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Role of Plant Growth Regulator "Gibberellins" in Vegetable Production: An Overview

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ABSTRACT

This review provides a comprehensive overview of the basic and applied aspects of gibberellins (GAs) and its application in the regulation of growth and development of different vegetable crops. Plant growth regulators are the substances which are synthesized in particular cells and are transferred to other cells where in extremely small quantities influence the developmental processes. The GAs are an important group of phytohormones which exert various effects on promotion and regulation of plant growth. Gibberellic acid (GA3) is a type of GA plant hormone, with great economical and industrial importance. GAs affect stem elongation, germination, elimination of dormancy, flowering, sex expression, flooding responses, enzyme induction and leaf and fruit senescence. Foliar application of GA3 has been shown to change the physiological and developmental processes, including plant vegetative growth, sex expression, yield, and yield components in different vegetable crops. This study aims to reveal the impacts of GAs on different aspect of crop production with special emphasis on vegetable crops. Furthermore, appropriate concentration for the applications of GA3 in vegetable crops would be discussed so that the use of such regulators is environmentally and toxicologically safe for both plants and the consumers.

Introduction

Vegetables have been part of the human diet from ancient time. They are important as the world food source yet. Variety of plant species and cultural conditions embraced limits each one's economic potential for the use of growth regulators. This can be used in vegetables to improve germination, crop uniformity, ease of harvesting and storage. Application of growth regulators regulates the physiological activity of vegetable crops finally enhance the vegetable production.

Plant growth regulators are natural or synthetic substances that influence the growth and development of vegetable crops. They control one or more specific biochemical and physiological functions probably by their influence on gene and enzyme activities (Olaiya et al., 2013). An organic chemical substance other than nutrients which are active in low concentration in promoting, inhibiting or otherwise modifying growth and development may be called growth regulators. Prajapati et al. (2015) stated that although, photosynthesis supplies the carbon and respiration supplies the energy for plant growth, a group of chemicals produced by plants known as plant growth regulator (PGR) control the growth and development of plant. Other terms used for PGR are phyto-hormone or plant hormone or bio–regulator or growth hormone. Phytohormones are organic substances produced naturally by the plants in minute / low concentration. The concentration of hormones required for the plant response is very low (10^{-9} to 10^{-5} M),

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comparing with the requirement of mineral and vitamin for plants as plant hormones are not nutrient, but chemicals that in small amounts promote and influence the growth, development, and differentiation of cells and tissues. All plant hormones are plant growth regulators but all PGRs are not phytohormones.

There are five types of PGRs such as auxins, GAs, cytokinins, abscisic acid and ethylene (Singh, 2011). Among this, auxins, GAs, cytokinins are growth promoting hormones and abscisic acid and ethylene are growth inhibiting hormones.

GAs are the second important growth hormones found in plants. In 1926, Japanese scientist Eiichi Kurosawa identified that foolish seedling disease was caused by the fungus *Gibberella fujikuroi* (Stowe et al., 1957). Most abundant gibberellin present in *G. Fujikuro* was GA3 known as gibberellic acid (Curtis and Cross 1954). They are endogenous or natural hormones that can be produced by some tissues in plants (Meena, 2015). The physiological processes like growth and development of the plant, enhancement of the fruit color, flower differentiation, fruit ripening, tissue growth, etc. are controlled by the appropriate application of GAs (Prajapati et al., 2015). The objective of the present study was to highlight the physiological effects and practical application of GAs in vegetable crops and to emphasis their role and the use of appropriate concentration of GAs in various vegetable crops.

Biosynthesis of GAs

GAs are synthesized by the action of terpene cyclases, cytochrome P450 mono-oxygenases and 2-oxoglutarate-dependent dioxygenases localized, respectively, in plastids, the endomembrane system and the cytosol (Yamaguchi 2008). GAs are synthesized in actively growing organs on plants like young leaves, roots, developing seeds (developing endosperm) and fruits (Heden and Thomas, 2012).

Function of GAs

The following items are the most important roles of GAs in plant: i) Seed germination and seedling growth ii) Breaking of seed dormancy iii) Production of parthenocarpic fruit iv) Induction of fruit enlargement v) Promotion of cell division and stem elongation vi) Promotion of flowering in long day plants vii) Regulation of sex expression in some plants like cucurbits viii) Tolerance to chilling ix) Prevention of genetic dwarfism.

