APPLICATION OF PLANT GROWTH REGULATORS IN ORNAMENTAL PLANTS: A REVIEW

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Ornamental plants hold an important status in the horticultural industry of the world. Plant growth regulators consist of a large group of naturally occurring or synthetically produced organic chemicals and considered as helping tool in the modern production system of ornamentals. Their exogenous application helps to improve the different economically important and market desirable characteristics of ornamental plants. The use of plant growth regulators is being practiced by the commercial growers of ornamental plants as a part of cultural practice. There are various factors contributing to the efficacy of plant growth regulators and the method of application plays key role in determining the effectiveness of plant growth regulators, as PGRs can be effective if properly absorbed by plants. There are various methods of application of PGRs but the most popular are foliar sprays, drenching and pre-plant soaking while the efficacy of each method depends on the various factors including the mode of absorption of PGRs by different plant parts, method of application and environmental factors. Further development to focus the variables that can affect the response of plant to plant growth regulators will help to increase the efficiency of PGRs and avoid phytotoxicity which can maximize their productivity.

Keywords: Phytohormones, ornamental horticulture, plant production, growth regulation, application methods

INTRODUCTION

Economic importance of ornamental plants: Ornamental plants represent a great diversity of beautiful plants, including cut foliage, cut flowers, bedding plants, indoor plants, potted plants, bulbous plants, outdoor plants, which may be annuals, biennials or perennials in their growth habit. Thus ornamentals bring aesthetic feelings to our surroundings (Riaz et al., 2002; Memon et al., 2013) and also economically important in horticultural trade, all over the world. They are also being used by the humans, even in the prehistoric times (Simpson and Ogorzaly, 2001) and the demand of ornamental plants for personal and ceremonial use has been increased. Cut flowers dominate among ornamental plants followed by flowering pot plants, tree and nursery plants, and flower bulbs (Lawson, 1996) but now the trend has been changed. The rapid rise is seen in the production of horticultural crops, including the ornamental plants (Janick, 2007), and covered the 42% of the total cash received from horticulture farms and 6% of all agriculture farms in Canada (AFACT, 2005). The total export of floriculture is increased by 1.9%, while 5.3% increase in case of cut flowers in 2011 (MNS, 2012). The ornamental plants (flowering and potted) having value of 32 billion euro were produced in the world in 2014 and Europe contributed 34.3% followed by China (15.9%) (AIPH, 2015). Area under production of flower and ornamental plants in Europe is 74 thousand hectare and Netherland is leading by sharing 35% of total area in 2013 (EUROSTAT, 2015).

What are plant growth regulators: Plant growth regulators (PGRs) consist of organic molecules, produced synthetically and used to alter the growth of plants or plant parts. They have ability to accelerate or retard the plant growth. The hormone which is produced in plants is called as plant hormone and also known as phytohormone. Phytohormone is defined as, an organic substance produced naturally in higher plants, controlling growth or other physiological functions at a site remote from its place of production, and active in minute amounts (Thimmann, 1948). PGRs sometimes confused with plant hormones, but there are certain differences among them as the term PGRs is used by agrochemical industry to indicate synthetic plant growth regulators, while plant hormones are a group of naturally occurring, organic substances which influence physiological processes at low concentrations (Davies, 2010). The growth hormone is the phytohormone and is essential to growth of organs as buds, stems, roots, fruits, and so on by cellular enlargement, both in length and in width, while growth regulator referred to organic compounds other than nutrients, small amounts of which are capable of modifying growth (Leopold, 1955). The PGRs can be biostimulant or bioinhibitor and are active even at very low concentrations in plant cells and have ability to alter the growth and development. The plant growth regulators represent various categories as American Society for Horticultural Science...
also divides the plant growth regulators into six classes including gibberellins, auxins, cytokinins, ethylene generators, growth inhibitors and growth retardants. There are certain other groups which are considered as PGRs including polyamines, as they have an important role in plants and are also categorized as a new class of plant growth bio regulators due to their promotive effect on plant growth (Mahgoub et al., 2006, 2011) and vitamins which are also considered as growth bio-regulators as their low concentration may exert a great influence on factors that affect metabolic pathways, plant growth regulation and physiological processes including synthesis of enzymes and co-enzymes (Hathout, 1995; Robinson, 1973). There are various commercial available formulations of synthetic growth regulators being used on ornamental plants (Table 1).

