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ROLE OF PLANT GROWTH REGULATORS IN STRAWBERRY CULTIVATION: A REVIEW

H.S. Sona[1*], S. D. Magar[1], D. B. Kshirsagar[1], R. V Patil [2] and V. R. Pawar [2]

[1]Department of Horticulture (Fruit Science), Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, India

[2]Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, India

*Corresponding author-mail: hss048682@gmail.com

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ABSTRACT

Strawberry (*Fragaria x ananassa* Duch.), is a small fruit that has great importance. It is triggered by a number of physiological, genetic and biochemical processes. Plant growth regulators or the phytohormones are organic substances produced naturally in plants, controlling growth or other physiological functions. Various plant growth regulators perform different function in strawberry. Therefore, PGR's such as Gibberellins, NAA (auxin), tricontinol and plant growth inhibitors chlormequat chloride are essential for ripening, maturity indices and determine the quality of fruits. Various PGRs like auxin, gibberellin and cytokinin are used in strawberry in order to increase the fruit size, enhance fruit set, growth and yield. This paper reviews the influence of various phytohormones on growth and yield of strawberry. The application of PGRs were found to be very effective in increasing the vegetative growth, flowering and yield of berry fruits under temperate, tropical as well as subtropical regions where strawberry is grown commercially as well as in new areas of cultivation.

***Key words*:** Strawberry cultivars, plant growth regulators, growth and yield.

Introduction

Strawberry (*Fragaria x ananassa* Duch.) is soft, luscious, nutritious, tasty and perishable fruit which is grown in temperate climatic conditions where the plant behaves like a small perennial herb and also grown in a sub-tropical climate where plant behaves as an annual herb. It is a short-day plant belonging to the family Rosaceae. Strawberry is a non-climacteric fruit and characterized by a high softening rate, short post-harvest life and fast decay (Bustamante *et al.*, 2009). Strawberry is a small fruit crop of great nutritional and medicinal value. It contains antioxidant, anti-inflammatory, anti-neurodegenerative and anti-cancer component called ellagic acid. It is rich source of vitamin A, B, C, niacin and minerals like phosphorus, potassium, calcium and iron and has a tantalizing flavour and aroma (Karakara and Dwivedi, 2002). Higher pectin contains (0.55%) in the form of calcium pectate serves as an excellent ingredient for making jelly. In addition to fresh consumption, the strawberry is in special demand by the fruit processing units for preparing jam, ice cream, syrup, quick freezing and canning.

Plant growth regulators (PGRs) are organic compounds that, when applied to plants in balanced amounts, inhibit, promote or change physiological processes (Arteta *et al.,* 2022). PGRs also play a positive role in regulating secondary metabolites in strawberry plants. They influence biosynthetic pathways, enzyme activity and signalling networks, thereby controlling the production and accumulation of secondary metabolites (Hilal *et al.,* 2023). This regulation enables plants to adapt to their environment, defend against pathogens and perform various physiological functions that improves crop yield. Plant growth regulators (PGR's) are organic compounds other than nutrients that we apply on plants to cause any physiological response. In general plant hormones can be divided into plant growth promoters (substances which improve the overall health, growth and

development of plants) and growth retardants (group of chemicals which have common physiological effect of reducing stem growth by inhibiting cell division of sub apical meristem). According to scientific findings, the strawberry plant responded positively to the application of a growth regulators (Sharma and Sharma, 2004).

Role of plant growth regulators

Gibberellic acid (GA_3)

Gibberellic acid progressively increased the plant height, canopy spread, leaf area, number of leaves, petiole length and induces stem elongation when applied exogenously to strawberry plants (Kasim *et al.*, 2007, Sharma and Singh 2009). Plant height, number of runners, number of flowers, fruit set percentage, number of fruits, fruit size, fruit weight and fruit quality are all influenced by gibberellic acid (Kumra *et al.*, 2018). Exogenous application of Gibberellic acid (GA_3) promoted the flowering in non-chilled strawberry plants, shortened the cropping season and increased vegetative growth and fruit number (Paroussi *et al.*, 2002). It controls the growth and development of plants in numerous ways at different stages. GA_3 influences vegetative growth in strawberry plants through a well-defined molecular mechanism. (Verma *et al.,* 2022).

Naphthalene acetic acid (NAA)

NAA is a synthetic version of auxin that aids in cell elongation, cell division, vascular tissue differentiation, root initiation, apical dominance, leaf senescence, leaf and fruit abscission, fruit setting ratio, fruit dropping prevention and flower sex ratio promotion (Mehraj *et al.*, 2015). Application of NAA increases fruit size and delays the ripening and increases anthocyanin accumulation in strawberry fruits. It promotes growth parameters, slows ripening and enhances anthocyanin accumulation. It furthermore enhances the blooming period and improve fruit output and quality **(**Mir *et al.*, 2004). NAA is a synthetic auxin that is most commonly employed in the production of high-quality strawberries in terms of total sugars, ascorbic acid content and titratable acidity percentage (Bhople *et al.*, 2020).

