Uddain *et al.* (2009). The maximum plant height at 15 days after transplanting - DAT (33.41 cm), 30 DAT (59.07 cm) and 45 DAT (76.36 cm), number of leaves plant at 15 DAT (15.08), 30 DAT (47.20) and 45 DAT (72.86), number of branches plant at 15 DAT (8.06), 30 DAT (12.13) and 45 DAT (17.85), number of flowers cluster (5.81), number of flower cluster plant (8.83), number of flowers plant (59.62), number of fruits cluster (4.81), number of fruits plant (42.66), average weight of individual fruit (92.06 g), yield plant (2.49 kg) and yield hectare (93.23 t ha^{-1}) were found in plant growth regulators and the minimum for all the parameters were found in control.

Sajid *et al.* (2009) worked with foliar application of either GA_3 (20mg l^{-1}), or a nutrient solution (comprising of KNO_3, 19 mg l^{-1}, NH_4NO_3, 16.5 mg l^{-1}, KH_2PO_4, 1.7 mg l^{-1}, $CaCl_2$, 4.4 mg l^{-1} and $MgSO_4$, 3.7 mg l^{-1}) or both on lily plants. Foliar application of GA_3 and nutrients application was found to have improved the productivity and quality of lily cut flowers and may be exploited commercially in horticulture industry to fetch premium price for cut flowers.

Another example in ornamental plants are exposed by Meijón *et al.* (2009). The authors seeking out improvement of compactness and floral quality in azalea by means of application of plant growth regulators (daminozide, paclobutrazol and chlormequat chloride). The results showed that daminozide and paclobutrazol are the best options to control vegetative development and to promote the flowering of azalea japonica in a cold and humid zone such as Asturias. However, daminozide treatment induces floral deformation in one of the tested cultivars (Blaauw’s Pink).

In the same way, Shirzad *et al.* (2012) demonstrated the influence of plant growth regulators (indole butyric acid - IBA, gibberellin - GA_3 and ethylene - as ethephon) and planting method on growth and yield in oil pumpkin (*Cucurbita pepo* var. styriaca). This authors showed that plant growth regulators and planting method had significant effects on vegetative, flowering and yield characteristics including: leaf area, number of male and female flowers per plant, number of fruit by plant, fruits fresh weight, seeds length and width, number of seed per fruit, seed yield, percentage of seeds oil and oil yield. Hence spraying with GA_3 (25 mg l^{-1}) in four leaf stage at trellis method could be a suitable treatment for enhancing growth and yield of medicinal pumpkin.

The effects of PGRs also have been studied in plant abiotic stress. In this sense, Ullah *et al.* (2012) showed the effects of PGRs (as SA and Put) on growth and oil quality of canola (*Brassica napus* L.) under drought stress. Growth regulators were highly effective in ameliorating the adverse effects of drought stress on both cultivars. The applied growth regulators maintained the water budget of canola plants, augmented the accumulation of osmolyte proline and protected photosynthetic pigments from adverse effects of drought stress. The salicylic acid was effective to reduce the drought-induced accumulation of glucosinolates and erucic acid in canola oil. It is inferred that SA is economical and environment friendly alternative and can be implicated to improve the plant growth and oil quality of *B. napus* in current scenario of drought and climate change. Besides, Latif *et al.* (2016) studying that effects on growth and accumulation of phenolics by salicylic acid in *Zea mays* L. under drought stress.

Another important aspect in the PGRs applications is the determination of its residually in agriculture derived foods. Multi residue determination of PGRs (i.e., chlormequat, mepiquat, paclobutrazol, uniconazole, ethephon and flumetralin) in apples (*Malus domestica* Borkh.) and tomatoes by liquid chromatography/tandem mass spectrometry by Xue *et al.* (2011) revealed that the limits of quantification were lower than their maximum residue limits. The procedure was concluded as a practical method to determine the plant growth regulators residues in fruit and vegetables and is suitable for the simultaneous analysis of the amounts of samples for routine monitoring. The analytical method described demonstrates a strong potential for its application in the field of PGRs multi residue analysis to help assure food safety.

