

Improving Production and Quality of Strawberry (*Fragaria × ananassa* Duch.) Cv. Chandler with Plant Growth Regulators: A Study in Northern Punjab, India

ABSTRACT

The use of plant growth regulators was researched to improve strawberry production and fruit and fruit quality in the cooler, northern Punjab regions, known for their superior output and fruit quality by randomized block experiment using strawberry “Chandler”, *Fragaria × Ananassa* Duch. uniform runners cultivated in open fields with paddy straw mulch. After 30 and 60 days of planting, we foliar sprayed the plants with NAA 60, 90, 120, and 150 mg l⁻¹ and GA₃ 60, 90, 120, and 150 mg l⁻¹. The experiment recorded plant growth characteristics, such as number of leaves, stems, leaf area, petiole length, and runners, at their highest levels with the application of 120 mg l⁻¹ GA₃. Similarly, we found the optimal number of strawberries produced in terms of flowers, fruits, weight, marketability, and overall fruit yield with the same application. On the other hand, the application of 150 mg l⁻¹ NAA produced strawberries with the highest total soluble solids, ascorbic acid, reducing sugar, non-reducing sugar, and total sugar contents. Nonetheless, we did not observe any significant effect of the plant growth regulator treatments on the number of days required for 50.0% blooming, the firmness of the fruit, or the acidity level of strawberry fruits. Our findings provide a low-cost production system that can improve the yield and quality of strawberries, potentially contributing to poverty alleviation among farmers in the region.

Keywords: Foliar spraying, fruit quality, plant growth regulators, poverty alleviation.

INTRODUCTION

Strawberry, *Fragaria X ananassa* Duch., “Chandler”, a member of the Rosaceae family, is a significant fruit crop that is popular in international markets for its attractive red color, delicious aroma, and high nutritional content, including vitamins A and C, and minerals Fe and K. According to the National Center for Home Food Preservation, strawberries are one of the fruits that contain enough natural pectin to make a good jelly without adding any additional pectin. Furthermore, the consumption of strawberries has been linked to the prevention of various malignancies and heart-related diseases, as well as reducing inflammation and diseases associated with obesity (Arfin *et al.*, 2016). The demand for strawberries in the market is gradually rising, prompting growers to cultivate this crop to increase their income.

Strawberries can be grown effectively in both temperate and subtropical climates in open conditions, as well as in protected environments (Kafkas, 2017). In India, most of the strawberry-growing regions are devoted to this fruit crop, primarily by poor or marginal farmers in open fields using paddy straw mulching. However, the productivity of strawberries in this region does not match that found in other parts of the nation. Therefore, there is a need for a technically innovative, cost-effective, and long-lasting solution for strawberry cultivation. Strawberries grown in open fields require additional attention and sensible management techniques to achieve excellent yields. Plant growth regulators have been found to have

immediate stimulatory effects on plant responses, including growth, blooming, and fruiting. Strawberry plant responds favorably to the application of growth regulators. Among plant growth regulators, gibberellins (GA₃) and Naphthalene acetic acid (NAA) have undergone extensive testing due to their low-cost viability for application in the present agricultural system in several fruits (Bisht *et al.*, 2018). The current study aimed to investigate the effects of NAA and GA₃ on strawberry growth, yield, and quality in the Punjab region.

MATERIALS AND METHOD

This study was carried out during the 2022 growing season at Lovely Professional University (LPU), Punjab, India, to investigate the effects of plant growth regulators on the growth, yield, and quality of strawberry, *Fragaria X ananassa* Duch Cv. Chandler. The experimental site had a sandy loam soil with a pH of 6.7. Before planting, a recommended amount of farmyard manure (15t h⁻¹) and chemical fertilizers, including urea, single super phosphate (SSP), and muriate of potash (MOP) at the rates of 110, 90, and 90 kg ha⁻¹, respectively, were applied. Healthy and uniform runner plantlets free of pests and diseases were transplanted at a spacing of 2ft x 1ft. The plant growth regulators, Naphthalene acetic acid (NAA) and gibberellins (GA₃), were applied to the leaves of the plants at a concentration of 60, 90, 120, and 150 mg l⁻¹, respectively, 30 and 60 days after planting. The experimental design was a randomized complete block design (RCBD) with three replications of each of the nine treatments: T₁= 60 mg l⁻¹ NAA, T₂ = 90 mg l⁻¹ NAA, T₃ = 120 mg l⁻¹ NAA, T₄ = 150 mg l⁻¹ NAA, T₅ = 60 mg l⁻¹ GA₃, T₆= 90 mg l⁻¹ GA₃, T₇ = 120 mg l⁻¹ GA₃, T₈ = 150 mg l⁻¹ GA₃, and T₉ = No spray as control. Six plants from each treatment were tagged and monitored for growth and development. Leaf area was measured using a leaf area meter (Biovis PSM-L2000) and expressed in cm². Ten berries were randomly selected from each treatment for measurement of their physicochemical characteristics, including total soluble solid (TSS) content, fruit firmness, titratable acidity, sugar content, and ascorbic acid levels. Fruits weighing less than 15 g, misshapen, or diseased were considered unmarketable. The data were analyzed using analysis of variance (ANOVA), and significant differences among treatments were compared using the Least Significant Difference (LSD) test at p ≤ 0.05.