Benzyl Adenine (BA)

BA, as a plant growth regulator, that enhances the size and shape of fruits, lateral bud break and lateral shoot growth, leading to improved branching in fruit trees and flowering (Shouming *et al.*, 2007). It also increases the fruit size and delay chlorophyll break down and fruit ageing. BA also decreases loss in firmness, delay ethylene production, decreases respiration rate and induces mechanical resistance which reduces the senescence rate after harvest. Among the most important physiological effects of cytokinins is to stimulate cell division and elongation and the growth of stems, roots and side shoots as they work to end the apical dominance induced by auxin and break the dormancy of seeds and buds (Al-Taey DKA and Majid ZZ. 2018) .

Brassinosteroid

Brassinosteroids (BRs) are a class of plant steroidal hormones that play a crucial role in the regulation of growth, development, and stress responses in various plant species, including strawberry (Clouse *et al.*, 1998). BRs have also been implicated in plant responses to abiotic stress. Despite the correlation between abiotic stress and BR levels in higher plants, the physiological rationale for such alteration in BR levels is still not known. These hormones are also known to change in plants responding to biotic stress. (Krishna 2003). In strawberries, BRs have been found to significantly influence vegetative growth, fruit set, fruit enlargement, and quality attributes such as color, sugar content, and shelf life (Li *et al.*, 2020)

Role of plant growth inhibitor

Chlormequat (CCC)

Chlormequat chloride, also called cycocel (CCC), is rapidly absorbed and easily translocated in the xylem and phloem tissue. Chlormequat chloride, soluble in water and absorbed by all plant tissues, is effective when applied as a drench or spray method. Chlormequat chloride indirectly promotes flowering and improves fruit sets by controlling excessive vegetative growth. Chlormequat inhibits gibberellin biosynthesis, leading to reduced stem elongation. This results in shorter and sturdier plants that are less prone to lodging. The chlormequat and triacontanol in strawberries work together to optimize plant growth, flowering and fruit development, leading to increased yield and improved fruit quality in cultivar Chandler (Bhat *et al.,* 2012).

Influence of plant growth regulators on strawberry

Influence of gibberellic acid on growth and quality of strawberry: The growth and quality features of the strawberry fruit are modified by the use of GA_3. Gibberellic acid regulates the early flower initiation and earlier fruit set in strawberry plants which is responsible for vigorous growth of plant in all the vegetative stages, where they can store sufficient amount of photosynthates for producing a greater number of flowers and also known to overcome the endogenous dormancy factors and promotes flowering by causing rapid growth of flower primordia thereby initiating the early flower in plants sprayed with gibberellins. It influences on early flowering, increased duration of flowering, harvesting and yield, helps

in cell elongation and cell enlargement, increases vegetative growth and minimizes time of maturity and increases fruit set (Sharma and Singh 2009). The maximum numbers of runners produced from strawberry plants with the application of GA_3 which is due to GA_3 stimulated activity that redistributed the gibberellins in greater concentration in the crown region which later induced the runner emergence (Eshghi *et al.,* 2012). Gibberellic acid @ 75 ppm at 30 and 45 DAP caused the production of maximum plant height, plant spread, petiole length, leaf area and number of leaves per plant, due to the fact that gibberellins regulated the growth of strawberry plants by causing cell elongation and increased cell division. This might be due to the fact that gibberellins cause the elongation in internodal length (Saima *et al.*, 2014). At the highest concentration of GA_3 @ 150 ppm, maximum number of crowns per plant were obtained because of GA_3 regulation increases the cell elongation and enhanced photosynthates which forced plant to produce maximum number of crowns per plant (Ruchitha *et al.,* 2020).

The various quality parameters were monitored with the application of GA_3 like maximum total sugar, reducing sugar and non-reducing sugar were found in the strawberry plants treated with GA_3 @ 75ppm. This increase is due to the quick metabolic transformation of starch and pectin in to soluble compounds and rapid translocation of sugars from leaves to developing fruits (Kumar *et al.,* 2022). The highest TSS, sugar content and pH of fruit at lower concentration of GA_3 @ 50 ppm and highest vitamin C was obtained with GA_3 @ 100 ppm (Saravanan *et al.,* 2013). The maximum specific gravity, pH value and total soluble solids were reported with application of GA_3 @ 100 ppm. The quality parameters like total sugar and anthocyanin content were highest and acidity was found lowest with the treatment of strawberry fruits at higher concentration of GA_3 (100ppm), which rapidly converted into sugar, increased respirational demand and adequate supply of nutrients, synthesis of invertase and starch splitting enzymes decrease the acidity in fruit and also affect the physiological processes such as respiration and photosynthesis, which improved the supply of dry matter, minerals and carbohydrates towards the developing fruits (Lad *et al.*, (2025). The quality responses of strawberry fruits (Winter Dawn, Sweet Sensation, Florida Beauty) to exogenous gibberellic acid at various concentrations like 50, 75, 100 and 125 ppm under protected condition. The physicochemical analysis revealed that the maximum TSS (8.62 °Brix) with 100 ppm GA_3 and the minimum TSS (7.34 °Brix) was recorded in plants treated with 125 ppm @ GA_3. A higher amount of antioxidants (71.10%) was observed in Sweet Sensation and a minimum in Winter Dawn (67.02%) (Shrestha *et al.,* 2025)