Effects of GA3 on seed germination

Certain light sensitive seeds like lettuce show poor germination in dark. Germination starts vigorously when exposed to light or red light. The requirement of light is overcome if the seeds are treated with GA3 in darkness. GA activates germination of seeds which otherwise require cold (stratification) or light to induce germination.

Soaking of seeds for 24 h in GA3 at 10-40 ppm and 0.5 ppm improves germination in brinjal and tomato respectively. A study was conducted on Arka Anamika variety of okra having 6 treatments (T1: seed priming with tap water, T2: seed priming with 200 ppm NAA solution, T3: seed priming with 10% PEG-200 solution, T4: seed priming with 200 ppm GA3 solution, T5: seed priming with 5% trichoderma solution and T6 no priming) and it revealed that seed priming with 200 ppm GA3 was found to be best in terms of maximum seed germination, seed vigor index, mean germination rate (Lamichhane et al., 2021). Soaking of pea seeds in GA3 (10 ppm) for 12 hours give the highest germination. Pre-soaking of eggplant seeds in GA3 at 750 mg/L accelerated the seed germination process and the seedling emergence, and led to an increase in seedling height up to 30 days (Rodrigues and Ono, 2017). The effects of GA3 on seed germination of vegetable crops are summarized in Table 1.

Table 1. Effect of GA3 on seed germination of various vegetable crops

Crops	Concentration	Method of Application	Effects on germination	References
Eggplant	750 mg/L	Presoaking of seed	Accelerated seed germination process, seedling emergence and increased seedling height up to 30 days	(Rodrigues and Ono, 2017)
Pea	10 ppm	Seed soaking	Highest germination rate	(Bahadur and Singh, 2011)
Okra	200 ppm	Seed priming	Maximum seed germination, seed vigor index, mean germination rate	(Lamichhane et al., 2021)
Tomato	0.5 ppm	Soaking	Enhances germination	(Bahadur and Singh, 2011)

Effects of GA3 on seed dormancy

In temperate region the buds formed in autumn remain dormant until next spring due to severe cold, this dormancy of buds can be broken by GAs treatment. GA3 is used to break the seed dormancy of freshly harvested seeds in many vegetable crops such as potato and lettuce. Soaking the tuber in solution containing 5-10 ppm GA3 for 10-20 minutes can be used to break the dormancy of potato (Bryan, 1989). Late application of GA3 leads for induction of high percentage of sprouted tubers prior to harvest and also lead to increase physiological age of tubers (Alexopoulos et al., 2006). Lizarazo-peña et al. (2020) have used of GA3 and 6-benzylaminopurine (6BAP) (0, 25, and 50 mg/L) and the immersion time (10, 60, and 120 min) and found that application of GA3 and immersion time had an effect on dormancy breakage; the treatments with 25 mg/L GA3 and 60 min of immersion were enough to reduce dormancy compared to untreated

