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A review on role and use of gibberellic acid (GA_3) in flower production

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Abstract
The 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 flowering plants. Plant growth regulators are being used by the commercial growers of ornamental plants as a part of cultural practice. Plant growth regulators have quicker impact on vegetative as well as flower yield of flowering crops. Among them, Gibberellic Acid (GA_3) plays important role in flower production, quality and yield of the flower crops. The Gibberellic Acid (GA_3) is a tetracyclic di-terpenoid compound and a plant hormone stimulating plant growth and development. GAs stimulate seed germination, trigger transitions from meristem to shoot growth, juvenile to adult leaf stage, vegetative to flowering, determines sex expression and grain development along with an interaction of different environmental factors *viz.*, light, temperature and water. The production of flower with good quality flowers has greater importance. Their exogenous application helps to improve the different economically important and market desirable characteristics of flower plants. As it have various advantages like less time consuming to treat the plant and environment friendly. Use of growth regulators in flowering crops must be specific their action and toxicologically and environmentally safe. The physiological activities of flowering crops regulate by the application of growth regulators like GA_3 has finally affect the growth and flower production in flowering crops. There are various factors contributing to the efficacy of plant growth regulators among them the method of application plays a key role in determining the effectiveness of plant growth regulators, as they can be effective if properly absorbed by plants. The physiological activities of flowering crops regulate by the application of growth regulators and finally affect the growth and flower production in flowering crops. In this review, we have summarised critically on the role and use of Gibberellic Acid (GA_3) on flower production of commercial crops.

Keywords: gibberellic acid, growth, flowering, yield and economics

Introduction

Floriculture has been emerging as a future thrust industry in India and referred as tomorrow's green cultivation. Importance of cut flowers in international flower market makes the growers to take up its cultivation in India. The production of flower crop using growth regulator plays an important role in higher production and quality flowers to market. Plant growth regulators are being used by the commercial growers of ornamental plants as a part of cultural practice. Plant growth regulators have quicker impact on vegetative as well as flower yield of flowering crops. As it have various advantages like less time consuming to treat the plant and environment friendly. There are various factors contributing to the efficacy of plant growth regulators among them the method of application plays a key role in determining the effectiveness of plant growth regulators, as they can be effective if properly absorbed by plants. Use of growth regulators in flowering crops must be specific their action and toxicologically and environmentally safe. The physiological activities of flowering crops regulate by the application of growth regulators and finally affect the growth and flower production in flowering crops.

The Gibberellic Acid (GA_3) is a tetracyclic di-terpenoid compound and a plant hormone stimulating plant growth and development. GAs stimulate seed germination, trigger transitions from meristem to shoot growth, juvenile to adult leaf stage, vegetative to flowering, determines sex expression and grain development along with an interaction of different environmental factors *viz.*, light, temperature and water.

The production of flower with good quality flowers has greater importance. Their exogenous application helps to improve the different economically important and market desirable characteristics of flower plants. As it have various advantages like less time consuming to treat the plant and environment friendly. Use of growth regulators in flowering crops must be specific their action and toxicologically and environmentally safe. The physiological activities of flowering crops regulate by the application of growth regulators like GA_3 has finally affect the growth and flower production in flowering crops. There are various factors contributing to the efficacy of plant growth regulators among them the method of application plays a key role in determining the effectiveness of plant growth regulators, as they can be effective if properly absorbed by plants. The physiological activities of flowering crops regulate by the application of growth regulators and finally affect the growth and flower production in flowering crops. In this review, we have summarised critically on the role and use of Gibberellic Acid (GA_3) on flower production of commercial crops.

Floriculture has been emerging as a future thrust industry in India and referred as tomorrow's green cultivation. Importance of cut flowers in international flower market makes the growers to take up its cultivation in India. The production of flower crop using growth regulator plays an important role in higher production and quality flowers to market. Plant growth regulators are being used by the commercial growers of ornamental plants as a part of cultural practice. Plant growth regulators have quicker impact on vegetative as well as flower yield of flowering crops. As it have various advantages like less time consuming to treat the plant and environment friendly. There are various factors contributing to the efficacy of plant growth regulators among them the method of application plays a key role in determining the effectiveness of plant growth regulators, as they can be effective if properly absorbed by plants. Use of growth regulators in flowering crops must be specific their action and toxicologically and environmentally safe. The physiological activities of flowering crops regulate by the application of growth regulators and finally affect the growth and flower production in flowering crops.

The Gibberellic Acid (GA_3) is a tetracyclic di-terpenoid compound and a plant hormone stimulating plant growth and development. GAs stimulate seed germination, trigger transitions from meristem to shoot growth, juvenile to adult leaf stage, vegetative to flowering, determines sex expression and grain development along with an interaction of different environmental factors *viz.*, light, temperature and water.

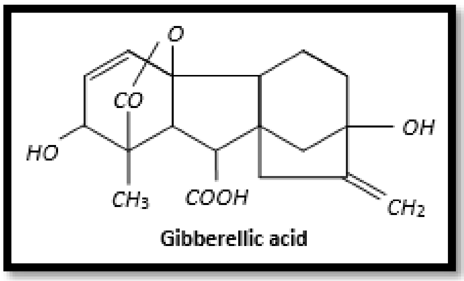
Gibberellins commonly known as Gibberellicacids had been discovered much earlier in Japan. Rice farmers of Japan had long known of a fungal disease called foolish seedling or *bakanae* disease that causes rice plants to grow taller and eliminated seed production. Plant pathologists found that these symptoms in rice plant were induced by a chemical secreted by a pathogenic fungus, *Gibberella fujikuroi*. Upon culturing this fungus in the laboratory and analyzing the culture filtrate enabled Japanese scientists in the 1930s to obtain impure crystal of two fungal "compounds" possessing plant growth promoting activity. One of these, was isolated from the fungus *Gibberella*, was named gibberellin A. In 1950s scientists of Tokyo University separated and characterized 3 different gibberellins from gibberellin A sample, and named them gibberellin A_1, gibberellin A_2 and gibberellin A_3. The numbering system for gibberellins used in the past 50 years builds on this initial nomenclature of gibberellins A_1 (GA_1), GA_2, and GA_3.