Influence of Gibberellic acid on yield of Strawberry: Uddin *et al.,* (2012) stated that fruit weight increased with gibberellic acid application. They stated that this increase was more in optimum dose *i.e.*75 ppm than the 50 and 100 ppm dose. In another study, fruit weight was increased in strawberries cv. Chandler cultivar applied 50, 75 and 100 ppm GA_3 and the maximum increase was determined in the application of 75 ppm GA_3 (Saima *et al*., 2014). The enhancement in number of fruits per plant, fruit weight, fruit length, fruit diameter and fruit yield by GA_3 is due to that promotes more vegetative growth, increased flowering and more fruit set. Additionally, GA_3 improved the better supply of nutrients and other compounds to the fruits that are vital for their proper growth and development, which resulted in improved fruit size and ultimately higher yield. GA_3 resulted in the significant increase in marketable yield and fruit size of strawberry cv. Camarosa (Roussos *et al.,* 2009). Application of GA_3 recorded the maximum fruit weight per berry. This might be due to fact that such treatment-induced good vegetative growth and flower bunch hence initiated a higher number of flowers and percent berry set. This could also be attributed to the improvement in the water, which might increase the photosynthetic rate causing maximum fruit weight (Nor *et al.,* 2014). The very higher concentration of GA_3 (125 mg l^{-1}) resulted slightly stunted growth in strawberry plants. Since, application of GA at high concentrations is reported to have an inhibitory action in plants (Hedden and Sponsel, 2015). In addition to promoting vegetative growth, GA_3 also regulates runner formation, flower development, stolon formation, fruit set percentage, fruit size, and fruit weight, destroys rosetting, and slows down flower initiation (Katel *et al.,* 2022).

Influence of NAA on strawberry on growth and yield: Generally, auxin and particularly NAA induce flowering by stimulating florigen which moved from petiole to growing tip and convert vegetative bud to flowering bud. Minimum days taken to produce first flower by the application of NAA to strawberry plants (Thakur *et al.,* 1991). The maximum fruit length diameter ratio obtained from NAA @ 50 ppm. Recently, molecular analysis have confirmed the prominent role played by auxin signalling in triggering and coordinating the transition from flower to fruit. The growth of the ovary is blocked before pollination and that auxin is involved in depression of ovary growth after fertilization, so fruit size increases with

exogenous application of NAA with a particular concentration (Khunte *et al.,* 2014)

NAA influences on minimum days taken to first flower, it is due to auxin particularly NAA induces flowering by stimulating florigen which moved from petiole to growing tip and converts vegetative bud to flowering bud and fruit set refers to the change in the ovary leading to the development of the fruit. These changes are usually induced after pollination and fertilization which is triggered by NAA (Kumar *et al.,* 2011). NAA improved the output of berries with greater width and length, as well as weight (Wang *et al.,* 2015). The maximum number of flowers obtained from NAA @ 100 ppm treated plants. The numbers of flowers per plant were obtained more in NAA treated plants due to more number of flowering stocks arisen from those plants as the stimulus (florigen) convert vegetative bud to fruiting bud with the help of exogenously applied NAA (Palei *et al.,* (2016). Spraying strawberry cv. Tioga with 400 ppm of NAA resulted in the greatest yield viz., width, weight, volume and plant stature, spread, number of leaves per plant, petiole length, leaf region records, days to first blooming and days to fruit bud advancement, fruit yield per plant, maximum fruit yield per hectare (Emam *et al.,* (2020)

Influence of NAA on strawberry on quality: NAA at different concentrations applied at 2 to 3 leaf stage on strawberry cv. Sweet Charlie increased in quality parameters of the strawberry fruits like total soluble solids, total sugar and decreasing the acidity (Mir *et al.,* 2004). Plants treated with NAA at a concentration of 19.97 mg/ l produced berries with the highest total soluble solids, total sugars (Kumar and Tripathi, (2009). The highest juice percentage was found in the fruit taken from the plants which were sprayed with NAA @ 50 ppm. This might be due to the increased vascularization in the pedicel or due to the increased sink strength and reduced senescence and respiration from the fruit (Kumar *et al.,* 2011, Khunte *et al.,* 2014). The highest TSS of strawberry fruits with NAA, the total sugars content which account for more than 60% of TSS percentage is due to the higher enzymatic activity like α amylase and invertase with the application of NAA which is responsible for higher total sugar content and non-reducing sugar content of strawberry fruits (Palei *et al.,* 2016). Due to increase level of metabolites stimulate the ascorbic acid biosynthesis in plants which received NAA (Singh *et al.,* 2017). Preharvest treatment with NAA has an impact on strawberry with the greater ascorbic acid concentration. Moreover, treating strawberries with NAA restrains aging and anthocyanin amassing (Ali *et al.,* 2021). NAA at higher concentration produces maximum TSS, ascorbic acid, reducing sugars, reducing sugars, and total sugar in strawberry (Rathod *et al.,* 2021). NAA showed the best result in terms of total soluble solids, acidity of the fruit and ascorbic acid in strawberry (Kharjana *et al.,* 2022).