Effects of GA3 on growth and development

GAs can influence growth and development of various vegetable crops. GA stimulates stem elongation and increase dry matter accumulation in plants. Haulm application of GA3 at 750 or 1000 ppm rates and dipping treatments of 40 or 50 ppm for 24 hours after harvest resulted significant increase in dry matter content in potato (Chindi and Tsegaw, 2019). Different concentrations of NAA at 25, 50, 75 and 100 ppm and GA3 20, 40, 60 and 80 ppm were sprayed on the plants of tomato and it was reported that maximum plant height was observed by using NAA at 100 ppm and GA3 at 80 ppm (Prasad, 2013). Foliar application of 15 ppm GA3 followed by 25 ppm NAA produced superior growth of tomato in Variety 'Sel-7' followed by 'Pusa Ruby'(Gurjar et al., 2018). Singh et al. (2019) reported that maximum plant height, maximum number of primary and secondary branches was observed with the application of GA3 at 30 ppm in tomato. The spray application of 10−5 M GA3 exerted a growth-promoting effect on unstressed seedlings and was successful in increasing salinity tolerance of tomato seedlings up to 25 mM NaCl (Miceli et al., 2020). Dalai et al. (2020) reported that GA3 at 200 ppm + NAA at 100 ppm gave highest vine length/plant (cm), no. of leaves/ plant in cucumber. Application of GA3 10 µg/mL significantly increased epicotyls length, plant height during flowering in cucumber on pre soaking of cucumber seed in different concentrations of GAs (0, 5µg/mL, 10 µg/mL and 20 µg/mL) (Sanusi, 2019). Sandra et al. (2015) reported that NAA at 200 ppm, GA3at 50 ppm and etheral at 50 ppm were very effective for enhancing vegetative growth in bitter gourd. GA3 (100 ppm) sprayed at 45 and 60 days after planting were more effective and showed a linear relationship in plant growth in onion (Ali et al., 2015). Dhakar and Singh (2015) observed that GA3 at 150 ppm gave highest plant height, number of leaves per plant, length of leaf, number of branches per plant and stem diameter as compared to GA3 at 100 ppm and 200 ppm and minimum recorded in control in brinjal. The highest plant height, number of leaves per plant, leaf length, leaf breadth at the time of harvest were recorded from planting of cauliflower on 15 November by use of IAA 10 ppm with GA3 70 ppm (Rahman, 2013). Chauasiy (2014) reported that NAA at 80 ppm and GA3 at 60 ppm gave highest plant height, number of leaves per plant, plant spreading, and stem diameter. GA3 at 50 ppm gave maximum plant height, minimum number of days taken to 50% curd initiation, minimum number of days taken to 50% marketable curd size in cauliflower (Kaur and Mal, 2018). For growth attributes, GA3 at 60 ppm gave maximum plant height, minimum number of days taken to 50% marketable curd size (Singh and Saxena, 2020). With the application of four concentrations of GA3 (0, 20, 40 and 60 ppm) on two cabbage cultivars (Asha and Red), maximum stem length, number of leaves per plant, and root length was recorded for cultivar cabbage red with the application of 60ppm of GA3 (Dev et al., 2020).

Ravat (2015) recorded that GA3 at 50 ppm gave maximum plant height, number of leaves, per plant number of nodes on okra. Maximum value for the plant height and plant spread was observed by the treatment 120 ppm NAA followed by GA3 60 ppm applied as aqueous spray twice at 28 and 45 days after transplanting of okra (Mandingbam et al., 2020). Use of GA3 at 20 and 60 ppm treated sweet pepper plants gave maximum plant height (Raj et al., 2016). Application of GA3 at 150 ppm in sweet pepper gave superior over other treatments in terms of plant height at 30 DAT, 60 DAT and at harvest, and no of branches/plant at 30 DAT (Singh and Singh, 2021).

Noor et al. (2017) reported that six levels of GA3, viz. 0, 30, 50, 70, 90 and 110 ppm sprayed at 18 days after sowing significantly increased plant height than the control plants in French bean. GA3 with 30 to 90 ppm significantly increased number of branches and leaves, leaf area, leaf area index (LAI), leaf dry matter and total dry matter at different growth stages. Exogenous application of GA3 7 days in cowpea after emergence at 30, 60 or 90 mg/L significantly increased plant height, first node height, leaf area, leaf number/plant, nodulation, and dry matter accumulation (Emonger, 2007). The effects of GA3 on seed germination of vegetable crops are summarized in Table 2.

potato tubers.

Table 2. Effect of GA3 on growth and development of various vegetables crops

Crop	Concentration	Method of Application	Effects on Growth	References
Potato	750-1000 ppm + 40 0r 50ppm	Haulm application followed by dipping after harvest	increase dry matter content	(Chindi and Tsegaw, 2019)
Tomato	80 ppm GA3 + 100 ppm NAA 15 ppm GA3+ 25 ppm NAA 30 ppm	Foliar spray Foliar spray Foliar spray	increase plant height increase height and number of branches increase plant height and number of primary and secondary branch	(Prasad, 2013) (Gurjar et al., 2018) (Singh et al., 2019)
Cucumber	200 ppm GA3+ 100ppm NAA 10 μg/ml	Foliar spray Pre soaking of seed	increases vine length and number of leaves per plant increase epicotyls and vine length	(Dalai et al., 2020) (Sanusi, 2019)
Brinjal	150 ppm	Foliar spray	increase plant height, number of leaves and branches per plant, length of leaf and stem diameter	(Dhakar and Singh, 2015)
Cauliflower	50-60 ppm IAA 10 ppm + GA3 70 ppm or NAA 80 ppm + GA3 60 ppm	Foliar spray Foliar spray	increase plant height, earliness to 50% curd initiation and marketable curd size increase plant height, number of leaves per plant, leaf length and breadth, plant spreading and stem diameter	(Kaur and Mal, 2018; Singh and Saxena, 2020) (Chauasiy, 2014; Rahman, 2013)
Cabbage	60 ppm	Foliar spray	increase stem length, number of leaves per plant, root length,	(Dev et al., 2020)
Okra	120 ppm NAA + GA3 60 ppm 50 ppm	Aqueous spray Foliar spray	increase plant height and plant spread increase plant height, number of leaves, per plant number of nodes	(Mandingbam et al., 2020) (Ravat , 2015)
French bean	30-70 ppm	Foliar spray	increase number of branches and leaves, leaf area, leaf area index (LAI), leaf and total dry matter	(Noor et al., 2017)
Sweet Pepper	150 ppm 20 ppm or 60 ppm	Foliar spray	increase plant height at 30 DAT, 60 DAT and at harvest, no of branches/plant increase plant height	(Singh and Singh, 2021) (Raj et al., 2016)
Cowpea	30, 60 or 90 mg/l	Foliar spray	increase plant height, first node height, leaf area, leaf number/plant, nodulation, dry matter accumulation	(Emonger, 2007)