In the same year, 2 research groups, one at Imperial Chemical Industries in Britain and other at the US Department of Agriculture (USDA) in Illinois, elucidated the chemical structure of the compound that they had purified from *Gibberella* culture filtration and named gibberellic acid. This compound was later shown to be identical to the gibberellin isolated by the Japanese scientist. For this GA_3 is also referred to as gibberellic acid. GA_3 is the principal component in *Gibberella* culture. The GA_3 is the most frequently produced GA in commercial industrial scale fermentations of *Gibberella* for agronomic, horticultural and other scientific uses. Identification of a GA from a plant extract was first made in 1958 with the discovery of GA_1 from immature seeds of runner bean (*Phaseolus cocineus*). As more and more GAs from *Gibberella* and different plant sources were characterized, a scheme was adopted in 1968 to number them (GA_1–GA_4), in chronological order of their discovery.

Influence of GA_3 on Growth parameters of flower crops

Sadanand *et. al.* (2000) [40] reported increased plant height, shoot length and maximum number of leaves per plant with the application of GA_3 @ 200 ppm in rose cv. First Red.

Beena (2000) [6] investigated the effect of growth regulators on growth and flowering of *Anthurium andreanum* Linden. The varieties used were Liver red (L.R), Ceylon Red (C.R) and Kalympong Orange (K.O). Three growth regulators namely Gibberellic acid (GA_3), Tri Iodo Benzoic Acid (TIBA) and Kinetin (K) were used at 100, 300 and 500 ppm concentrations. The results of the experiments revealed that the growth regulators had significant effect on most of the characters under study. The maximum plant height (69.82 cm) was obtained nine months after the first spray for Kalympong Orange treated with GA_3 @ 500 ppm and number of leaves per plant (9.00) was recorded by Ceylon Red treated with GA_3 @ 300 ppm and also Highest number of suckers/plant (4.60) was produced by Kalympong Orange treated with GA @ 500 ppm, obtained nine months after the first spray.



Chandrappa (2002) [9] studied the impact of growth regulators on growth characters of *Anthurium* cv. Royal Red. Among all the treatments GA_3 @ 750 ppm recorded maximum plant height (42.55 cm), leaf area (248.66 sq.cm) and number of leaves per plant (3.40).

Preeti *et al*. (2004) [36] studied the effect of different plant growth regulators *i.e.* MH (500 ppm and 1000 ppm), GA_3 (300 ppm and 500 ppm), BAP (200 ppm and 400 ppm), ethylene (500 ppm and 750 ppm) and IAA (200 ppm and 300 ppm) on vegetative characters of *Anthurium andreanum* cv. Agnihotri and they opined that among different plant growth regulators GA_3 @ 500 ppm recorded maximum plant height (40.22 cm) which was at par with GA_3 @ 300 ppm (38.08 cm) and BAP @ 400 ppm (36.63 cm) and minimum (27.00 cm) was recorded by MH @ 1000 ppm, whereas GA_3 @ 500 ppm recorded maximum number of leaves per plant (9.50) which is at par with GA_3 @ 300 ppm (9.33) and BAP @ 400 ppm (8.17), whereas minimum (5.33) was recorded by control.

Srinivasa (2005) [54] revealed the influence of GA_3 on growth of anthurium cv. Mauritius Red. From the experiment it was reported that plants treated with GA_3 @ 300 ppm recorded maximum plant height (44.44 cm) and leaf width (11.19 cm) compared to all other treatments and GA_3 @ 225 ppm showed maximum number of leaves (13.33) per plant whereas GA_3 @300 ppm showed maximum leaf length (21.00 cm) comparatively.

Panwar *et. al.* (2006) [32] on tuberose found that foliar application of GA_3 @ 0, 25, 50, 75 and 100 ppm was done on plants at 4-5 leaf stage. Among all treatments, application of GA_3 at 100 ppm was found best resulting in more number of leaves / plant.

Devadanam *et. al.* (2007) [16] conducted a trial on the effects of GA_3 (50, 100 or 150 ppm) on growth and yield of *Polianthes tuberosa*. GA_3 was sprayed to plants at 30, 60 and 90 days after planting significantly enhanced the growth. GA_3 @ 150 ppm resulted in the greatest plant height (59.13cm).

Ismaeil and Youssef (2008) [21] on *Hemerocallis aurantiaca* concluded that all GA_3 concentrations (50, 100 and 200 ppm) significantly increased the number of leaves and fresh and dry weights of leaves when compared with untreated plants "control" in both seasons.

Delvadia *et al.* (2009) [14] experimented on the effect of different GA_3 concentration and frequency on growth, flowering and yield in gaillardia (*Gaillardia pulchella* Foug.) *cv.* Lorenziana and they opined that maximum plant height (45.20 cm) was produced when plant treated with GA_3 @ 250 ppm at single stage and minimum (22.96 cm) was in control.

Soad *et al.* (2010) [51] conducted a pot experiment to study the effect of foliar application with benzyl adenine @ 50, 100 and 150 ppm and gibberellic acid @ 100, 150 and 200 ppm on the vegetative growth of croton plants. The highest recorded data for plant height of 70.53 cm was obtained in plants treated with GA_3 @ 200 ppm, whereas 61.48 cm and GA_3 @ 200 ppm produced 261.40 leaves / plant.while, GA_3 @ 200 ppm exhibited highest leaf area (122.71 cm^2) which is at par with BA @ 150 ppm (117.82 cm^2).

Pancholi *et al.* (2010) [33] done with the experiment on response of Anthurium to foliar application of urea and growth regulators in shade net house and documented that compare to all other combinations (BA, GA_3 and Urea,) the foliar application of GA_3 @ 150 ppm recorded significantly maximum number of leaves per plant in anthurium cv. Coralis (5.20) and Patino (4.60) under shade net and GA3 @ 150 ppm enhanced the sucker production per plant in anthurium *cv.* Coralis (1.80) and Patino (1.50) under shade net.