Influence of BA on growth and yield of strawberry: Benzyl adenine (6-benzyl amino purine) is one of the most important groups of synthetic cytokines, which are plant hormones naturally produced by plants, derived from adenine its molecules contain a nitrogenous base (Purine) (Hamza and AL-Taey, 2020). With the spraying of plant growth regulator benzyl adenine to strawberry plants led to the significant increase in the average number of flowers, total fruits, fruit set percentage, average length, diameter, size of fruit, average fruit weight, average yield per plant and yield per area. The reason for this is that application of benzyl adenine treatment may stimulate the synthesis of nucleic acids and that proteins and help to transport nutrients and hormones, including auxins, to the treated area. In addition to the role of cytokinin in stimulating division, cell elongation, growth of lateral buds and breaking dormancy of buds, it is one of the main determinants of fruit growth and reaching the final size, as the addition of synthetic cytokinins increases the effectiveness of cytokinin-like compounds in plant tissues, which stimulates the growth of fruits in some plants. (Wilkins, M.B. 1979 and AL-Taey DKA, 2021).

BA resulted in significant increase in number of flower trusses per plant and total number of flowers per plant in cv. Sweet Charlie (Singh and Singh, 2005). BA is also reported to promote growth by increasing plasticity of cell wall followed by hydrolysis of starch into sugar which reduces cell wall potential, resulting in the entry of water into the cell and causing its elongation thereby increasing in fruit length of strawberry plants (Richard, 2006). BA influences the runner growth, number of runners production in strawberry (Li *et al.,* 2020). The higher number of marketable fruits were produced as a result of the exogenous application of BA, which indirectly affected the benzylidene metabolism and increased the fruit yield (Rathod *et al.,* 2021). Combination of benzyladenine and gibberellic acid resulted in maximum number of leaves and runners/mother plant, highest plant growth as height, plant spread and number of crowns/ plant (Momenpour*et al.,* 2009, Hazarika *et al.,*2015, Kour *et al.,* 2017)

Influence of Brassinosteroid on strawberry: Brassinosteroids are new plant growth regulators that plays an important role in cell elongation, cell division, vascular differentiation, flowering and pollen formation and on fruit ripening (Clouse, 2011). Castasterone, a

brassinosteroid precursor, remains constant at basal levels during strawberry ripening (Symons *et al.,* 2012), leading to the belief that there is not a direct influence in strawberry ripening. However, subsequent studies have shown that inhibition of brassinosteroid delayed red colour in ripe strawberry fruits (Chai *et al.,* 2013), indicating that this regulator may have influence on specific attributes of strawberry maturation, however, evidencing that there is little knowledge about the role of brassinosteroid in strawberry ripening.

Brassinosteroids treatments on harvested fruits of strawberry marked an improvement on quality parameters (Nunes and Emond, 2007). It causes a lower brightness loss. Additionally, when analysing the fruit colour, evaluated by the chroma parameter (C*), fruits exhibited a more vivid and intense colour and the latter is a well-known parameter that correlates positively with consumer acceptance, as for their visual appearance (Velickova *et al.,* 2013). Recently it was observed that brassinosteroid injection in strawberry at pink stage increases the receptors and transcription factors expression but for phytochemical characteristics the brassinosteroid influence mainly starts in the white stage for total sugar and soluble solid and in addition, there is a positive effect on vitamin C content and total anthocyanins for the treated red fruits, suggesting that brassinosteroid is involved in strawberry fruit ripening, in different stages, mainly in a phenylpropanoid pathway.(Ayub *et al.,* 2018)

Strawberry plants with brassinosteroid resulted in maximum production per plant, minimum number of days for flower bud initiation to flowering, maximum fruit length and maximum fruit diameter, maximum fruit weight (Thakur *et al.,* 2015). Agronomic response of strawberry plants to the application of brassinosteroid increased strawberry fruit yield between 9 and 34%, mainly in marketable fruits (Salazar *et al.,* 2016). Increase in leaf area of strawberry by application of brassinosteroid (Ali *et al.,* 2022).