Effects of GA3 on flowering

GAs treatment induces bolting and activates flowering in long day plants. Application of GA at 50 mg/L to young leaves of non-flowering varieties of potato, when floral buds had just formed, resulted in flower induction in all varieties. Root dipping of one month old egg plant seedlings in ascorbic acid, GA3, IAA and thiourea advances the flowering by 4-5 days. Dhage et al. (2011) revealed by the application of GA3 at 150 ppm, minimum days are required for first flowering and minimum days were required for first harvesting.

Effects of GA3 on sex expression

Treatment with growth regulators has been found to change sex expression in cucurbits, okra and pepper. Female inducing hormones are auxin and ethylene whereas male inducing hormone is GA3. GA3 have been used for maintenance of gynoecious lines in cucurbits. Sanusi (2019) reported that on presoaking of cucumber seed in GA3 10 μg/mL significantly decreased staminate flower number and increased pistillate flower number. Sandra et al. (2015) reported that NAA at 200 ppm, GA3 at 50 ppm and etheral at 50 ppm were very effective for modification of sex expressions in bitter gourd. GA3 (25 ppm) applied at two-true-leaf stage and repeated the spray at 4-true-leaf stage are found most effective in increasing number of female flowers in watermelon. Hidayatullah et al. (2012) revealed that GA3 at 30 ppm increased production of pistillate flowers as compared to control in bottle gourd. Application of 40 ppm GA3 at 2-4 leaf stage was found most effective in terms of number of female flowers per vine of bottle gourd over control and other treatments (Wamiq et al., 2020). Ansari and Chowdhary (2018) suggested that seed soaking of bottle gourd in 0.5% borax (0.05% boron) solution for 12 hours and spraying of GA 100 ppm at two and four true leaf stages resulted maximum number of female flowers as compared to control and other treatments. Application of GA3 at the time of flowering elongates the stigmatic position of flower and avoids selfing in tomato. Such lines can be used as female line in hybrid seed production program (Meena, 2015). The effects of GA3 on sex expression of vegetable crops are summarized in Table 3.

Table 3. Effect of GA3 on Sex expression of various vegetables crops

Crop	Concentration	Method of Application	Sex Expression Affected	References
Cucumber	10 µg/mL	Pre-soaking of seed	decrease number of staminate flower and increase pistillate flower	(Sanusi, 2019)
Bottle gourd	30-40 ppm	Foliar spray	increase production of pistillate flowers	(Hidayatullah et al., 2012; Wamiq et al., 2020)
	0.5% borax+ 100 ppm GA3	Seed soaking followed by foliar spray	increase number of female flowers	(Ansari and Chowdhary, 2018)
Bitter gourd	50 ppm	Foliar spray	increase number of female flowers	(Sandra et al., 2015)