RESULTS AND DISCUSSION

1. Effect on growth and flowering of strawberry plant

The impact of foliar spraying of plant growth regulators on the development of strawberry plants was investigated and analyzed. Results showed that foliar spraying of 120 mg l⁻¹ GA₃ had a significant effect on plant spread (28.72 cm), leaf lamina (122.25 cm²), petiole length (11.80 cm), as well as on the production of strawberry runners (4.43), crowns (3.03), and leaves (29.33) (Table 1). The study found that exogenous administration of plant growth regulators did not affect the time it took for strawberry plants to reach 50% flowering. However, strawberry plants treated with 120 mg l⁻¹ GA₃ showed the earliest flowering and produced significantly more flowers than control plants (Table 1). The results suggest that foliar spraying of 120 mg l⁻¹ GA₃ is an effective method for enhancing the growth and yield of strawberry plants.

According to Bisht *et al.* (2018), gibberellins have the ability to stimulate cell division and expansion in epidermal and parenchyma cells, particularly in the meristematic tissue of leaf primordial in plants treated with GA₃. This stimulation may result in a greater number of leaves with broader leaf lamina and petioles of longer length. The authors also note that higher concentrations of GA₃ can increase these effects even

further. Previous research has indicated that exogenous application of GA₃ can lead to a higher number of leaves with large leaves and petioles in strawberries (Massetani and Neri, 2016). However, the study also found that very high concentrations of GA₃ can result in slightly stunted growth in strawberry plants. This inhibitory action of GA₃ at high concentrations in plants is consistent with the findings of Hedden and Sponsel (2015). The trifoliate leaves of strawberry are arranged in a rosette at crowns, and the length of the petiole determines the relative plant spread (Massetani and Neri, 2016). Vishal *et al.* (2016) investigated the effects of GA₃ on the growth and development of strawberry plants, specifically the Sujatha cultivar. The results of their study showed that GA₃ application led to increased plant growth, number of leaves, and crown and runner formation, which is consistent with the findings of the previous studies. The study also suggested that the increased number of leaves in GA₃-treated plants facilitated the synthesis of more photosynthates, which led to the formation of a greater number of crowns and runners. This is important for strawberry production as more crowns and runners lead to a higher yield of fruits.

Table 1. Effect of plant growth regulators (PGRs) on the growth and flowering of strawberry, *Fragaria × ananassa* Duch.. Cv chandler.

Treatments	Plant Spread (cm)	Leaves Plant ⁻¹	Leaf Area (cm ²)	Length of Petiole (cm)	Crowns Plant ⁻¹	Runners plant ⁻¹	Days Taken to 50% flowering	Flowers plant ⁻¹
T ₁	22.21	20.87	105.88	9.03	2.17	3.17	47.67	27.30
T ₂	22.52	22.67	106.58	9.81	2.37	3.30	44.67	27.36
T ₃	25.28	23.53	108.59	10.77	2.43	4.03	44.00	28.10
T ₄	25.56	24.87	109.67	11.30	2.77	4.30	43.67	29.50
T ₅	21.92	21.53	108.20	9.43	2.23	2.83	45.67	27.50
T ₆	24.04	25.67	110.69	10.74	2.50	3.90	43.33	29.03
T ₇	28.72	29.33	123.25	11.80	3.03	4.43	43.00	31.23
T ₈	26.64	27.33	117.54	11.60	2.90	4.17	43.67	31.00
T ₉	20.15	20.67	102.45	8.80	2.10	3.17	48.67	27.23
LSD p≤0.05	3.99	5.23	11.68	1.39	0.53	0.78	NS	2.55