Plant growth inhibitor

Influence of Chlormequat (cycocel) on strawberry: Chlormequat chloride is a plant growth regulator commonly used in crops as a growth retardant. It is a gibberellins biosynthesis inhibitor and prevents the cyclization of geranyl pyrophosphate to copalyl pyrophosphate (Xiao *et al.,* 2022). Strawberry vegetative growth has been found to be aided by GA_3 and the use of cycocel increased the number of flowers, fruit per plant, yield strawberry yield and quality (Kumar *et al.,* 2012). Cycocel @ 750 ppm, 1000 ppm led to the increase in length, diameter, weight and volume of the berries. This might be due to the greater supply of photosynthates to the reproductive growth than the vegetative growth and also due to lower percentage of fruit set and lower number of fruits which enables fruit growth to its maximum extent (Rajesh *et al.,* 2012, Saima *et al.,* 2014). Cycocel is involved in enhancing the rate of photosynthesis by increasing total chlorophyll content of leaves which leads to more food production within the plant thus improves fruit weight and fruit diameter (Rao *et al.,* 2016). The longer duration of flowering by foliar spray of cycocel is due to the increased translocation of cytokinin from roots to shoots, leading to prolonged life span of floral parts of plant due to its anti-senescence activity thereby increasing flowering duration and number of flowers in strawberry (Pourmohammad *et al.,* 2013, Altintas, 2011 and Khunte *et al.,* 2020). Cycocel has recorded the minimum titratable acidity. The reduction due to the conversion of more organic acids and photosynthates into sugars during the fruit ripening stage of strawberry. Ghora *et al.,* 2000 revealed the reverse effect of strawberry fruit yield with the plant growth i.e. maximum yield was found under the treatment of 500 ppm cycocel where vegetative growth promotion was least. However, all the cycocel treatments were statistically at par with each other for fruit yieldtoo obtained 90% increase in yield without affecting fruit size while treated with cycocel.

Conclusion

The literature available revealed that plant growth regulators and inhibitor gives an instant impact on crop growth. The use of PGRs is increasing day by day mainly in many horticultural fruit crops. Therefore, the number of synthetic chemicals is used for the regulations of growth and development of cultivated plants. Latest scientific findings showed that GA_3 is an effective PGR for improving vegetative growth, yield, quality and runners' production in strawberry. Application of NAA improves the physiochemical properties of strawberry and as cycocel is a growth retardant, it increases number of flowers, improve fruit quality and yield of strawberry.

References

Ali, A., Kumar A., Rasool K., Ganai N.A., Lone A., Baba T.R., Hamid M. and Haq A. (2021). Triacontanol spray mediated plant growth and productivity in fruits crops : a review. *The Pharma Innovative Journal,* **10(7)**, 789-792.

Ali, M.M., Anwar R., Malik A.U., Khan A.S., Ahmad S., Hussain Z., Hasan M.U., Nasir M. and Chen F. (2022). Plant growth and fruit quality response of strawberry is improved after exogenous application of 24-epibrassinolide. *Journal of Plant Growth Regulation*, **41**, 1786-1799.

AL-Taey, D.K.A., Saadoon A.H.S. and AL-Azawi S.S.M. (2021). Study of Kinetin treatment on growth and activity of

some antioxidant enzymes of spinach under salt stress. *Current Trends in Natural Sciences,* **10(19)**, 457-465.

Al-Taey, D.K.A. and Majid Z.Z. (2018). Study Effect of Kinetin, bio-fertilizers and organic matter application in lettuce under salt stress. *Journal of Global Pharma Technology*. **10(1)**, 148-164.

Altintas, S. (2011). Effects of chlormequat chloride and different rates of prohexadione calcium on seedling growth , flowering , fruit development and yield of tomato. *African Journal of Biotechnology,* **10(75)**, 17160-17169.

Arteta, T.A., Hameg R., Landin M., Galego P.P. and Barreal M.E. (2022). Artificial neuralnetworks elucidated the essential role of mineral nutrients versus vitamins and plantgrowth regulators in achieving healthy micropropagated plants, *Plants*, **11(10)**, 1284.

Ayub, R.A., Reis L., Bosetto L., Lopes P.Z., Galvão C.W. and Etto R.M. (2018). Brassinosteroid plays a role on pink stage for receptor and transcription factors involved in strawberry fruit ripening. *Journal of Plant Growth Regulation,* **83(1)**, 159-167.

Bhat, P., Devi K.M., Jayalaxmi H., Sophia I. and Prajna P.S. (2012). Effect of plant growth regulators on establishment and growth of straw berry (*Fragaria x ananassa* Duch.) var. chandler in vitro. *Agriculture Science Research Journal*, **2**, 623-632.

Bhople, A.A., Kullarkar P.P., Singh S.K. and Saxena D. (2020). Studies on impact of growth regulators on performance of strawberry cv. Camarosa under polyhouse condition. *Annals of Agriculture Biology Resources*, **25(2)**, 234-238.