Additionally, the effect of plant regulators on vegetables has been studied with satisfactory results in different plant species. For instance, *Ipomoea batatas* (L.) Lam. (Alam *et al*., 2010), ridgegourd (*Luffa acutangula* L. Roxb) (Hilli *et al*., 2010), potato (*Solanum tuberosum* L.) (Hartmann *et al*., 2011), lettuce (*Lactuca sativa* L.) (Mohebodini *et al*., 2011), onion (*Allium cepa* L.) and garlic (*Allium sativum* L.) (Ouzounidou *et al*., 2011), pumpkin (Shirzad *et al*., 2012), tomato (*Solanum lycopersicum* L.) (Choudhury *et al*., 2013).

The new technologies have recently emerged as powerful tools in the context of 'green' biotechnologies in tree fruits, as plant breeding (Costa *et al.,* 2017). Also highlighted as new technology is the use of plant regulators and hormonal plant regulation. Šimura *et al.* (2018) validated and made a hormonomic (with quantification of the main phytohormone classes or groups: cytokinins, auxins, brassinosteroids, gibberellins, jasmonates, salicylates, and abscisates) approach in salt-stressed and control *Arabidopsis thaliana* seedlings.

In vitro plant tissue culture

In plant tissue culture the use of PGR is an important practice, regardless of the plant species.

For example, in rapid *in vitro* micropropagation of sugarcane (*Saccharum officinarum* L.) through callus culture (Behera and Sahoo, 2009), and in the study of hormonal regulation of branching in grasses especially with auxin, cytokinin, strigolactones, among others (McSteen, 2009). Idowu *et al*. (2009) revealed the importance of the use of plant growth regulators and tissue culture techniques to horticulture, the achievements, and limitations of tissue culture and some insights into current and possible future developments.

On the other hand, Perera *et al.* (2009) evaluated the effect of plant growth regulators on ovary culture of coconut (*Cocos nucifera* L.) and founded consistent callogenesis was obtained by culturing unfertilized ovaries at -4 stage in CRI 72 medium containing 100 µM 2,4-D and 0.1% activated charcoal. Callus formation was improved by application of 9 µM TDZ. Embryogenic calli were subcultured onto somatic embryogenesis induction medium containing 66 µM 2,4-D. Stunted growth was observed in the somatic embryos after subculture onto CRI 72 medium containing ABA. Maturation of somatic embryos could be achieved in Y3 medium without growth regulators. Conversion of somatic embryos was induced by adding GA_3 to conversion medium containing 5 µM BA while 2-isopentyl adenine (2iP) increased the frequency of plant regeneration.

Plant regeneration of *Brassica oleracea* subsp. *italica* (Broccoli) cv. 'Green Marvel' is affected by plant growth regulators such as BAP and NAA. The highest percentage of shoot tip explant producing shoot (100%) and highest number of shoot produced per shoot tip explant (3.76) were recorded with 5 mg l^{-1} BAP. For rooting of shoots, NAA, IAA and IBA at 0, 0.2 mg l^{-1} and 1 mg l^{-1} were applied. The highest percentage of shoots with roots (100%) and highest mean number of roots produced per shoot (6.5) occurred on medium with 0.2 mg l^{-1} IBA (Ravanfar *et al.*, 2009).

The effect of plant growth regulators (NAA, 2,4-D, BA and TDZ) on callus induction and plant regeneration in tuber segment culture of potato cultivar 'Diamant' worked by Elaleem *et al.* (2009) demonstrated that the best degree for callus formation (6.0) was obtained on MS medium supplemented with 2,4-D alone at 3.0 mg l^{-1} or 2,4-D in combination with BA both at 2.0 mg l^{-1}. MS media supplemented with different levels of BA and TDZ were employed for shoot regeneration. MS medium containing 5.0 mg l^{-1} TDZ was the best for days to shoot initiation, the highest percentage of callus with shoot (81%) and highest number of shoot per callus (3.4). Callus derived shoots were rooted most effectively in half-strength MS medium containing 0.5 mg l^{-1} IBA. As well as, plant growth regulators on callus induction and plant regeneration in tuber segment culture of potato.

Garcia *et al.* (2011) on *in vitro* study related to the influence 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*), checked that the direct organogenesis in this species was obtained through shoot development from internodal segments in the presence of BA. Indirect organogenesis was achieved from all explant types on media supplemented with BA, used alone or in combination with NAA. The highest regeneration efficiency was obtained from internodal segments cultured on MSM medium plus 44.4 µM BA. Compact, friable, or mucilaginous non-morphogenic calluses were induced by TDZ, Picloram, 2,4-D, and NAA.