Shinde (2010) [48] concluded that the maximum leaf area $plant^{-1}$, leaf area index and leaf area duration (0.981m2 plant-1, 3.78 m^2 $plant^{-1}$, and 14.04 m^2 day^{-1}) were recorded in plants sprayed with foliar application of GA_3 @ 200 ppm followed by GA_3 @ 150 ppm (0.980 $m^2 plant^{-1}$, 2.54 m^2 $plant^{-1}$, and 13.37 m^2 day^{-1} in chrysanthemum (*Chrysanthemum morifolium* Ramat.) cv. IIHR-6 under middle Gujarat conditions.

Sharifuzzaman *et al*. (2011) [44] studied the effect of GA_3, CCC and MH on vegetative growth, flower yield and quality of chrysanthemum and revealed the highest number of leaves (60.00) was produced by the application of GA_3 @ 150 ppm as a foliar spray, however CCC @ 800 ppm showed minimum (22.00) number of leaves/plants. The highest number of suckers (20.00) per plant was produced when plants were treated with GA_3 @ 150 ppm followed by GA_3 @ 100 ppm (18.00), whereas, use of CCC at 600 and 800 ppm produced the lowest number of suckers (7.00 and 6.00, respectively).

Sainath *et al*. (2012) [41] reported the maximum plant height (97.28 cm), number of leaves $plant^{-1}$ (702.43) and leaf area $plant^{-1}$ (4497.24 cm^2) were recorded in plants sprayed with GA_3 @ 200 ppm at the time of final harvest in annual chrysanthemum (*Chrysanthemum coronarium* L.).

Muthukumar *et al.* (2012) [31] studied the influence of various growth regulating chemicals on growth, yield and quality characters of cut rose cv. First Red. The study involved pre-harvest spraying with gibberellic acid (50 ppm and 100 ppm), maleic hydrazide (50 ppm and 100 ppm) and salicylic acid (25 ppm and 50 ppm). Gibberellic acid @ 100 ppm as a pre-harvest spray excreted a significant influence on crop growth and recorded highest mean values for plant height (76.18cm), whereas minimum plant height was recorded by maleic hydrazide @ 100 ppm (46.77 cm).

Taha (2012) [55] indicated that the effect of some growth regulators on growth, flowering, bulb productivity and chemical composition of Iris plants The highest percentage of the total carbohydrates in the bulbs was obtained by the application of GA_3 @ 750 ppm followed by CCC @ 1000 and Alar @ 500 ppm.

Aparna (2012) [4] conducted an experiment on the effect of different concentrations of GA3 (0, 200, 300 and 400 ppm) on two cultivars (Snowball and Thai Chen Queen) of chrysanthemum. Foliar spray of GA_3 @ 400 ppm recorded the maximum crop growth rate (0.005 g^{-1} m^2 d^{-1} and 0.18 g^{-1} m^2 d^{-1}), relative growth rate (0.020 g g^{-1} d^{-1} and 0.056 g g^{-1} d^{-1}) and total chlorophyll content (1.77 mg g^{-1} and 1.75 mg g^{-1}) in chrysanthemum (*Chrysanthemum morifolium* Ramat) cv.s. Snowball and Thai Chen Queen.

Anjali (2013) [3] evaluated the response of GA_3 on growth and yield of anthurium (*Anthurium andreanum* Lind.) under shade net condition. Among the different level of treatment, GA_3 @ 600 ppm exhibited the highest plant height (64.87 cm) which was on par with treatment GA_3 @ 450 ppm (63.58cm) and it was lowest (59.47 cm) in control at 15 months after planting, whereas more number of leaves per plant (6.56), maximum leaf width (21.83 cm) and highest leaf length (36.92 cm) was recorded in treatment GA_3 @ 600 ppm.

Handaragall *et al*. (2013) [18] studied the effect of GA_3 and foliar nutrients along with bio fertilizers on growth and flowering of *Anthurium andreanum* cv. Tropical Red. The results documented that among the different treatments GA3 @ 100 ppm along with bio-fertilizers significantly increased plant height (26.43 cm) and also increased the number of leaves per plant (9.73) compare to all other treatments in *Anthurium andreanum* cv. Tropical Red

Rani and Singh (2013) [37] experimented on the impact of gibberellic acid pre-treatment on growth and flowering of tuberose (*Polianthes tuberosa* L.) *cv.* Prajwal and they revealed that GA_3 @ 150 ppm showed maximum plant height (71.27 cm) and maximum (59.60) number of leaves/plant.

Shanan *et al.* (2014) [45] studied the response of *Celosia cristatacv.* Red Velvet to organo and bio-stimulants. Here they used two organo- stimulants (PGRs) *i.e,* gibberellic acid @ 200 ppm and benzyladenine @ 50 ppm. The results revealed that, GA_3 @ 200 ppmincreased the plant height (56.47 cm) and total chlorophyll content (63.95 SPAD) compared to other treatments.

Lima *et al.* (2014) [25] experimented on growth and yield of anthurium in response to gibberellic acid.Application of GA_3

@ 150 ppm, 300 ppm and 450 ppm promoted the total leaf area of the plant, where in maximum was found in GA_3 @ 450 ppm (380.00 cm^2).

Deshmukh *et al*. (2014) [15] conducted an experiment on effect of four GA_3 at different concentrations *i.e* 0, 100, 200 and 300 ppm in african mariglod (*Tagetets erecta* L.). Among the different concentrations the maximum plant height (53.95 cm), plant spread (53.95 cm^2) and fresh weight $plant^{-1}$ (375.85 g) were observed in plants treated with GA_3 @ 300 ppm followed by GA_3 @ 200 ppm (62.04 cm, 52.63 cm^2 and 346.87 g,respecctively).