Factors affecting efficiency of PGRs: The effects of PGRs in plants depend on various factors which play important role to achieve expected results. These factors include the application method, time of application, concentration of PGRs, plant species and also the environmental conditions in which plants are grown (Grzesik, 1989; Wroblewska and Debicz, 2013). The intensity of applications is also considered an important factor affecting the efficacy of PGRs, as some plants respond well to a single application, but in most of cases, multiple applications are beneficial to attain good results (Carey et al., 2007). The other supplementary factors may include the chemical properties of PGRs solution, particularly the pH, which plays a key role in the absorption of PGRs by the plants. We discuss the application methods and their possible advantages over one another.

**Application methods:** There are various methods of application of PGRs in plants reported in literature, mostly including foliar application (Sajjad et al., 2014), drenching (Matsumoto, 2006), pre-plant sowing (Currey and Lopez, 2010), seed priming (Pill and Gunter, 2001), pasting (Saniewski et al., 2010), capillary string (Carswell et al., 1996) and injection (de Vries and Dubois, 1988). The most commercially adopted methods for ornamental plants are foliar spray, drenching and pre-plant soaking (includes dips for shorter period of time) as shown in Table 2. The research in methods of application of PGRs reported that their early application such as dipping before planting and substrate drenching at planting time are helpful in obtaining desired results and also supportive in the efficient use of these chemicals (Magnitskiy et al., 2006; Ranwala et al., 2005). The possible effects of PGRs depend on their method of application due to the difference in their mode of absorption by the plant, as some chemicals are absorbed only through root, leaves or stem, and some are absorbed through all mentioned organs having an advantage to apply in either way, as ancydimid is absorbed by the roots, stem and also leaves (Whipker et al., 2003b) while B-Nine is only absorbed through foliar sprays but Bonzi and sumagic are absorbed through the stem and root zone (Latimer, 2009). Foliar application and soil drenching are the most common methods being used by commercial growers (Lee and Rho, 2000) and relatively higher concentrations of PGRs are used

<table>
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<tr>
<th>Plant Name</th>
<th>Active Compounds</th>
<th>Trade Names</th>
<th>Main Effects</th>
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<tbody>
<tr>
<td>Begonia</td>
<td>Ethephon</td>
<td>Florel</td>
<td>Enhance lateral branching, as pinching agent</td>
<td>Bailey and Whipker, 1998; Whipker, 2013</td>
</tr>
<tr>
<td>Dhalia</td>
<td>Uniconazole</td>
<td>Sumagic, Concise</td>
<td>Control plant growth</td>
<td>Bailey and Whipker, 1998; Whipker, 2013</td>
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<tr>
<td>Easter</td>
<td>6-benzyladenine and gibberellins A4 + A7</td>
<td>Fascination, Fresco</td>
<td>Prevent yellowing of leaves</td>
<td>Latimer, 2009</td>
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<td>Fagus</td>
<td>Indole Butyric Acid</td>
<td>Chryzopon, C-mone, Rhizopon</td>
<td>Promote rooting</td>
<td>Percival and Barnes, 2004</td>
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<tr>
<td>Gomphrena</td>
<td>Chlormequat chloride</td>
<td>Citadel, Cycocel</td>
<td>Control plant growth</td>
<td>Bailey and Whipker, 1998; Whipker, 2013</td>
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<tr>
<td>Impatiens</td>
<td>Paclobutrazol</td>
<td>Bonzi, Downsizer, Paczol, Piccolo</td>
<td>Control plant growth</td>
<td>Bailey and Whipker, 1998; Whipker, 2013</td>
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<tr>
<td>Kalanchoe</td>
<td>Dikegulac sodium</td>
<td>Attrimmec, Augeo</td>
<td>Enhance lateral branching</td>
<td>Bailey and Whipker, 1998; Whipker, 2013</td>
</tr>
<tr>
<td>Ornithogalum</td>
<td>Gibberellic acid</td>
<td>Florgib, ProGibb</td>
<td>Promote vegetative and flower growth</td>
<td>Wang and walter, 2006</td>
</tr>
<tr>
<td>Petunia</td>
<td>6-benzyladenine</td>
<td>Configure</td>
<td>Increase lateral branches</td>
<td>Carey et al., 2007</td>
</tr>
<tr>
<td>Vinca</td>
<td>Flurprimidol</td>
<td>Topflor</td>
<td>Control plant growth</td>
<td>Whipker et al., 2003a</td>
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in case of foliar sprays (Al-Khassawneh et al., 2006). It is required to use compressed air sprayer and same nozzle for all the plants to ensure the equal volume of PGRs to plants in case of foliar sprays. The high concentration of some PGRs can cause toxicity to the plant (Ranwala et al., 2002), sometimes resulted in stunted growth (Cox and Keever, 1988) and also increases the input cost. Foliar application can be more effective if applied at the right stage of growth for controlling specific characters and it requires information about the phenology of the target plant. Another advantage of foliar spray is the repetition of application as many times as required can be made to attain certain goals. The plant response to foliar application also depends on the absorption rate and absorption is driven by the environmental conditions, temperature and humidity are the most important. Slightly high temperature, high humidity and longer drying time are reported to increase the absorption of PGRs in plants (Stover and Greene, 2005).