Also with grape (*Vitis* spp.), Alizadeh *et al*. (2012) verified that culture establishment increased using either BAP or KIN but the treatment, 2.0 mg l^{-1} BAP + 0.2 mg l^{-1} NAA was most effective with regard to enhancement in culture establishment and reduction in time to bud sprouting of *in vitro* multiplication in four grape rootstock genotypes.

INTERRELATIONS BETWEEN THE DIFFERENT ECOPHYSIOLOGICAL AND METABOLIC PROCESSES

Several interrelationships between the different ecophysiological and metabolic processes with plant growth regulators appear, affecting too much the growth and development of many agricultural crops.

Receptors for several of these hormones been identified, revealing novel mechanisms for perceiving chemical signals and providing plant biologists with a much clearer picture of hormonal control of growth and development (Spartz and Gray, 2008; Pieterse *et al*., 2009; Simon and Petrášek, 2011).

In this sense, Dharmasiri *et al.* (2013) discuss about the findings related to these hormonal signaling pathways highlighting the mechanisms of hormone perception and subsequent signaling pathways leading to the regulation of gene expression. Additionally, chemically and structurally diverse groups of hormones regulate plant growth and development. During the last few decades, many advances have been made in understanding the perception and mechanisms of action of these plant hormones. While certain hormone responses are not necessarily related to gene regulation, all these hormones are involved in modulating gene expression by controlling either the abundance of transcriptional factors or repressors, or their activities through post-translational modifications. In this regard, ubiquitin mediated protein degradation has become a central theme in many plant hormone signaling pathways. Besides, multitudes of novel signaling mechanisms have been uncovered for several other plant hormones, including cell wall fragments and peptides, during the past decade (Yamaguchi and Huffaker, 2011; Dharmasiri *et al*., 2013).

Significant progress has been made in identifying the key components and understanding the role of salicylic acid (SA), jasmonates (JA) and ethylene (ET) in plant responses to biotic stresses. Some studies indicate that other hormones such as abscisic acid (ABA), auxin, gibberellic acid (GA_3), cytokinin (CK), brassinosteroids (BR) and peptide hormones are also implicated in plant defence signaling pathways (Bari and Jones, 2009).

In recent years, considerable attention has been paid to plant growth promoting Rhizobacteria (PGPR) to replace agrochemicals (fertilizers and pesticides) for the plant growth promotion by a variety of mechanisms. It involve soil structure formation, decomposition of organic matter, recycling of essential elements, solubilization of mineral nutrients, producing numerous plant growth regulators, degrading organic pollutants, stimulation of root growth, crucial for soil fertility, biocontrol of soil and seed borne plant pathogens and in promoting changes in vegetation (Sivasakhti *et al*., 2014).

Soil is dynamic living matrix and it is not only a critical resource in agricultural and food security but it is also towards maintenance of all life process. Pathogenic microorganisms affecting plant health are a major and chronic threat to sustainable agriculture and ecosystem stability worldwide. The chemical fertilizers used in the agriculture to increase yields, kill pathogens, pests, and weeds, have a big harmful impact on the ecosystem. Because of current public concerns about the side effects of agrochemicals, there is an increasing interest in improving the understanding of cooperative activities among plants and rhizosphere microbial populations. Therefore, there is an urgent need of biological agents is accepted worldwide. The use of PGPR is a better alternative to solve this problem. They play an important role to increase in soil fertility, plant growth promotion, and suppression of phytopathogens for development of ecofriendly sustainable agriculture (Gupta *et al*., 2015).

The system plant defense responses against phytopathogens is favorable to the use of PGRs. In the work of Rivas-San Vicente and Plasencia (2011) that evidenced salicylic acid (SA) has been the focus of intensive research due to its function as an endogenous signal mediating local and systemic plant defense responses against pathogens. It has also been found that salicylic acid plays a role during the plant response to abiotic stresses such as drought, chilling, heavy metal toxicity, heat, and osmotic stress. In this sense, salicylic acid appears to be, just like in mammals, an 'effective therapeutic agent' for plants. Besides, this function during biotic and abiotic stress, salicylic acid plays a crucial role in the regulation of physiological and biochemical processes during the entire lifespan of the plant. The discovery of its targets and the understanding of its molecular modes of action in physiological processes could help in the dissection of the complex salicylic acid signaling network, confirming its important role in both plant health and disease. Here, the evidence that supports the role of salicylic acid during plant growth and development by comparing experiments performed by exogenous application of salicylic acid with analysis of genotypes affected by salicylic acid levels and/or perception.