Kesav (2014) [23] carried out an experiment on the different growth regulators GA_3 @ 100 ppm and 200 ppm, NAA @ 25 ppm and 50 ppm and etherel @ 500 ppm and 800 ppm in african marigold (*Tagetus erecta* L.) cv. Pusa Narangi Gainda. Among the different growth regulators plants sprayed with GA3 @ 200 ppm recorded maximum plant height (84.79 cm), plant spread (50.56 cm), number of primary branches $plant^{-1}$ (18.87), number of secondary branches $plant^{-1}$ (45.72), total chlorophyll content (49.72 SPAD units), fresh weight $plant^{-1}$ (299.59 g) and dry weight $plant^{-1}$ (102.54 g).

Raveendra *et al*. (2014) [38] studied the influence of GA_3 @ 150 ppm on 9 different varieties of daisy. Among the different treatments maximum plant height (48.33 cm), plant spread (803 cm2), number of leaves $plant^{-1}$ (62.86), leaf area $plant^{-1}$ (557.33 cm^2) and number of suckers $plant^{-1}$ (4.81) were recorded in plants sprayed with GA_3 @ 150 ppm in Purple long petal variety of daisy (*Aster amellus* L.).

Maitra and Roychowdhury (2015) [26] verified the effect of three different levels (50 ppm, 75 ppm and 100 ppm) of each of BA, GA_3, NAA and ethrel on carnation (*Dianthus caryophyllus* L.) cv. Chabaud Super Mix and they opined that growth regulators had a profound effect on the plant height of carnation and the longest plants were recorded as a result of application of GA_3 @ 75 ppm (75.28 cm) whereas the shortest were from untreated plants (59.78 cm).

Sharma and Joshi (2015) [46] studied the effect of foliar spray of plant growth regulators *viz.,* gibberellic acid (GA_3 @ 150 ppm and 250 ppm) and 1-Naphthaleneacetic acid (NAA @ 25 and 50 ppm) on vegetative parameters on three china aster cultivars. They opined that maximum plant height (56.18cm) and maximum leaf area (3968.88 cm^2) was exhibited by the treatment GA_3 @ 250 ppm and least by NAA @ 50 ppm (39.96 cm).

Prakash *et al*. (2015) [35] carried out an experiment on effect of different growth regulators i.e., GA_3 @ 100, 200 and 300 ppm, NAA @ 50,100 and 150 ppm, and BA @ 50,100 and 150 ppm, along with control (water spray) on chrysanthemum (*Dendranthema grandiflora* L.) cv. Vasantika. Among the growth regulators GA_3 @ 300 ppm recorded maximum plant height (27.20 cm), plant spread (27.20 cm) and number of primary branches (5.47) followed by GA_3 @ 200 ppm (60.07 cm, 25.67 cm, 5.07).

Singh and Nigam (2015) [50] observed that plants sprayed with GA_3 @ 250 ppm recorded the maximum plant height (58.60 cm and 46.78 cm), plant spread (31.79 cm and 28.26 cm), number of branches $plant^{-1}$ (17.22 and 20.87) in chrysanthemum cvs. Birbal Sahni and Julia.

Sethy *et al.* (2016) [43] experimented the effect of plant growth regulators on growth and flowering of ornamental sunflower and the results of the study revealed that application of GA_3 @ 200 ppm recorded significantly higher plant height (139.55 cm) and minimum by MH @ 1500 ppm (50.86 cm) whereas application of GA_3 @ 200 ppm recorded significantly maximum number of leaves (26.66) in contrast to it, minimum (17.60) was recorded by MH @ 1500 ppm.

Reshmi and Sheela (2016) [39] conducted a study to standardize growth regulators for enhancing propagation efficiency in three exotic cultivars of heliconia. Two field trials were carried out for this purpose. Based on the results of the preliminary field trial, second experiment was laid out. Application of growth regulators had pronounced effect on sucker production at all the stages. During the first experiment, BA @ 750 ppm produced the highest number (4.19) of suckers/plant.In the second experiment, variation was evident in the total number of suckers. Here, BA @ 850 ppm produced the highest number (4.33) of suckers and it was on par with BA @ 700 ppm (4.00) and GA_3 @ 650 ppm (3.79).

Anuradha *et al.* (2017) [2] conducted an experiment on effect of different plant growth regulators *i.e* water spray, GA3 @ 200 ppm, NAA @ 60 ppm, CCC @ 1000 ppm and TIBA @ 1000 ppm in african marigold cv. Culcatta Orange. Among the different treatment's plants sprayed with GA3 @ 200 ppm recorded maximum plant height (64.52 cm), number of primary branches $plant^{-1}$ (22.60) and number of secondary branches $plant^{-1}$ (53.25) at 90 DAT.

Mishra *et al*. (2018) [29] studied foliar application of GA_3 (50, 100 and 150 ppm) with different spray frequencies (twice and thrice) on growth, flowering and yield of china aster (*Callistephus chinensis* L.) NEES. Among the different frequencies, maximum height (69.03 cm), number of primary branches $plant^{-1}$ (15.63) and number of leaves $plant^{-1}$ (302.81) were recorded in plants sprayed thrice with GA3 @ 100 ppm.

Singh *et al*. (2018) [53] carried out an experiment on effect of GA_3 (50, 100 and 150 ppm) and CCC (1000, 5000 and 10000 ppm) on growth, flowering and yield of chrysanthemum (*Dendranthema grandiflora* Ramat) cv. Birbal Sahni. The maximum plant height (58.60 cm), plant spread (31.79 cm), number of branches $plant^{-1}$ (17.22) and number of leaves $plant^{-1}$ (219.74) registered with GA_3 @ 150 ppm while minimum was recorded in control.

Influence of plant growth regulators on flowering and quality cut flowers

Beena (2000) [6] investigated the effect of growth regulators on growth and flowering of *Anthurium andreanum* Linden. The varieties used were Liver Red, Ceylon Red and Kalympong Orange. Three growth regulators namely GA_3, TIBA and K were used at 100 ppm, 300 ppm and 500 ppm concentrations. The highest length of spadix (43.52 cm) was showed six months after the first spray by Liver Red treated with GA @ 500 ppm.

