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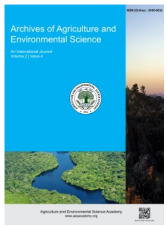

REVIEW ARTICLE

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Effects of plant growth regulators on growth, flowering, fruiting and fruit yield of cucumber (*Cucumis sativus* L.): A review

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ABSTRACT

This review provides a comprehensive overview of the basic and applied aspects of different plant growth regulators in the regulation of growth and development of cucumber plants. The study is completely based on the use of secondary sources of data; related journals, government institutes, and relevant reports. Foliar application of PGRs has been shown to change the physiological and developmental processes, including plant vegetative growth, sex expression, yield, and yield components in cucumber. There are basically two types of growth regulators; plant growth promoters such as auxin, gibberellins, cytokinins, maleic hydrazide, ethephon, etc. and plant growth inhibitors such as ethylene, abscisic acids, dormins, etc. The combined use of auxins and gibberellins result in increased secondary growth. Maleic hydrazide (MH) along with Ethephon at 100 ppm each increases the number of nodes and primary branches. Ethrel at 300-400 ppm retards the secondary development and increase femaleness, and at 200-300 ppm make fruit surface smooth. Silver nitrate ($AgNO_3$) at 400 ppm enhances the maleness in cucumber. Application of Ethephon at 300 ppm reduces the harvesting time of the fruit. Salicylic acid (at 2 doses of 0.07 mm/l + 0.18 mm/l) increases chlorophyll content and its exogenous application increases the fruit yield. Maleic Hydrazide (MH) alone at 100 ppm increases the femaleness, inhibits apical growth at 50-100 ppm, and increases fruit size at 200 ppm. Therefore, various auxin [indole-3-acetic acid (IAA), NAA], auxin transport inhibitor (TIBA), cytokinins (KIN), gibberellin [gibberellic acid (GA3)], ABA, ethylene [(2-chloroethylphosphonic acid (ethrel; ethephon; CEPA)] and growth retardant (MH) have been applied to control the vegetative growth and to maximize yield of cucumber. Numerous obstacles have hindered the quality cucumber production in Nepal; like environmental stresses, biotic and abiotic constraints, pest and disease outbreaks, and many others. The use of exogenous plant growth regulators has been crucial to Nepali cucumber producers as plant growth regulators has hasty effect on vegetative as well as the quality yield of plants. This study aims to reveal the suitable concentrations for the applications of growth regulators so that the use of such regulators is environmentally and toxicologically safe for both plants and the consumers.

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INTRODUCTION

Vegetables are the good source of human diet as they are rich in vitamins and minerals and help to fulfill our nutritional requirements. They are naturally good and can help us to keep healthy by protecting against some diseases. Different crops have different health, economic, social, biological, and religious significance. Cucumber (*Cucumis sativus*), an annual trailing vine vegetable belonging to Cucurbitaceae family, is the most widely grown vegetable of the family after watermelon. The demand and supply for cucumber has been expeditiously increased in the last few years and now it is grown throughout the world using fields or greenhouse culture. It has a diploid chromosome number of 14, 2n= 14 (Kadi *et al.*, 2018). Although it is very watery, with little flavor and not very nutritious, it is a common ingredients of salads and pickles, being valued primarily for its crisp texture and juiciness. The seeds are extremely enriched with nutritive compounds; protein (33.8%), fat (45.2%), carbohydrates (10.3%), and crude fibers (2.0%) and the seed oil consist of four chief fatty acids; linoleic acid (61.6%), oleic acid (15.7%), stearic acid (11.1%), and palmitic acid (10.7%) as described by Mariod *et al.* (2017). The fruits are extremely nutritive and consist of 95% water, extremely small calories (about 15 calories per cup) reported by Mukherjee *et al.* (2013). The fruit also consists of calcium (20mg/100g), iron (0.7mg/100g), thiamin (0.3mg/100g), niacin (0.01mg/100gm) and some natural antioxidants that reduce chronic diseases (Trichopoulou *et al.*, 2000; Baset Mia *et al.*, 2014). It is often applied in cosmetics, beauty, and sometimes in case of burns and skin complications since it contains high percentage of water and lactic acid (~7-8% w/w) which acts as detoxifying agent (Sotiroudis *et al.*, 2010). It is very rich in antioxidants and vitamin K and C (Jyoti *et al.*, 2016). The major problem is maleness in cucumber which greatly decrease the fruit yield (Singh *et al.*, 2015). Other problems include shape distortion, untimed maturity, fruit drop, late flowering, early senescence, and so on which can be solved by the recommended dose of plant growth regulators. With the consistent growing awareness among the Nepalese for organic foods, such as cucumber, numerous scopes of organic farming are also surging. People are nowadays better concerned about what they eat and how they are produced or processed (Khanal, 2020). For this reason, healthy concentrations of plant growth regulators should be applied.