Others substances as phytoalexins are favorable in defense against pathogens (Ahuja *et al*., 2012). On the other hand, current use of plant growth regulators in horticulture especially with vegetables with low economic expression has been little spread.

FUTURE PERSPECTIVES

Future perspectives for the use and application of plant growth regulators in agriculture are promising, especially in the case of horticultural crops. A major challenge would be to understand how the information conveyed by these simple compounds is integrated during plant growth (Santner *et al.,* 2009). Besides that, the molecular mechanisms regulating hormone synthesis, signaling, and action have been elucidated during the past few years, and the roles of plant hormones for responses to changing environments have been demonstrated. These findings will facilitate the modification of hormone biosynthetic pathways for the generation of transgenic plants with enhanced abiotic stress tolerance. Controlling the hormone dose/response ratio remains a challenge, since the hormone levels attained should be moderate in order to maintain a balance between the positive effects of plant hormones on stress tolerance and the negative effects on growth and development. The use of conditional promoters driving gene expression at specific developmental stages, in specific tissues/organs and/or in response to specific environmental cues circumvents this problem. It will facilitate the generation of transgenic crops able to grow under various abiotic stresses with minimal yield losses (Peleg and Blumwald, 2011).

The need of today world is high output yield and enhanced production of the crop as well as fertility of soil to get in an ecofriendly manner. Future research in rhizosphere biology will rely on the development of molecular and biotechnological approaches to increase our knowledge of rhizosphere biology, biodiversity, multifunctional attributes for sustainable agriculture and to achieve an integrated management of soil microbial populations. Fresh alternatives should be explored for the use of bioinoculants for other high value crops such as vegetables, fruits, and flowers. The application of multi strain bacterial consortium over single inoculation could be an effective approach for reducing the harmful impact of stress on plant growth. A part from that future research in optimizing growth condition and increased self-life of plant growth promoting rhizobacteria (PGPR) products, not phytotoxic to crop plants, tolerate adverse environmental condition, higher yield and cost effective PGPR products for use of agricultural farmer will be helpful (Gupta *et al*., 2015; Yadav *et al*., 2017; Verma *et al*., 2017).

CONCLUSIONS

The use of plant regulators in horticulture is a trend with great advantages. The approach of the application of plant growth regulators in horticulture shows good results. However, it needs more studies and weights, discussions on the subject, which leads to conclude that the use of plant growth regulators in horticultural plants can be a challenge for all that act in the area, presenting practical advantages and favorable perspectives for future use.

The regulation of complex growth and plant developmental process requires the coordination and integration of many signaling events during plant growth. The PGRs would be favorable as a good technique to the production of the diverse horticulture plants in nursery, field, and greenhouse. The need of today world is high output yield and enhanced production of the crop as well as incorporates new technologies. Future research in horticulture and especially, the use of plant growth regulators in horticultural plants will rely on the development of molecular and biotechnological approaches to increase our knowledge of plant physiology. Fresh alternatives should be explored for the use of plant growth regulators for other high value crops such as vegetables, fruits, and flowers. The application of these compounds could be an effective approach for reducing the negative impact of stress on plant growth. In addition, the manipulation of the hormonal balance can bring gains to the crops of the different horticultural plants. The new technologies have recently emerged as powerful tools in the context of biotechnologies. As well as, highlighted, as new technology is the use of plant regulators and hormonal plant regulation.

The scientific and technological progress in horticulture is undoubtedly key factors to obtain successful in activity. The rapid technical development has provided us with tools enabling plant hormones and plant growth regulators (PGRs) to be used in agriculture and horticulture.

ACKNOWLEDGMENTS

At Universidade do Estado de Minas Gerais (UEMG) in Ituiutaba unit and fellows for valuable criticism of the manuscript.

Conflict of interest
The authors declare no conflict of interest.

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Recibido: 14-08-2018
Aceptado: 06-12-2018