Dhekney *et. al.* (2000) [17] reported that GA_3 at 200 ppm resulted an increase in bud length, bud circumference and flower diameter. They also stated that the maximum flower neck length (9.07 cm) was produced in rose cv. First Red by applying GA_3 @ 300 ppm while control recorded 6.43 cm. They observed that applying GA_3 @ 200 ppm produced maximum number of flowers (38.61) per m^2 compared to control (18.22).

Sadanand *et. al.* (2000) [40] recorded increased bud length and bud diameter with GA_3 application and the highest length and diameter were obtained in case of bud with GA_3 @ 200 ppm in rose cv. First Red.

Verma *et. al.* (2000) [58] stated that applying nitrogen (500 ppm) and GA_3 (50 ppm) per week were found to be effective in increasing the flower diameter and flower length in carnation.

Thamaraiselvi *et. al.* (2002) [56] reported that applying calcium acetate 0.5 percent + Panchakaya 5 percent significantly improved the floral characters such as flower weight, flower length, flower thickness and petal number in Edward rose.

Chandrappa (2002) [9] studied the effect of growth regulators on growth characters of Anthurium cv. Royal Red. Among the different treatments GA_3 @ 750 ppm showed maximum (44.78) stalk length and (7.02 cm) spadix length whereas minimum (41.58) was observed in TIBA @ 500 ppm and minimum (6.46 cm) was observed in TIBA @ 500 ppm respectively.

Katkar *et al*. (2003) [22] reported that plants sprayed with GA_3 @ 200 ppm recorded minimum number of days to first flower bud emergence (56.26) and days to 50 percentflowering (80.46) in china aster (*Callistephus chinensis*) cv. California Giant Mix.

Chakradhar *et. al.* (2003) [8] reported that flower bud length and diameter were maximum with application of GA_3@ 60 ppm and minimum with BA @ 100 ppm in rose cv. Gladiator. Significantly maximum flower diameter (7.09 cm) was recorded @ GA_3@100 ppm with DSF @ 75 percent of RDF in China aster as compared to control (4.87 cm)

Preeti *et al*. (2004) [36] studied the effect of different plant growth regulators *i.e.* MH (500 ppm and 1000 ppm), GA_3 (300 ppm and 500 ppm), BAP (200 ppm and 400 ppm), ethylene (500 ppm and 750 ppm) and IAA (200 ppm and 300 ppm) on floral characters of *Anthurium andreanumcv.* Agnihotri and they opined that among different plant growth regulators GA_3 @ 500 ppm recorded early to full bloom (26.13 days) which is at par with GA_3 @ 300 ppm (26.20 days) and BAP @ 400 ppm (26.53 days) whereas maximum days to full bloom was recorded by ethylene @ 750 ppm (30.40) andthe results also revealed that among different plant growth regulators GA_3 @ 500 ppm recorded maximum spathe length (8.60 cm), maximum spadix length (6.00cm) and maximum stalk length (36.67 cm).

Srinivasa (2005) [54] revealed the influence of GA_3 on growth of anthurium cv. Mauritius Red. He opined that plants treated with GA_3 @ 300 ppm recorded maximum stalk length (44.44 cm), spathe length (7.81 cm), spathe width (7.13) andspadix length (6.49 cm) compared to all other treatments.

Dhaduk *et al*. (2007) studied the effect of GA_3 on growth and yield attributes in anthurium. Foliar spray of GA_3 @ 500 ppm, recorded maximum stalk length (24.15 cm) compare to other treatments.

Devadanam *et. al.* (2007) [16] demonstrated that the effects of gibberellic acid (50, 100 or 150 ppm) on flowering of *Polianthes tuberosa.* GA_3 was sprayed to plants @ 30, 60 and 90 day after planting significantly enhanced flower spike. GA_3 @ 150 ppm resulted in the greatest number of florets per spike (30.49), flower yield/ha (6.25), and number of spikes/ha (2.48 lakhs).

Tyagi and Singh (2008) [57] indicated that the effect of gibberellic acid (GA_3) and IBA on flowering of tuberose (*Polianthes tuberosa*. cv. Double.) There were 17 treatments of soaking at 24h before planting and spraying at 30 days after planting of GA_3 @ (40, 80, 120 and 160 ppm) and IBA at (20, 40, 60 and 80 ppm). Spraying of GA_3 @ 160 ppm at 30 days after planting was the most effective for days emergence of spikes (80.33), florets per spike (38.85), spike diameter (0.97cm), spikes per plant (2.43), spike length (78.33 cm) and rachis length (34.48 cm).

Ismaeil and Youssef (2008) [21] reported that all GA_3 (50, 100 and 200ppm) treatments statistically increased the number of flowers/ clumps, Length and diameter of flower stalk, fresh and dry weights of flower as compared with control in both seasons.

Dalal *et. al.* (2009) [13] demonstrated that the effects of gibberellic acid (0, 50, 100 and 150 ppm) on growth, flowering, yield and quality of gerbera under polyhouse conditions. GA_3 was sprayed to plants at 30 and 60 day after transplanting. The result indicated that, maximum vegetative growth, flower yield and quality were observed with treatment of GA_3 at 150 ppm. Whereas early flowering was noticed in plant sprayed with 50 ppm GA_3.

Sajid *et al.* (2009) [42] opined that foliar application of plant growth regulators and nutrients for improved the quality of lily flowers. It was found that floral stem length of the plants sprayed with nutrients alone increased by 25 percent (78.00 cm) over those of the control plants (62.50 cm). Mean shoot length of the plants sprayed with both the GA_3 (20 ppm) and nutrients increased by 33 percent (82.00 cm) over the control plants and by 6 percent over the other set of plants, which received the treatment of nutrients alone.