Soil drenching is efficient method and PGRs are used in relatively lower doses but residual effects of PGRs are retained in pots which sometimes harm the plant. Drenching has advantage over foliar sprays because it ensures the uniformity of treatment as each plant receives the measured amount of PGRs and absorption occurs through root zone. This method is suitable for PGRs having efficient absorption through root medium (Sanderson et al., 1988). Substrate drenching requires more labor compared to other methods (Krug, 2004); hence, it may not be cost effective if the labor is heavily paid in that area.

Preplant soaking of plant material in PGRs is reported an efficient method but their use is relatively less common on commercial scale (Ranwal et al., 2002; Sajjad et al., 2015). This method has advantages of time and labor saving, accurate dosage over other methods, but disposal of residual solutions can be problematic (Larson et al., 1987) as some PGRs including paclobutrazole, uniconazole, ancymidole etc. cause toxicity to the surrounding environment when disposed in an open environment. This problem can be solved by applying the used solutions as a substrate drench for another time (Krug, 2004). There are certain factors which affect the effectiveness of this method, and the most important are the concentration of PGRs and duration of

<table>
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<tr>
<th>Plant Name</th>
<th>Method of application</th>
<th>Reference</th>
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<tr>
<td>African violet</td>
<td>Foliar sprays</td>
<td>Martin-Mex et al., 2005</td>
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<tr>
<td>Allium moly</td>
<td>Pre plant soaking/dipping</td>
<td>Laskowska et al., 2013</td>
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<tr>
<td>Argyranthemum frutescens</td>
<td>Pre plant soaking/dipping</td>
<td>Blanchard and Runkle, 2007</td>
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<tr>
<td>Bleillia striata</td>
<td>Pre plant soaking/dipping</td>
<td>Yoon et al., 2002</td>
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<tr>
<td>Bougainvillea glabra</td>
<td>Foliar sprays</td>
<td>Moneruzzaman et al., 2010</td>
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<tr>
<td>Caladium bicolor</td>
<td>Pre plant soaking/dipping</td>
<td>Whipker et al., 2005</td>
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<td>Chrysanthemum morifolium</td>
<td>Foliar sprays</td>
<td>Sugiyura, 2004</td>
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<td>Codiaeum variegatum</td>
<td>Foliar sprays</td>
<td>Eid and Abou-Leila, 2006</td>
</tr>
<tr>
<td>Dahlia pinnata</td>
<td>Foliar sprays</td>
<td>Mahgoub et al., 2011</td>
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<td>Euphorbia pulcherrima</td>
<td>Drenching</td>
<td>Lodeta et al., 2010</td>
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<td>Gladiolus grandiflorus</td>
<td>Foliar sprays</td>
<td>Sajjad et al., 2014</td>
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<td>Hemerocallis lilioasphodelus</td>
<td>Foliar sprays</td>
<td>Amling et al., 2007</td>
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<tr>
<td>Hibiscus coccineus</td>
<td>Foliar sprays</td>
<td>Warner and Erwin, 2003</td>
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<tr>
<td>Hosta spp.</td>
<td>Foliar sprays</td>
<td>Witomska et al., 2010</td>
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<tr>
<td>Hyacinth orientalis</td>
<td>Pre plant soaking/dipping</td>
<td>Krug et al., 2006</td>
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<td>Hylcocereus undatus</td>
<td>Foliar sprays</td>
<td>Khaimov and Mizrahi, 2006</td>
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<td>Iris germanica</td>
<td>Foliar sprays</td>
<td>Leeson and Harkess, 2006</td>
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<td>Lilium longiflorum</td>
<td>Pre plant soaking/dipping</td>
<td>Christopher and Lopez, 2010</td>
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<tr>
<td>Miltoniopsis vexillaria</td>
<td>Drenching</td>
<td>Matsumoto, 2006</td>
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<td>Nandina domestica</td>
<td>Foliar sprays</td>
<td>Keever and Morrison, 2003</td>
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<td>Phalaenopsis amabilis</td>
<td>Foliar sprays</td>
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<td>Phaloidendron Schott</td>
<td>Foliar sprays</td>
<td>Chen et al., 2003</td>
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<td>Reichardia tingitana</td>
<td>Drenching</td>
<td>Banon et al., 2003</td>
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<td>Rhodolodendron catawbiense</td>
<td>Drenching</td>
<td>Gent, 2004</td>
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<td>Rosa damascena</td>
<td>Foliar sprays</td>
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<td>Salvia officinalis</td>
<td>Foliar sprays</td>
<td>Carey et al., 2013</td>
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<td>Scaevola aemula</td>
<td>Pre plant soaking/dipping</td>
<td>Schnelle and Barrett, 2010</td>
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<td>Solida gorugosa</td>
<td>Foliar sprays</td>
<td>Lieth and Dodge, 2004</td>
</tr>
<tr>
<td>Tulipa gesneriana</td>
<td>Pre plant soaking/dipping</td>
<td>Ramzan et al., 2014</td>
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dipping of plant material in the solution (Ranwala et al., 2002). Application of PGRs in lower dose favors their use economically on large scale and use of low doses are effective if the duration of dipping is increased, as increase in duration may increase the absorption of chemical (Parivar et al., 1985) which can accelerate effectiveness.