Bustamante, C.A., Civello P.M. and Maru G.A. (2009). Cloning of the promoter region of bxylosidase (FaXyll) gene and effect of plant growth regulators on the expression of FaXyll in strawberry fruit, *Plant Science*, **177**, 49-56.

Chai, Y., Zhang Q., Tian L., Li C-L., Xing Y., Qin L. and Shen Y.Y. (2013). Brassinosteroid is involved in strawberry fruit ripening. *Journal of Plant Growth Regulation,* **69(1)**, 63-69.

Clouse, S.D. and Sasse J.M. (1998). Brassinosteroids, Essential regulators of plant growth and development. *Annual Review of Plant Biology*, **49(1)**, 427-451.

Clouse, S.D. (2011). Brassinosteroid signal transduction, from receptor kinase activation to transcriptional networks regulating plant development. *The Plant Cell, Rockville*, **23(4)**, 1219-1230.

Emam, A.S., Samia M.A., Marwa M.M., Samira M.N. and Wahed A.E. (2020). Egyptian academic journal of biological sciences. *Egypt Academy Journal Biological Science*. **13(4)**, 259-266.

Eshghi, S., Safizadeh M.R., Jamali B. and Sarseifi M. (2012). Influence of foliar application of volk oil, dormex, gibberellic acid and potassium nitrate on vegetative growth and reproductive characteristics of strawberry cv. 'Merak.' *Journal of Biology and Environmental Science*, **6(16)**, 35-38.

Ghora, Y., Vasilakakis M.G., Stavroulakis N.J., Fokkel M.A., Beek J.L., Steekelenburg T.L., Robinson and Verhoyen M.N.J. (2000). Effect of growth retardants on growth and development of red raspberry cultivar Autumn Bliss, cultivated under plastic greenhouse conditions in Chaniacrete, Greece. *Acta Horticulturae,* **513**, 453-458.

Hamza, O.M. and AL-Taey D.K.A. (2020). A study on the effect of glutamic acid and benzyl adenine application up on growth and yield parameters and active components of two Broccoli hybrids. *International Journal of Agriculture Statistics Science,* **16(1)**, 1163-1167.

Hazarika, T.K., Ralte Z., Nautiyal B.P. and Shukla A.C. (2015). Influence of biofertilizers and bioregulators on growth, yield and quality of strawberry (*Fragaria x ananassa* Duch.), *Indian Journal of Agricultural Sciences,* **85(9)**, 1201-1205.

Hedden, P. and Sponsel V. (2015). A century of gibberellin research. *Journal of Plant Growth Regulation*. **34(4)**, 740-760.

Hilal, B., Khan T.A and Fariduddin Q. (2023). Recent advances and mechanistic interactions of hydrogen sulfide with plant growth regulators in relation to abiotic stress tolerance in plants. *Plant Physiology Biochemistry*, **196**, 1065-1083.

Karakara, B.K. and Dwivedi M.P. (2002). Strawberry. In, Enhancement of Temperate Fruit Production in changing climate, UHF, Solan, 198-204.

Kasim, A.T.M., Abd El-Hameid A.M. and El-Greadly N.H.M. (2007). A comparison study on the effect of some treatment on earliness, yield and quality of Globe Artichoke (*Cynare scolymus* L.). *Resources of Journal of Agriculture and Bio Sciences,* **3(6)**, 695-700.

Katel, S., Mandal H.R., Kattel S., Yadav S.P.S. and Lamshal B.S. (2022). Impacts of plant growth regulators in strawberry plant, a review. *Heliyon.*

Kharjana, B., Kerketta A. and Topno S.E. (2022). Effect of NAA and GA_3 on growth, flowering, fruiting, yield and quality of strawberry (*Fragaria* × *ananassa* Duch.) cv winter dawn. *Environmental Ecology,* **40(4)**, 2016-2022.

Khunte, S.D., Kumar A., Kumar V., Singh S. and Saravanan S. (2014). Effect of plant growth regulators and organic manure on physicochemical properties of strawberry (*Fragaria x ananassa* Duch.) cv. Chandler. *International Journal of Science Resources and Education,* **2(7)**, 1424-1435.

Khunte, S., Das Kumar, Ansari N. and Saravanan S. (2020). Effect of Different Levels of PGRs with Organic Manure on Growth Characters and Economics of Strawberry (*Fragaria x ananassa* Duch.) cv. Chandler in Northern region Effect of Different Levels of PGRs with Organic Manure on Growth Characters and Economic. *International Journal of Current Microbiological Applied Sciences,* **9(1)**.

Kour, S., Kumar R., Wali V., Sharma A. and Bakshi P. (2017). Impact of benzyl adenine and gibberellic acid on quality and economics of runner production in Chandler

strawberry (*Fragaria x ananassa* Duch.) under subtropical climate. *Indian Journal of Agricultural Sciences,* **87**, 964-967.

Krishna, P. (2003). Brassinosteroid-mediated stress responses, Plant Growth Regulators. *Journal of Agriculture,* **22**, 289-297.