Hashemabadi and Zarchini (2010) [19] evaluated the effect of different levels of salicylic acid, gibberellic acid and cycocel at pre-harvest stage on the quality, yield and vase life of cut rose (*Rosa hybrida* 'Poison'). The best treatment to increase the stem length of flower was GA_3 @ 300 ppm which produced longest stems (49.33 cm) whereas minimum was showed by CCC @ 1500 ppm (29.93 cm).

Pancholi *et al*. (2010) [33] done with the experiment on response of Anthurium to foliar application of urea and growth regulators in shade net house and documented that compare to all other combinations, GA3 @ 150 ppm produced the maximum spathe length (7.10 cm) followed by BA @ 100 ppm (6.20 cm), whereas minimum was recorded by control (4.10 cm) and maximum spadix length (3.50 cm) followed by BA @ 100 ppm (2.90 cm) whereas minimum (2.10 cm) was recorded by control.

Soner and Osman (2010) [52] concluded that the effect of foliar applications of GA_3 and paclobutrazol on yield and quality parameters in goldenrod were investigated in the study. The study revealed that once and twice foliar applications of 250 mg of GA_3 shortened the days to flower and increased stem length, stem diameter, stem fresh weight, number of secondary inflorescences and number of stems per plant. In addition, the paclobutrazol treatments slightly retarded the days to flower and significantly reduced stem length and stem weight.

Sharifuzzaman *et al*. (2011) [44] studied the effect of GA_3, CCC and MH on flower yield and quality of chrysanthemum. They revealed that with different treatment combinations. Length of flower stalk significantly increased when plant was treated with GA_3 regardless of different concentrations. The application of GA_3 @ 150 ppm produced maximum length of flower stalk (14.00 cm). The minimum was shown by CCC @ 400 ppm (6.00).

Muthukumar *et al*. (2012) [31] studied the influence of various growth regulating chemicals on growth, yield and quality characters of cut rose *cv*. First Red. The study involved pre-harvest spraying with gibberellic acid (50 and 100 ppm), maleic hydrazide (50 and 100 ppm) and salicylic acid (25 and 50 ppm). Gibberellic acid @ 100 ppm as a pre harvest spray excreted a significant influence on crop growth and recorded highest mean values for stalk length (60.98 cm) whereas minimum (32.95 cm) flower stalk length was recorded by maleic hydrazide @ 100 ppm. and also, the growth regulators GA_3 @ 100 ppm recorded maximum vase life (2.60 days) while least (1.10 days) was observed in control.

Handaragall *et al*. (2013) [18] studied on effect of GA3 and foliar nutrients along with bio fertilizers on growth and flowering of *Anthurium andreanum* cv. Tropical Red. Results showed that among the different treatments GA3 @ 100 ppm along with bio-fertilizers exhibited early days to flower bud appearance (61.20) and early days to flower opening (12.00).

Rani and Singh (2013) [37] conducted a trial on the effects of GA_3 (50, 100 or 150 ppm) on growth, flowering and quality flower production of tuberose. It was concluded that GA_3 at 150 ppm proved to be best concentration in enhancing all the floral (spike length, number of florets/ spikes, floret length) and bulbous characteristics in tuberose. GA_3 also resulted in early flowering and more durable flowers which are the major contributing traits for floriculture industries. Better performance of tuberose with application of GA_3 might be due to efficient nutrient uptake, enhancing source and sink potential by promoting photosynthetic enzymes, leaf area, more trapping of light for increasing photosynthetic rate, proper metabolism of antioxidant enzymes to normal level.

Anjali (2013) [3] evaluated the response of GA_3 on growth and yield of anthurium (*Anthurium andreanum* Lind.) under shade net condition. Foliar application of GA_3 had a significant effect on promotion of stalk length in different varieties. At the end of the experimental period (15 months after planting), the treatment GA_3 @ 600 ppm recorded maximum stalk length (48.59 cm), whereas minimum in case of (42.84 cm) control.At the end of the experiment (15 months after planting) the maximum spathe length (12.61 cm) and spadix length (8.22 cm) was recorded in treatment GA_3 @ 600 ppm and it was minimum (10.70 cm) in treatment control. In case of GA_3 @600 ppm also recorded maximum angle (31.93^0) between spadix to spathe compare to control (30.00^0).

Chauhan *et al.* (2014) [10] studied the effect of gibberellic acid on flowering and cut flower yield in gerbera under protected condition. The results revealed that GA_3 @ 100 ppm increase the length of flower stalk (54.32 cm) which is at par with GA_3 @150 ppm (52.76 cm) and in case GA_3 @ 150 ppm had maximum vase life of gerbera (10.00 days) which is on par with GA_3 @ 100 ppm (9.63 days).

Kesav (2014) [23] conducted an experiment on the different growth regulators *viz*., GA_3 @ 100 ppm and 200 ppm, NAA @ 25 ppm and 50 ppm and etherel @ 500 ppm and 800 ppm in african marigold (*Tagetus erecta* L.) cv. Pusa Narangi Gainda. The minimum number of days taken for first flower bud appearance (22.83), first flower appearance (30.23), 50 percent flowering (42.06) and flower diameter (7.50 cm) were recorded in plants sprayed with GA_3 @ 200 ppm.

Munikrishnappa and Chandrashekar (2014) reported that maximum vase life was recorded with GA_3 @ 200 ppm (22.88 days) than control in china aster (*Callistephus chinensis* (L.) NEES.).

Raveendra *et al*. (2014) [38] found that significantly minimum days to first flowering (62.00), number of days taken for 50 percentflowering (71.39) and maximum spike length (54.89 cm) were observed in plants sprayed with GA_3 @ 150 ppm in daisy (*Aster amellus* L.).