Plant growth regulators, commonly known as phytohormones, are those chemical compounds that control all aspects of growth and development within the plants. There are five major classical phytohormones which consist of more than 20 types of PGRs; they are auxin, cytokinins, gibberellins, abscisic acid, and ethylene. In addition, cucumber also contains a diverse variety of biologically active, non-nutritive compounds regarded as phytochemicals like alkaloids, flavonoids, tannins, phlobatannins, steroids, saponins and many others. 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 plant growth regulators (Prajapati *et al.*, 2015). It also control vegetative growth of plant and helps to increase the plant population per area (Latimer, 2019). The plant regulators have positive role on growth, flowering, fruiting, and the fruit yield of cucumber. In fact, the application of growth regulators enhance the production of cucumber including other vegetables and fruits in respect of superior quality and better growth, which increase interests between the scientists and farmers for commercial use of growth regulators. Although cucumber is grown extensively in Nepal, the majority of the farmers are still unknown about the proper use of plant growth regulators and very limited research has been carried out to date regarding the improvement of the plants with the application of PGR. The producers need to know about the proper dose of PGR application as per the recommendation of experts to increase the production, quality, and yield. Therefore, this study was carried out with main objective to understand the role of plant growth regulators on growth pattern, fruiting, and fruit yield of cucumber, to understand the effective plant growth regulators on fruiting and flowering (maleness and femaleness) of cucumber and to study the interactions between different hormones on growth, fruiting, and yield of cucumber.

METHODOLOGY

This study is based on the secondary sources of information. This paper is based on the review of different publications. Pieces of Literature were collected from different Journal articles, Government institutes and other relevant reports were studied and the major findings were evaluated and summarized.

Climatic requirement for cucumber cultivation

Cucumbers are cultivated either in fields or green houses. Field cultivated cucumbers are usually started as seeds and may be mechanically or hand planted. The plants are typically trained and supported to grow on poles or trellises to keep the fruit suspended. Contrary to field grown, greenhouse cucumbers are generally cultivated as transplants. Such cucumbers have vigorously growing large leaves and need close monitoring of nutrients to keep the plant healthy and enhance the productivity. The cucumber cultivation is favored by the climatic requirements shown in Table 1.

The cucumber grows best in a semitropical climate. It flourishes well under environment of high temperature, humidity, and light intensity and with an uninterrupted irrigations and appropriate nutrients supply. Under favorable and suitable climatic and nutritional conditions and when pests are under control, the plants grow fast and yield heavily. Under excellent environments, more fruit may initially develop, so fruit may need thinning. Plants allowed to bear too much fruit become exhausted, abort fruit, and fluctuate widely in productivity over time. On the other hand, cucumbers are very sensitive to unfavorable environments, and the slightest stress has negative impacts on their growth and fruit yield. When cucumber could not meet the criteria of these environmental requirements, the effects are seen in the growth pattern, fruiting, flowering, and fruit yield and hence the need of application of PGRs will emerge whose applications shape the growth and development of the plants in right way.

Plant growth regulators

PGRs are a wide class of substances which include plant hormones, their synthetic analogs, inhibitors of hormone

Table 1. Description of Climatic requirement for cucumber cultivation.