Kumar, L., Kumar S., Verma R.S. and Yadav S. (2022). Effect of plant growth regulators and mulches on yield and quality of strawberry (*Fragaria x ananassa* Duch.) cv. Chandler. *The Pharma Innovation Journal*, **11(1)**, 291-293.

Kumar, R., Saravanan S., Bakshi P. and Srivastava J.N. (2011). Influence of plant growth regulators on growth, yield, and quality of strawberry (*Fragaria x ananassa* Duch) cv. Sweet Charlie. *Progressive Horticulture*, **43(2)**, 264-267.

Kumar, R., Sharma N., Jamwal M., Sharma R.M., Singh D.B., and Parmar A.M. (2012). Production and economic studies of PBRs treated strawberry (*Fragaria x ananassa* Duch.) cv. Sweet Charlie. *American-Eurasian Journal of Agriculture and Environmental Science,* **12(12)**, 1.

Kumar, R. and Tripathi V. (2009). Influence of NAA, GA_3 and boric acid on growth, yield and quality of strawberry cv. Chandler. *Progressive Horticulture* **41(1)**, 113-115.

Kumra, R. and Reena S.S. (2018). Influence of plant growth regulators on strawberry, a review Related papers. *International Journal of Chemical Studies,* **6(1)**, 1236-1239.

Lad, B., Solanki P.D., Gurjar R.A., Tandel B.M. and Chaudhary A.P. (2025). effect of foliar application of different nutrients and GA_3 on yield and quality of strawberry. *Plant Archives*, **25(1)**, 3099-3103.

Li, Y., Hu J., Wei H. and Jeong B.R. (2020). A long-day photoperiod and 6-benzyladenine promote runner formation through upregulation of soluble sugar content in strawberry. *International Journal of Molecular Sciences*, **21**, 4917.

Mehraj, H., Taufique T., Ali M.R., Mehraj H., Taufique T., Ali M.R., Sikder R.K. and Uddin A.F.M.J. (2015). Impact of GA_3 and NAA on horticultural traits of *Abelmoschus esculentus*. *World Applied Sciences of Journal*, **33(11)**, 1712-1717.

Mir, M.M., Barche S. and Singh D.B. (2004). Effect of plant growth regulators on growth, yield and quality of strawberry (*Fragaria x ananassa* Duch.) cv. Sweet Charlie. *Applied Biological Research,* **6(1/2)**, 48-51.

Momenpour, A., Taghavi T.S. and Manocher S. (2009). Effect of Benzylidene and Gibberellin on runner production and some vegetative traits of three strawberry cultivars, *African Journal of Agriculture Resources,* **6(18)**, 4357-4361.

Nor, S.S., Razifzh M.R., Mamat A.S. and Adzemi M.A. (2014). Application of gibberellic acid in stem cutting of dragon fruit (*Hylocereus polyrhizus*), Effect on fruit quality and yield at harvest. *Journal of Biology Agriculture and Healthcare*, **4(21)**, 51-55.

Nunes, C.N. and Emond J.P. (2007). Relationship between weight loss and visual quality of fruits and vegetables. *Proceedings of the Florida state horticultural Society*, **120**, 235-245.

Palei, S., Das A.K., Sahoo A.K., Dash D.K. and Swain S. (2016). Influence of plant growth regulators on strawberry (*Fragaria × ananassa* Duch) cv. Chandler under Odisha condition. *International Journal of Recent Scientific Research*. **7(4)**, 9945-9948.

Paroussi, G., Voyiatris D.G., Paroussi E. and Drogour P.D. (2002). Growth, flowering and yield responses to GA_3 of strawberry grown under different environmental conditions. *Scientia Horticulturae,* **96**, 103-13.

Pourmohammad, A., Shekari F. and Soltaniband V. (2013). Effects of cycocel priming on growth and early development of rapeseed under drought stress. *Acta Universitatis Sapientiae Agriculture and Environment*, **5(13)**, 5-18.

Rajesh, K., Manish B. and Singh D.B. (2012). Influence of plant growth regulators on growth, yield and quality of strawberry (*Fragaria × ananassa* Duch.) under U.P. sub tropics. *The Asian Journal of Horticulture,* **7**, 434-436.

Rao, S.S., Tanwar S.P.S. and Regar P.L. (2016). Effect of deficit irrigation, phosphorous inoculation and cycocel spray on root growth, seed cotton yield and water productivity of drip irrigated cotton in arid environment. *Agricultural Water Management*, **169**, 14-25.

Rathod, K.D., Ahlawat T.R., Kumar S., Sarkar M. and Chakraborty B. (2021). Effect of plant growth regulators on growth, yield and quality of strawberry (*Fragaria x ananassa* Duch.) Cv. Winter Dawn under open field conditions of south Gujarat. *Agriculture Science Digest*, **41(2)**, 329-333.