Effects of GA3 on yield and yield attributing characteristics

Foliar sprays with GA3 at 30–50 days after transplantation suppressed the growth of pre-formed tubers for about 10 days after application and promoted the induction of new tubers, leading to a higher number of tubers per plant in comparison with the untreated control and earlier sprouting and a higher number of sprouted buds per tuber were observed for the treatments in which GA was applied within 20 days of harvest (Alexopoulos et al., 2017). On using five levels of GA3 (0, 250,500, 750 and 1000 ppm) as haulm application a week prior to haulm destruction and five levels of GA3 (10, 20, 30, 40 and 50 ppm) as a dipping treatments immediately after harvest for 24 hours, haulm application of GA3 at 750 or 1000 ppm rates and dipping treatments of 40 or 50 ppm resulted in high total, marketable tuber yield, and tuber specific gravity (Chindi and Tsegaw, 2019). With use of GA3 and 6-benzylaminopurine (6-BAP) (0, 25, and 50 mg/L) and the immersion time (10, 60, and 120 min), GA3 at 25 mg/L increased tuber weight loss, generated sprouts with higher weight, higher length and growth rate, and lowers dry matter content, and it increased secondary sprouting in comparison with untreated tubers (Lizarazo-peña et al., 2020). Foliar application of 15 ppm GA3 followed by 25 ppm NAA produced superior yield attributing characters and ultimately fruit yield of tomato in variety 'Sel.-7' followed by 'Pusa Ruby'(Gurjar et al., 2018). Singh et al. (2019) used three levels of each growth regulator i.e. GA3 at 10, 20, 30 ppm, NAA at 20, 30, 40 ppm and 2,4 -D at 2.5, 5.0, 7.5 ppm and reported maximum fruit per plant, fruit yield per plant, and fruit yield per hectare with the application of GA3 at 30 ppm.

Total yield and fruit quality were significantly higher in F1 hybrid cucumber cv. 'KUK-9' under protected cultivation with 2.5 g/L potassium nitrate and 0.01 g/L GA3 spray over other treatment (Pal et al., 2016). Cucumber grown in poly house condition with application of 100 ppm GA3 produced maximum fruit yield whereas minimum yield in control treatment (Kadi et al., 2018). Dalai et al. (2020) reported that maximum number of fruits per plant was obtained with maximum fruit width and length in cucumber with application of GA3 at 200 ppm + NAA at 100 ppm. A study was conducted in Bangladesh with two growing conditions (control and foliar application of GA3); and four cucumber varieties (Shohag, Sarothi, Sufala-1 and Shila) and replicated thrice and it was reported that under foliar application of GA3, the maximum fruit yield was recorded in Sufala-1, whereas minimum fruit yield was recorded in Sarothi. Moderate fruit yield was recorded from rest of the two varieties in Shila and Shohag, respectively over control (Rahman et al., 2020). Hidayatullah et al. (2012) revealed that GA3 at 30 ppm gave maximum no. of fruits and fruit weight as compared to control in bottle gourd. Application of 40 ppm GA3 at 2- 4 leaf stage was found most effective in terms of flowers per vine, fruit per plant, fruit yield per plant, fruit yield per hectare over control and other treatment in bottle gourd (Wamiq et al ., 2020). Ansari and Chowdhary (2018) used two concentrations of each GA3, ethrel and maleic hydrazide (50 ppm and 100 ppm) for foliar spray at 2 and 4 true leaf stages along with the 12 hours seed soaking by boron (0.05%) in combination with each level of PGRs and reported that seed soaking in 0.5% borax (0.05% boron) solution for 12 hours and spraying of ethrel 100 ppm or GA 100 ppm at two and four true leaf stages resulted early maturity, highest fruit length, fruit diameter, average fruit weight, yield/vine, and yield/ha on bottle gourd.

A study on four levels of sulphur viz., 0 (control), 15, 30 and 45 kg/ha and four concentrations of GA3 viz., 0 (control), 50, 75, 100 ppm was conducted and findings revealed that treatment combination of sulphur at 30 kg/ha and GA3at 100 ppm was more suitable for higher yield and quality of onion than the rest of the treatment combinations (Rashid, 2010). Netam and Sharma (2014) studied that GA3 at 10 ppm and NAA at 20 ppm gave maximum, number of fruits, fresh fruit weight in brinjal. Bhattarai et al.

(2021) used three different concentrations of NAA viz. (20, 40 and 60 ppm), three different concentrations of GA3 (25, 50 and 75 ppm) and six different concentration of micronutrients Boron (0.1%, 0.2% and 0.3%) and Zinc (0.1%, 0.2% and 0.3%) over control and found that yield parameters of brinjal like number of fruits per plant, fruit weight, fruit yield per plant were found to be significantly superior at 25 ppm of GA3.