Parameters	Requirements
A. Temperature	
1. Night air temperature	18-20°C
2. Day air temperature	27-30°C
3. Average air temperature	15-24°C
4. Root temperature	20-23°C, 19°C*
5. Soil temperature	>15°C
B. Light	Full sun conditions, at least 8 hours of direct sunlight each day.
C. Relative humidity (RH)	
High RH	High growth
Medium RH	Reasonable growth
Low RH	growth of powdery mildew and spider mites
D. Soil Considerations	Slightly acidic, good drainage and adequate water-holding capacity, Optimum pH: 5.5-7

Note: (*): A minimum root temperature of 19°C is required; Source: (Haifa, 2018)

Table 2. Role of five major PGRs in cucumber production.

Plant Growth Regulators	Type	Examples	Functions
Auxins	+	IAA*, IBA**, NAA**, 2,4-D**, 2,4,5-T**	Favor apical dominance, cell elongation, secondary growth, flower induction, prevent premature fruit drop, delay leaf abscission, induce parthenocarpy, induce vascular differentiation
Gibberellins	+	Gibberellic acid (GA*, GA_3**, GA_7**)	Delay senescence of fruits, stem elongation, induces maleness, promotes seed germination, dormancy breaking, accelerates flowering, possesses pollencide effect
Cytokinins	+	Kinetin**, Zeatin*, TDZ**, zeatin riboside*	Promote cell division, induce cell enlargement, delays leaf senescence, inhibit apical dominance (anti-auxins), lateral shoot growth, adventitious root formation
Ethylene	-	Ethylene*, Ethepon**, Ethrel**	Induces fruit ripening, promotes abscission and senescence of leaf and flowers, break seed and bud dormancy, promote root hair formation
Dormins	-	Abscisic acid*	Induce senescence of leaves, inhibits seeds germination and development, regulate closing and opening of stomata

Note: (+): Plant growth promoters, (-): Plant growth inhibitors, (*): Endogenous hormones, (**): Exogenous plant growth regulators.

biosynthesis, and blockers of hormone receptors. The role of five different major plant growth regulators in cucumber plant is briefly presented in Table 2.

Several other plant growth regulators are identified such as morphactins, cycocel, maleic hydrazide, florigen, vernalin, brassinosteroids, etc. which influence the growth and ultimately the yield of cucumber. Brassinosteroids stimulate cell division and cell elongation, increase resistance to stresses, and inhibit root growth. Morphactins are the compounds which help on morphogenesis and modulate the expression of the plants. Florigen and Vernalin are the flowering hormones and Maleic hydrazide is a synthetic growth reductants. NAA and GA_3 are found to be more effective and are commonly used PGR by the producers.

Effect on vegetative growth

The applications of various plant growth regulators in a right proportion have a positive effect in the vegetative growth of plants. The attributes of vegetative part such as length of main vine per plant, number of primary branches per vine, intermodal distance, length and width of leaves are affected by different growth regulators. It is mainly due to energetic effect of chemical to the cell elongation and rapid cell division in apical portion of plant. Dalai *et al.* (2015) revealed experimentally that the mixed treatment of GA_3 @ 20 ppm and NAA @ 100 ppm was superior over all other treatment which produced maximum vine length of 155.28 cm per plant compared to minimum of 138.08 cm per plant and also obtained maximum branches (4.66 per plant) whereas 2.41 per plant in control treatment. Sahil (2016) and Pal *et al.* (2016) reported that exogenous applications of gibberellic acid have significant impact on growth attributes of vegetative part of cucumbers. Cell elongation is usually due to increasing malleability of cell wall, followed by hydrolysis of starch which drops water potential of cell. This resulted in the rapid vegetative growth either in terms of increase in vine length or leaf area and number of leaves which increase photosynthetic activity and resulted in cell division and cell elongation in apical part of plant (Sargent, 1965).