Kumar *et al*. (2015) [35] reported that the plants sprayed with GA_3 @ 300 ppm recorded early flower bud initiation (48 days), opening of first flower (89.87 days) and maximum length of flower stalk (8.95 cm) in china aster (*Callistephus chinensis* L. Nees) cv. Kamini

Parmar *et al*. (2015) [34] experimented on effect of GA_3 and CCC on flower yield of Dutch rose (*Rosa hybrida* Linn.) cv. Passion under polyhouse condition. The maximum (12.23 days) vase life of cut flower was exhibited by GA_3 @ 200 ppm

Huang *et al.* (2015) [20] experimented to study the influences of different concentration of gibberellic acid on the flowering parameters in *Remusatia vivipara.* The results revealed that plants sprayed with GA_3 @ 75 ppm recorded maximum (8.58 cm) spathe length

Baghele *et al*. (2016) [5] evaluated the effect of foliar spray of growth regulators *viz.* GA_3 (50, 100 and 150 ppm), BA (50, 100 and 150 ppm), NAA (50, 100 and 150 ppm) and cow urine on growth of Rose (*Rosa hybrida*) cv. Poison under naturally ventilated polyhouse. All the treatment combination comprising of foliar spray significantly improved flower parameters and yield over control. Among all plant growth regulators and cow urine, the application of GA_3 @ 100 ppm showed maximum stalk length (55.33 cm) and it was on par with GA_3 @ 150 ppm (4.65 cm) and BA @ 150 ppm (52.58 cm) and application of GA_3 @ 100 ppm showed maximum vase life (9.87 days) followed by GA_3 @ 150 ppm (9.27 days) and BA @ 150 ppm (8.27 days).

Anuradha *et al*. (2017) [2] recorded the minimum number of days taken for flower bud appearance (41.40), flower initiation (57.69) and maximum flower yield plant^{-1} (397.25 g) in the plants treated with GA_3 @ 200 ppm in african marigold cv. Culcatta Orange.

Cherik *et al*. (2017) [11] observed the maximum vase life in the treatment GA_3 @ 100 ppm (14.80 days) in gerbera (*Gerbera jamesonii* L.) cv. Pink Elegance under naturally ventilated polyhouse.

Markam (2017) [27] conducted an experiment on effect of different plant growth regulators i.e GA_3 @ 200 ppm and 300 ppm and CCC @ 1000 ppm and 1500 ppm. Significantly the minimum number of days taken for first harvest of flowers (50.26) was recorded in plants sprayed twice with GA_3 @ 300 ppm followed by of GA_3 @ 200 ppm at 25 and 45 DAT (51.42 d) in african marigold (*Tagetes erecta* L.) under Chhattisgarh plains.

Maurya *et al*. (2017) [28] observed that plants sprayed with GA_3 @ 150 ppm recorded minimum number of days to first flowering (62.80), maximum number of flowers plant^{-1} (75.73) and flower diameter (5.96 cm) in china aster (*Callistephus chinensis*).

Choudhari *et al*. (2018) [12] reported that plants sprayed with GA_3 @ 150 ppm recorded minimum number of days for first flowering (61.00), days for 50 percent flowering (71.33) and maximum flower stalk length (60.17 cm) and vase life (3.78 days) in cut chrysanthemum (*Dendranthema grandiflora* Tzevelev.) cv. Yellow Gold.

Sindhuja *et al*. (2018) [49] observed that the foliar application of GA_3 @ 200 ppm recorded maximum flower diameter (6.21 cm) and vase life (8.96 days) in china aster (*Callistephus chinensis* L. Nees) cv. Shashank.

Singh *et al*. (2018) [53] reported that maximum flower Size (4.29 cm) and length of flower stalk (8.46 cm) were recorded with the foliar application of GA_3 @ 150 ppm in chrysanthemum (*Dendranthema grandiflora* Ramat) cv. Birbal Sahni.

Influence of plant growth regulators on yield

Chandrappa (2002) [9] studied the effect of growth regulators on growth characters of anthurium cv. Royal Red. Among all the growth regulators GA_3 @ 750 ppm produced maximum no. flowers /plant (3.29), whereas minimum (2. 90 flowers/plant) was recorded by TIBA @ 500 ppm.

Preeti *et al*. (2004) [36] studied the effect of different plant growth regulators *i.e.* MH (500 ppm and 1000 ppm), GA_3 (300 ppm and 500 ppm), BAP (200 ppm and 400 ppm), ethylene (500 ppm and 750 ppm) and IAA (200 ppm and 300 ppm) on floral characters of *Anthurium andreanum* cv. Agnihotri. The results revealed that among different plant growth regulators GA_3 @ 500 ppm recorded maximum number of flowers/plant (3.80) which is at par with GA_3 @ 300 ppm (3.00) and BAP @ 200 ppm (2.93), whereas least (2.13) in case of control.

Srinivasa (2005) [54] revealed the influence of GA_3 on growth of anthurium cv. Mauritius Red. He opined that plants treated with GA_3 @ 300 ppm recorded maximum no. of flowers/plant (6.56) and maximum flower weight (37.56 g) compared to all other treatments.

Delvadia *et al.* (2009) [14] experimented on the effect of different GA_3 concentration and frequency on growth, flowering and yield in gaillardia (*Gaillardia pulchella* Foug.) cv. Lorenziana and they opined that maximum number of flower yield (18.06 tons/ha), number of flowers/plant (150.48) and total weight of flowers/plant (341.60 g) was produced when plant treated with GA_3 @ 250 ppm at single stage and minimum was in control.

Sajid *et al.* (2009) [42] opined that foliar application of plant growth regulators and nutrients greatly improved the yield of lily flowers. Mean number of flowers in control plants was 3.00 whereas in nutrients-fed plants, it was 3.50, which are 14 percent more than untreated plants. Number of flowers per plant in the set of plants, which received dual treatment (GA_3 + nutrients) was 4.50, which are 50 percent more than control plants.

Hashemabadi and Zarchini (2010) [19] evaluated the effect of different levels of salicylic acid, gibberellic acid and cycocel at pre-harvest stage on the quality, yield and vase life of cut rose (*Rosa hybrida* 'Poison'). Results showed that the highest record of flower yield was obtained by application of GA_3 @ 200 ppm (192.00 cut flowers /year/$m^{2)}$ and in case of maximum fresh weight (47.35 g) of flower was recorded by GA_3@ 150 ppm and minimum (31.53 g) by CCC @ 500 ppm.