Foliar spray of GA3 at 50 mg/L in cauliflower gave better results for diameter of curd, net weight of curd, curd yield and required minimum days to 50% marketable curd (Sitapara, 2011). Singh and Saxena (2020) concluded that GA3 at 60 ppm increases yield attributing characters such as curd diameter, gross yield, net yield, yield per plot, and yield per hectare in cauliflower. GA3 at 50 ppm gave superior yield and yield attributing characters such as maximum curd diameter, individual curd weight, yield per plot, and yield per hectare (Kaur and Mal, 2018). Chauasiy (2014) reported that NAA 80 ppm and GA3 60 ppm gave highest weight of cabbage head, and head yield as compared to all the other treatments and control. Islam (2017) used four different levels of GA3 such as 0, 90, 120 and 150 ppm on cabbage and reported highest marketable yield and diameter of head was recorded by using GA3 at 120 ppm while minimum in GA 0 ppm. Reza et al. (2015) used four levels of GA3 i.e. 0, 25, 50 and 75 ppm on broccoli (*Brassica oleracea* var. *Italica*) and revealed that maximum main curd length, main curd diameter, main curd weight and maximum yield was found from the application of 50 ppm GA while the minimum from control. Foliar application of GA3 50 mg/L treatment at 20 and 40 days after transplanting of broccoli was found most effective treatment with regards to yield and quality parameters as well as economics in broccoli cv. Pusa KTS -1 (Barad et al., 2020). Rai et al. (2020) used different levels of concentrations (25, 50 and 75 ppm) of foliar application of GA3 and Kinetin along with control after 20 days of transplanting, at an interval of two days and found that combination of both GA3 25 ppm and Kinetin 50 ppm proves to be most effective on the yield and quality of the broccoli among rest of the treatments.

Foliar application of 50 ppm GA3 increased the growth and yield contributing characteristics and ultimately increased the yield in okra (Mehraj et al., 2015). Gaikwad et al. (2021) used three growth regulators viz. gibberellic acid (25, 50, 50 ppm), naphthalene acetic acid (25, 50, 75 ppm) and indole-3-butyric acid (25, 50, 75 ppm) and reported that fruit yield of okra improved with the foliar application of GA3 followed by NAA, IBA compared to control. Application of GA3 at 150 ppm gave superior over other treatments in terms of fruit length, fresh weight of 10 fruits of sweet pepper, number of fruits/plant, fruit yield/plant, and fruit yield/ha in chilly (Singh and Singh, 2021).

Singh (2016) reported that GA3 at 200 ppm gave significantly increased number of pods, length of pod and 100 seed weight in garden pea. Number of dry pods /plant, number of seeds/pod, 1000 seed weight, fresh fodder, fresh pod, dry seed yield, and harvest index significantly increased with GA3 (30-70 ppm) sprayed at 18 days after sowing in French bean (Noor et al., 2017). The effects of GA3 on yield and yield attributing characteristics of vegetable crops are summarized in Table 4.

Table 4. Effect of GA3 on yield and yield attributing characteristics of various vegetables crops

Crop	Concentration	Method of Application	Yield Attributing Characteristics Affected	References
Potato	750-1000 ppm + 40 or 50 ppm	haulm application followed by dipping after harvest	increase total marketable tuber yield and tuber specific gravity	(Chindi and Tsegaw, 2019)
	25 mg/L	Soaking of tuber	increase tuber weight loss, generate sprouts with higher weight, length and growth rate, and lowers dry matter content.	(Lizarazo-peña et al., 2020).
Tomato	30 ppm	Foliar spray	increase fruit per plant, fruit yield per plant and fruit yield	(Singh et al., 2019)
	15 ppm GA3+ 25 ppm NAA	Foliar spray	superior yield attributing characters and increase yield	Gurjar et al., 2018)
Cucumber	200 ppm GA3+ 100ppm NAA	Foliar spray	increases fruit width and length	(Dalai et al., 2020)
	10 μg/ml	Presoaking of seed	increase epicotyls and vine length	(Sanusi, 2019)
	100 ppm	Foliar spray	increase fruit yield	(Kadi et al., 2018).
Bottle gourd	30 ppm	Foliar spray	increase number of fruits and fruit weight	(Hidayatullah et al., 2012)
	40 ppm	Foliar spray	increase flowers number per vine, fruit per plant, fruit yield per plant, fruit yield	(Wamiq et al., 2020)
	0.5% borax+ 100 ppm GA3	Seed soaking followed by foliar spray	result early maturity, increase fruit length, fruit diameter, average fruit weight, yield/vine and yield/ha	(Ansari and Chowdhary, 2018)