Additionally, Thappa *et al.* (2011) have determined that both maleic hydrazide and ethephon reduced the main stem and increased primary branches. He also reported that when MH and ethephon, each of 100ppm concentration applied together, it produced maximum number of nodes (19.97) per unit length of vine and minimum internodal distance of 5.02 cm. When 100

Table 3. Effect of different PGRs on vegetative growth of cucumber.

PGR	Dosage	Vegetative attributes affected
GA_3 + NAA	20 ppm + 100 ppm respectively	increase vine length and branches
Gibberellin	15-20 ppm	increase the length of shoot
MH + Ethephon	100 ppm each	increase number of nodes and primary branches
MH	50-100 ppm	affect cell division, inhibit apical growth
Ethrel	300-400 ppm	decrease shoot length, inhibit cell division and cell elongation
Salicylic acid	2 doses of 0.07 mm/l + 0.18 mm/l	increase chlorophylls content, stem diameter and number of leaves
IAA	10-15 mg/L	enhance seed germination

IAA: Indole-3 Acetic Acid, NAA: Naphthalene Acetic Acid, MH: Maleic hydrazide.

Table 4. Effect of different PGRs on flowering attributes of cucumber.

PGR	Dosage	Flowering attributes affected
GA_3 + NAA	50-100 ppm	Minimum sex ratio, increases no. of functional female organs
MH	450 μM/L or 100 ppm	lower sex ratio, produce more female flowers
Ethrel	1750 μM/L or 150-200 ppm	increase pistillate flower and reduce staminate flower
GA_3	15 μM/L or 10-20 ppm	suppressed male flower and produce more no. of female flowers
GA	1500-2000 ppm	produce more male flowers
Ethylene	200 ppm	enhance female sex expression
Silver Nitrate ($AgNo_3$)	400 ppm	Increase number of staminate (male) flowers
MH + Ethephon	100 ppm each	Earliness, increase sex ratio, and reduce plant expansion

Source: Summary of the above review.

ppm of maleic hydrazide was applied, maximum number of primary branches was obtained. Cell division is affected by maleic hydrazide which results in inhibition of apical growth (Greulach and Atchison, 1953). To contrary, application of ethrel is opposite to GA_3. Moreover, Thappa *et al.* (2011), Ouzounidou and Al (2008) and Rajala (2001) studied the effect of ethrel application and reported that in meristematic shoots ethrel inhibits cell division and elongation resulted in formation of shorter shoot with lowest effect on physiology and morphology. Also, application of KNO_3, $CaNO_3$, alfaton on cucumber seedling and NAA, maleic hydrazide in cucumber plants enhanced vegetative growth (Ahmad *et al.*, 2019). Sultan *et al.* (2016) reported that the pretreatment of two concentration of salicylic acid of 0.07mm and 0.18mm proved to be very beneficial for increase in chlorophyll content, diameter of stem and number of leaves. The effects of different PGRs on vegetative growth of cucumber are summarized in Table 3.

Effect on flowering

Plant growth regulators significantly contribute to early flower development and induce the femaleness or maleness in cucumber plants. Female flowers per plant and sex ratio are flowering parameters which determine the net production potential of plants. Minimum sex ratio is resulted by combined dose of GA_3 and NAA which increases functional female organ and affinity besides lowering the embryo termination in plant (Dalai *et al.*, 2020). The application of MH 450μM/l helps in lowering the sex ratio which enhanced the production of IAA hormone that increases the number of pistillate flowers. Ethrel is effective at 1750 μM/l which increase pistillate flowers per plant and decrease staminate flower. GA_3 at concentration 15μM/l suppressed the staminate flower production (Bano and Khokhar, 2009). (Sanoussi, 1970) reported that GA_3 was effective plant growth regulator which reduce requirement of number of days for 1^{st} flower formation and at 10μg/ml of GA_3, maximum number of female flowers and minimum number of male flowers was produced. Also, it was reported that most number of female flower per plant and lowest sex ratio of male female flower (3.31) was produced when GA_3@ 20mg/liter was applied (Asghar *et al.*, 1990). Furthermore, Suthar *et al.* (2007) founded that the application of 25 ppm ethrel increased the pistillate flowering and delayed staminate flowering. Also, narrow sex ratio was obtained by pruning followed by application of 25 ppm ethrel in protected condition.