**Various attributes of ornamentals improved by exogenous application of PGRs:** The exogenous application of PGRs has been reported numerous times in various ornamental plants including gladiolus (Sajjad et al., 2015), tulip (Ramzan et al., 2014), dahlia (Mahgoub et al., 2011), lily (Currey and Lopez, 2010), iris (Leeson and Harkess, 2006) etc. Their application was restricted in scientific experiments initially, but later on, was started to use on commercial farms and now is being applied by the progressive growers to improve different characteristics in ornamental plants. Although, the objective of the application of PGRs differs according to the type of plant but the increase in compactness of foliage is required in certain ornamental plants and improvement in flower characteristics is also a key objective in some other ornamental plants. The PGRs has been applied to alter various characteristics in ornamental plant including the increase or reduction in plant height (Christopher and Lopez, 2010; Francescangeli et al., 2007), increase compactness in plants (Meijon et al., 2009; Rademacher, 1991), an increase in number of flowers (Sajjad et al., 2014; Carey et al., 2013), early flowering (Cardosol et al., 2010; Khaimov and Mizrahi, 2006), increase in number of lateral shoots (Wroblewska and Debicz, 2013; Witomska et al., 2010), delay in flowering (Taha, 2012), control of sex ratio in flowers (Gayakvad et al., 2014), delayed senescence (Chang et al., 2003; Duan et al., 2006), increase flower life (Khandaker et al., 2013; Gulzar et al., 2005), induce systemic acquired resistance against diseases (Darras et al., 2011; Dinh et al., 2007), resistance against pathogen (Pozo et al., 2005; Jameson and Clarke, 2002), breaking dormancy (Gashi et al., 2012; Guleryuz et al., 2011), reduce the vernalization requirement (Wang and Walter, 2006), improve seed germination (Rehman and Park, 2000; Khan et al., 2004) and increase vase life (Gholami et al., 2011; Iqbal et al., 2012).

**Future challenges for PGRs and their alternatives:** Although the use of PGRs is encouraged in the modern production system of ornamentals and also helpful in altering various growth characteristics but their unjudicial use can threaten the environment and also effect the consumer acceptability, as commercial available PGRs formulations consists of synthetic growth regulators. The synthesis of ecological safe formulation of PGRs and their usage in optimum dosage will enhance their acceptability by the growers as well as consumers. The second way is to use alternative approaches for alteration of growth characteristics in ornamentals including the genetic engineering, gene silencing, manipulation of environmental factors especially temperature, light, and water stress technique to control growth of ornamentals.

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