Crop	Concentration	Method of Application	Yield Attributing Characteristics Affected	References
Brinjal	GA3 10 ppm + NAA 20 ppm	Foliar spray	increase number of fruits, fresh fruit weight	(Netam and Sharma, 2014)
	25 ppm	Foliar spray	number of fruits per plant, fruit weight, fruit yield per plant	(Bhattarai et al., 2021)
Cauliflower	50-60 ppm	Foliar spray	curd diameter, gross yield, net yield, yield per plot and yield per hectare	(Kaur and Mal, 2018; Singh and Saxena, 2020)
	50 mg/l	Foliar spray	increase curd diameter, curd net weight of and yield	(Sitapara, 2011).
Cabbage	120 ppm	Foliar spray	increase marketable yield and diameter of head	(Islam, 2017)
	NAA 80 ppm + GA3 60 ppm	Foliar spray	increase weight of cabbage head, and head yield	(Chauasiy, 2014)
Broccoli	50 ppm	Foliar spray	increase main curd length, main curd diameter, main curd weight and yield	(Reza et al., 2015)
	50 mg/l or GA3 25 ppm + Kinetin 50 ppm	Foliar spray	increase yield and other quality parameters	(Barad et al., 2020; Rai et al., 2020)
Okra	50 ppm	Foliar spray	increase yield contributing characteristics and ultimately increase yield	(Mehraj et al., 2015)
	75 ppm	Foliar spray	fruit yield of okra	(Gaikwad et al., 2021)
Sweet pepper	150 ppm	Foliar spray	increase fruit length, fresh weight of 10 fruits of chilli, number of fruits/plant, fruit yield/plant, fruit yield/ha	(Singh and Singh, 2021)
French bean	30-70 ppm	Foliar spray at 18 days after sowing	increase number of dry pods /plant, number of seeds/pod, 1000 seed weight, fresh fodder, fresh pod, dry seed yield and harvest index	(Noor et al., 2017)
Garden pea	200 ppm	Foliar spray	increase number of pods, length of pod and 100 seed weight	(Singh, 2016)

Effects of GA3 on parthenocarpy

Parthenocarpy is the phenomenon in which an unfertilized ovary is develops into a seedless fruit that can be induced artificially through hormonal application. GA3 at 200 mg/L treatment induced seedless fruit in tomato applied at anthesis and ovaries were collected 20 days after hormone application.

Effects of GA on quality traits of vegetable crops

Quality traits such as TSS, Acidity, Vitamine C, and total Sugar (reducing sugar and non-reducing sugar) in vegetable crops could be obtained by the use of plant growth regulators. Foliar application of GA3 are effective for obtaining maximum TSS and total sugar. Combined application of NAA (25 ppm) and GA3 (40 ppm) was more effective than their individual application in terms of TSS and vitamin C content, respectively (Saha et al., 2009). Netam and Sharma (2014) reported that GA3 at 10 ppm and NAA at 20 ppm gave highest total soluble solid in brinjal over control and other treatment. Significantly higher total soluble solids, ascorbic acid content and TSS/acid ratio and lower acidity percentage was obtained with application of GA3 at 50 ppm compared to 25 ppm GA3 (Meena et al. 2008). Vitamin C content at harvest was superior with application of GA3 at 150 ppm over other treatment in chilly (Singh and Singh, 2021).

Conclusion

Plant growth regulator has an immense potential in vegetable crop production in order to increase the yield and quality of vegetables, synchronization in flowering, earliness, cold and high temperature fruit setting, sex modification, increase post-harvest life and resistance to biotic and abiotic stresses of vegetables with the aim of fulfilling the requirements of food supply in general. It is concluded that the application of GAs has a considerable impact on the growth, flowering, fruiting, and fruit yield of different vegetable crops. It is obvious that changes in the level of endogenous hormones due to biotic and abiotic stresses alter the crop growth and any sort of manipulation including exogenous application of growth substances like GA3 would help for crop yield improvement. However, more research is still needed to develop simple, economical and technical viable production system of growth regulators and it should be recognized as more than academic curiosities.

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