Femaleness and maleness varies due to the environmental factors such as temperature, photoperiod, and nutrition or by PGRs application (MA *et al.*, 2014). NAA application are not effective to increase pistillate flowers in the winter season, especially when there is low temperature (Hikosaka and Sugiyama, 2015). In addition to that Yamasaki *et al.* (2000) reported that CS-ETR and CS-ERS mRNA are highly accumulated when endogenous hormone (ethylene) are highly produced which help in development of female flower in cucumber. He concluded that femaleness in cucumber is mainly persuaded by ethylene and auxin. Ethylene, a gaseous hormone, is a major determining compound for female sex expression where auxin acts collaterally by stimulating the ethylene production (Trebitsh *et al.*, 1987). Also, Hossain *et al.* (2006) reported that if PGRs are applied at two and four leaf stage, the critical stage for promotion or suppression of both sex, it plays an important role in alternation of sex ratio. The summary of the overall effects of growth regulators in flowering of cucumber is presented in Table 4.

Effect on fruiting

Fruit size, fruit length or fruit diameter can be increased by PGRs like TIBA, NAA, and MH (Tantasawat *et al.*, 2015). Cell division, cell elongation and differentiation are mainly due to auxin which ultimately increase fruit size (Growth, 1986). Translocation and photosynthetic activity is accelerated by the application of GA_3 which resulted in improved cell elongation, rapid cell division, and finally shortened fruit maturation period (Al-Sanoussi, 1970). When cucumber was sprayed with combined dose of GA_3 @ 200ppm and NAA @ 100ppm, the highest number of fruits per plant was obtained with maximum fruit width and length (Dalai *et al.*, 2020). At the treatment of GA_3, NAA, and its combination, Singh *et al.* (2015) founded that application of GA_3@20ppm and NAA @ 100ppm combined produced maximum number of fruit per plant (10.34) and maximum length and diameter of fruit whereas control treatment produced lowest number of fruit per plant 5.25).

Likewise, Ahmad *et al.* (2020) also reported that exogenous application of cycocel and ethrel also increase in average fruit length and weight in cucumber. Auxin level might alter by the application of MH @ 200ppm and ethephon @ 300ppm which enhance the cucumber fruit size. And the number of fruit per plant were highest when ethephon @ 300 ppm was applied which also reduces the time required for harvesting fruit (Mir, 2019). Smooth surface of fruit was expressed by ethrel at 200 ppm or 300 ppm where as NAA, GA_3 exhibited rough surface and GA_3 applied @ 200 ppm resulted maximum fruit (Kadi *et al.*, 2018). All the concentration of plant growth regulators help in the enhancement of the fruit yield per vine where as maximum fruit yield was recorded at the application of maleic hydrazide and ethephon each rate of 100ppm (Kaur *et al.*, 2016). Table 5 shows the different effects of PGRs on fruiting of the cucumber plant.

Effect on fruit yield

The application of growth regulators significantly hastened fruit development as compared with the control treatment. In the presence of PGRs, plant remain physiologically more active which helps in development of female flower of fruits, ultimately contribute to higher fruit yield in cucumber. There are various effect of GA_3, NAA, MH and their combination in fruit yield. The weight of fruit decreased as GA_3 doses decreased up to 10 ppm and fruit yield result highest per plant when NAA doses up to 150 ppm. Consequently, combined application of GA_3@ 20ppm + NAA @ 100ppm was found to be superior in fruit yield of cucumber (Dalai *et al.*, 2020). Higher concentration of ethrel and MH decreased average fruit yield. Also, the lowest and highest average fruit yield /plant was obtained by the application of ethrel @ 3800μM/l and GA_3 @ 60μM/l respectively. The highest fruit yield /plant are produced with the application of 450μM/l ethrel (Bano and Khokhar, 2009).