Richard (2006). The influence of exogenous hormone on the flowering and fruiting of Strawberry (*Fragaria x ananassa* Duch). *Journal of Biology Agriculture Healthcare*, **2(4)**, 2224-3208.

Roussos, P.A., Denaxa N.K and Damvakaris T. (2009). Strawberry fruit quality attributes after application of plant growth stimulating compounds. *Scientia Horticulturae*, **119(2)**, 138-46.

Ruchitha, T., Shivakumar B.S., Madaiah D., Ganapathi M. and Chaitanya H.S. (2020). Influence of foliar nutrients and plant growth regulators on growth and yield of strawberry (*Fragaria × ananassa* Duch.) under naturally ventilated polyhouse. *Journal of Pharmacognosy and Phytochemistry*, **9(4)**, 1720-1723.

Saima, Z., Sharma A., Umar I and Wali V.K. (2014). Effect of plant bio-regulators on vegetative growth, yield, and quality of strawberry cv. Chandler. *African Journal of Agricultural Research.* **9(22)**, 1694-99.

Salazar, S. M., Coll Y., Viejobueno J. and Coll F. (2016). Response of strawberry plants to the application of brassinosteroid under field conditions. *RevistaAgronómica del Noroeste Argentino,* **36(1)**, 37-41.

Saravanan, R.K., Bakshi S.P. and Sharma R.M. (2013). Influence

of gibberellic acid and blossom removal on fruit quality of strawberry (*Fragaria x ananassa* Duch.) cv. Belrubi. *Vegetos*. **26(1)**, 107-10.

Sharma, R.R. and Singh R. (2009). Gibberellic acid influences the production of malformed and button berries, fruit yield and quality in strawberry (*Fragaria x ananassa* Duch.). *Scientia Horticulture,* **119(4)**, 430-433.

Sharma, V.P. and Sharma R.R. (2004). The strawberry. *Indian Council of Agricultural Research, New Delhi, India*. 162.

ShouMing, S., GuoJie L., ShaoHua L. and PengFei M. (2007). Effects of IAA, GA_3 and 6-BA applied in autumn on plant quality of strawberry. *Journal of Fruit Science,* **24(4)**, 545-548.

Shrestha, B., Tripathia K.M., Shrestha A.K. and Gautamb R. (2025). Quality responses of strawberry (*Fragraria x ananassa* Duch.) fruits to exogenous gibberellic acid applications under protected condition. *Journal of Agriculture and Forestry University,* **6(1)**, 20-30.

Singh, A. and Singh J.N. (2005). Flowering fruiting and yield responses to plant bioregulators of strawberry cv. Sweet Charlie. *Environment and Ecology.,* **23(4)**, 714-716.

Singh, K., Sharma M. and Singh S.K. (2017). Effect of plant growth regulators on fruit yield and quality of guava (*Psidium guajava*) cv. Allahabad Safeda. *Journal of Pure and Applied Microbiology,* **11(2)**, 1149-1155.

Symons, G.M., Chua Y.J., Ross J.J., Quittenden L.J., Davies N.W. and Reid J.B. (2012). Hormonal changes during non-climacteric ripening in Strawberry. *Journal of Experimental Botany, Oxford*, **63(2)**, 695-709.

Thakur, A.S., Jinda K.K. and Sud A. (1991). Effect of plant growth regulators on Strawberry. *Indian Journal of Horticulture*, **48**, 286-290.

Thakur, S., Mehta K. and Sekhar R.S. (2015). Effect of GA_3 and plant growth promoting rhizobacteria on growth, yield and fruit quality of strawberry (*Fragaria x ananassa* Duch.) cv. Chandler. *International Journal of Advances Resources,* **3(11)**, 312-17.

Uddin, A.J., Hossan M.J., Islam M.S., Ahsan M.K. and Mehraj H. (2012). Strawberry growth and yield responses to gibberellic acid concentrations. *Journal of Experimental Biosciences,* **3**, 51-56.

Velickova, E., Winkelhausen E., Kuzmanova S., Alves V.D. and Moldão-Martins M. (2013). Impact of chitosan-beeswax edible coatings on the quality of fresh strawberries (*Fragaria xananassa* Duch.) cv Camarosa under commercial storage conditions. *LWT-Food Science and Technology*, **52(2)**, 80-92.

Verma, S., Dwivedi A.K. and Tripathi D.V. (2022). Effect of gibberellic acid and boron on growth, yield and yield attributory traits in strawberry (*Fragaria x ananassa* Duch) under North Gangetic plains. *Biology Forum*, **13(3)**, 262-267.

Wilkins, M.B. (1979). The physiology of plant growth and development. Mc Graw – Hill , London, 695.

Xiao, Q., Hou X., Kang C., Xu L., Yuan L., Zhao Z and Hao W. (2022). Chlorocholine chloride induced testosterone secretion inhibition mediated by endoplasmic reticulum stress in primary rat Leydig cells. *Toxicol. Lett.*, **356**, 161-171.