Anburani and Vijay (2010) investigated that effect of growth retardants on growth and yield in *nerium* (*Nerium odorum*) and stated that among different growth retardants MH @ 1500 ppm exhibited maximum number of flowers (Kg) / hectare (1074.07 Kg/ha) compared to CCC, ethrel and alar at different concentrations.

Pancholi *et al*. (2010) [33] done with the experiment on response of anthurium to foliar application of urea and growth regulators in shade net house and documented that compare to all other combinations (BA, GA_3, Urea) GA_3 @ 150 ppm produced more number of flowers/plant (4.10) and least (2.00) was recorded by control

Bhatt and Chauhan (2012) [7] investigated the effect of GA_3 and BA on growth and flowering of *Dendrobium* cv. Sonia. It was observed that GA_3 @ 15 ppm showed maximum no. flowers/plant (6.00) compared to BA @ 15 ppm (4.00).

Kumar *et al*. (2012) [24] conducted an experiment on effect of different growth regulators *i.e* MH @ 50 ppm and 100 ppm and GA_3 @ 100 ppm and 200 ppm on flowering and yield characters in african marigold. The results showed that foliar spray of GA_3 @ 200 ppm registered significantly maximum flower yield $plant^{-1}$ (639.18 g).

Anjali (2013) [3] evaluated the response of GA_3 on growth and yield of anthurium (*Anthurium andreanum* lind.) under shade net condition. Different levels of GA_3 sprayrecorded significantly higher yield at 12 to 15 months after planting. Flower yield per square meter (22.77) and number of flowers per plant (3.25) were maximum in treatment GA_3 @ 600 ppm and minimum in control.

Handaragall *et al*. (2013) [18] studied on effect of GA3 and foliar nutrients along with bio fertilizers on growth and flowering of *Anthurium andreanum* cv. Tropical Red. Results showed that among the different treatments. The maximum flower yield per m^2 (34.00) were recorded in the plants treated with NPK 30:10:10 at 0.2 percent spray along with bio-fertilizers and GA_3 @ 100 ppm which was at par with NPK 15:0:10 at 0.2 percent spray + *Azospirillum* + Phosphobacteria +VAM+ GA_3 @ 100 ppm (30.35) and with NPK 30:10:10 at 0.2 percent spray + *Azospirillum*+ phosphobacteria +VAM +GA_3 @ 200 ppm (28.33), while minimum flower yield per sq. m (15.45) were recorded in control.

Chauhan *et al.* (2014) [10] studied the effect of gibberellic acid on flowering and cut flower yield in gerbera under protected condition. The results revealed that GA_3 @ 100 ppm increases the no. flowers/ sq. m (80.20) followed by GA_3 @ 150 ppm (79.80). whereas GA_3 @ 100 ppm increases the flower yield / hectare (16.04 lakh) followed by GA_3 @ 150 ppm (15.96 lakh).

Kesav (2014) [23] studied the effect of different growth regulators and pinching levels in african marigold (*Tagetus erecta* L.) cv. Pusa Narangi Gainda. The maximum number of flowers $plant^{-1}$ (77.78) and fresh weight of flowers $plant^{-1}$ (577.90 g) and flower yield $hectare^{-1}$ (240.79 q) were recorded in plants sprayed with GA_3 @ 200 ppm.

Deshmukh *et al*. (2014) [15] concluded that plants sprayed with GA_3 @ 100 ppm recorded the maximum yield of flowers $hectare^{-1}$ (79.56 q) followed by GA_3 @ 200 ppm (77.85q) in african mariglod (*Tagetets erecta* L.)

Prakash *et al*. (2015) [35] concluded that foliar spray of GA_3 @ 300 ppm recorded maximum number of flowers $plant^{-1}$ (59.0), flower yield $plant^{-1}$ (149.39 g), followed by GA_3 @ 200 ppm (49.80 and 106.28 g) in chrysanthemum (*Dendranthema grandiflora* L.) cv. Vasantika.

Parmar *et al*. (2015) [34] experimented on effect of GA_3 and CCC on flower yield of dutch rose (*Rosa hybrida* Linn.) cv. Passion under polyhouse condition. Among different treatments GA_3 @ 200 ppm (140.33) produced maximum number of flowers/ sq. m. and produced more number of flowers/ hectare (14.03 lakh flowers) comparatively and also recorded (28.07) maximum number of flowers/plants.

Sharma and Joshi (2015) [46] investigated the effect of foliar spray of plant growth regulators *viz*., GA_3 (150 ppm and 250 ppm) and NAA (25 ppm and 50 ppm) on floral parameters of three china aster cultivars and they concluded that GA_3 @ 250 ppm showed maximum (55.78) number of flowers/plants

Anuradha *et al*. (2017) [2] concluded that the maximum flower yield $plant^{-1}$ was recorded in GA_3 at 200 ppm (397.25 g) than the control (165.50) in African marigold cv. Culcatta Orange.

Mishra *et al*. (2018) [29] concluded that three sprays of 100 ppm GA_3 @ (30, 40 & 50 DAT) recorded maximum number of flowers $plant^{-1}$ (77.04) while minimum number of flowers $plant^{-1}$ was recorded under control (61.81) in china aster (*Callistephus chinensis* L. NEES.)

Singh *et al*. (2018) [53] reported that maximum number of flowers $plant^{-1}$ (69.53) was recorded with foliar application of GA_3 @ 150 ppm in chrysanthemum (*Dendranthema grandiflora* Ramat) cv. Birbal Sahni.

Conclusion

Thus, from the present review concluded that use of GA_3 helps in better growth, development, side-shoot production, earliness, flowering and post-harvest life of cut-flowers and loose flower. Gibberellic Acid (GA_3) has proven as a valuable production tools that can enhance product quality and marketability.

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