The combination of maleic hydrazide and ethephon each of 100 ppm gives maximum yield (11.72 ton/ha) and only 7.23 ton/ha was obtained in control treatment which is 45% less than best treatment. Whereas naphthalene acetic acid, either or in combination with others PGRs, does not give significant yield (Thappa *et al.*, 2011). In poly house condition, the application of 100 ppm GA_3 produced maximum yield of 178.67 (q/ha) whereas minimum yield (160q/ha) obtained in control treatment (Kadi *et al.*, 2018). Also, Larqué-Saavedra and Martin-Mex (2007) studied the effect of salicylic acid and reported that exogenous application of SA enhanced the fruit yield of cucumber. Similarly, Imran *et al.* (2007) founded that the delay in senescence of plant organs (leaves and flower) in reaction of SA enhanced the fruit yield of plant. The effects of different dosages of PGRs on fruit yield of cucumber are briefly shown in Table 6.

Table 5. Effect of different PGRs on fruiting attributes of cucumber.

PGR	Dosage	Fruiting attributes affected
TIBA, NAA, MH	200-400 ppm	increase fruit size, fruit length, or fruit diameter
GA_3	20-30 ppm	Accelerate translocation and photosynthesis, shorten fruit maturation period
GA_3 + NAA	200 ppm + 100 ppm respectively	Increase no. of fruits, fruit diameter and length, exhibit rough fruit surface
Cycocel + Ethrel	–	Increase weight and length of fruits
MH	200 ppm	Increase fruit size
Ethephon	300 ppm	Reduce harvesting time
Ethrel	200 ppm or 300 ppm	Make fruit surface smooth

Source: Summary of the above review; TIBA: 2, 3, 5-tri-iodobenzoic acid

Table 6. Effect of different PGRs on fruit yield of cucumber.

PGR	Dosage	Fruit yield attributes
GA_3	10 ppm	Drastically decrease fruit yield
GA_3	60 um/l	optimum fruit yield
NAA	150 ppm	Produce maximum yield
GA_3 + NAA	20 ppm + 200 ppm respectively	Superior yield
Ethrel + MH	High concentration	Decrease average yield
Ethrel	3800 Um/L	lowest yield
Ethrel	450 um/l	Highest yield
MH + Ethephon	100 ppm each	Enhance yield
Salicylic acid (SAA)	exogenous application	increase yield

Source: Summary of the above review.

Conclusion

Cucumber has medicinal values. It is widely consumed in salads, pickles, or most frequently eaten in the preserved form. Although cucumber is a highly nutritive and increasingly demanded vegetable in Nepal, the expected potential yield hasn't been achieved yet. It is concluded that the application of different growth regulators has a considerable impact on the growth, flowering, fruiting, and fruit yield of cucumber plants. Plant growth regulators leave determining impact on the overall growth and developmental processes, such as germination, shoot elongation, leaf expansion, flowering, fruit set, fruit growth and ripening, and the ultimate yield of the cucumber. Plant growth regulators (PGRs) may have an important role in regulating both yield and fruit quality during the production of cucumber. Some growth regulators promote the growth of plants while other acts as inhibitors that result in the reduction of growth and yield attributes of plants. Exogenous application of PGRs affect on endogenous hormone of plant which alter the physiological process of plant. Various types of plant growth regulators in recommended concentrations give better growth, early flowering, and minimum sex ratio, highest fruit yield with superior quality of fruit. There are also growth regulators which suppress the plant growth. Mostly, the growth regulator helps in the production of marketable fruit in minimum number of days. Different PGRs applications showed significant effect on stem length, number of branches, total number of flower, fruiting, yield and other yield contributing characters. Auxins enhances root elongation, fruit set and fruit development whereas gibberellins enhances the cell elongation and the secondary growth. Cytokinins delay the senescence of the fruit and increase the fruit yield. This way, the review meets the objective of assessing the role of different dosage of plant growth regulators on growth, fruiting, flowering, and fruit yield of cucumber.

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