2. Effect on fruiting and yield of strawberry

The effects of various plant growth regulator (PGR) treatments on the fruiting process of strawberry plants (Table 2). Among the treatments, foliar spraying of GA₃ at a concentration of 120 mg l⁻¹ resulted in the highest fruit production, weight (16.07 g), and length (4.88 cm). The same treatment also produced the maximum number of fruits (19.17) and marketable fruits (16.70 or 86.90% per plant), as well as the highest total marketable fruit yield (268.36 g plant⁻¹) and total fruit yield (308.06 g plant⁻¹). In contrast, the control plants exhibited the lowest number of total and marketable fruits and yield [Fig 1(a) and (b)]. GA₃ plays a regulatory role in the mobilization of metabolites from foliage to developing fruits. Kumar *et al.* (2014) reported that high concentrations of GA₃ can lead to faster initiation of flowering, which can be beneficial for crop production. The evidence also suggests that GA₃ can help improve fruit quality in strawberries, as it can result in a higher number of flowers, fruits, and yield (Saima *et al.*, 2014; Rajbhar *et al.*, 2015). These findings are consistent with previous research that has demonstrated the

positive effects of GA₃ on plant growth and development. Overall, the application of GA₃ can be an effective tool for improving crop yield and quality in strawberries. However, the optimal dosage and application timing may vary depending on the plant species and growing conditions.

Table 2: Effect of plant growth regulators (PGRs) on the fruiting of strawberry (*Fragaria × ananassa* Duch.) Cv chandler.

Treatments	Fruit weight (g)	Fruit length (cm)	Marketable fruits plant ⁻¹	Non-marketable Fruits Plant ⁻¹	Total fruits Plant ⁻¹	Marketable Fruits (%)
T ₁	12.88	4.49	13.39	4.00	16.77	79.00(63.00)
T ₂	13.07	4.50	14.03	3.60	17.03	81.85(64.89)
T ₃	13.59	4.62	15.30	3.00	17.70	86.13(68.15)
T ₄	14.20	4.80	15.83	3.25	18.50	85.27(66.50)
T ₅	12.20	4.34	13.90	3.60	16.90	81.80(65.05)
T ₆	13.46	4.55	14.90	3.35	17.77	83.20(66.13)
T ₇	16.07	4.88	16.70	3.10	19.17	86.90(68.99)
T ₈	15.18	4.86	15.70	3.65	18.83	82.00(65.80)
T ₉	12.14	4.18	13.03	4.20	16.70	78.12(61.87)
LSD p≤0.05	1.59	0.37	1.66	0.76	1.65	3.34

3. Effect on fruit quality of strawberry

The impact of foliar spraying of plant growth regulators on the firmness and acidity of strawberry fruits was insignificant. Nonetheless, the most nutritious fruits were produced by the plants treated with 150 mg l⁻¹ NAA, as evidenced by their highest TSS and sugar content. In contrast, the fruit from the unsprayed plants had the lowest TSS and sugar levels. Furthermore, plants treated with 150 mg l⁻¹ NAA produced fruits with the highest ascorbic acid content (Table 3).

The application of GA₃ can significantly increase TSS and reduce titratable acidity in fruits. Exogenous application of GA₃ increased the number of marketable fruits and fruit yield in strawberries. Rathod *et al.* (2021) also reported that the application of GA₃ increased the fruit yield in strawberry plants. It has been suggested that the positive effects of GA₃ on fruit yield are related to its ability to regulate auxin metabolism, which can indirectly impact fruit growth and development. Thakur *et al.* (2015) found a significant increase in TSS with the spray of GA₃. Rajbhar *et al.* (2015) also found that GA₃ resulted in more TSS (10.68°Brix) in strawberry var. Douglas. Additionally, the evidence suggests that GA₃ can also impact other fruit quality parameters, such as fruit length, diameter, and weight. NAA application in strawberry plants may have increased the concentration of volatile compounds and the hydrolysis of starchy compounds, leading to an increase in TSS levels. Palei *et al.* (2016) also observed a similar effect on TSS when 50 ppm NAA was added to strawberry fruits. More than 60% of the TSS content is made up of total sugars, and the increased total and non-reducing sugar content of strawberry fruits may be attributed to greater enzymatic activity, such as -amylase and invertase, after the use of NAA. NAA may stimulate the production of precursor metabolites that activate ascorbic acid production in plants, resulting in higher

ascorbic acid content in strawberry fruits. Singh *et al.* (2017) reported that the application of 200 ppm NAA (naphthalene acetic acid) resulted in a similar increase in ascorbic acid content in guava.

Table 3: Effect of plant growth regulators (PGRs) on physicochemical properties of strawberry (*Fragaria × ananassa* Duch.) Cv Chandler.

Treatments	Fruit Firmness (Kg cm ⁻²)	TSS (Brix)	Acidity (%)	Abсорbic Acid (Mg 100 g ⁻¹)	Reducing Sugar (%)	Non-reducing sugar (%)	Total Sugar (%)
T ₁	0.85	8.32	0.82	80.35	4.82	4.16	8.98
T ₂	0.89	8.57	0.80	87.45	4.84	4.18	9.20
T ₃	0.95	8.88	0.78	94.55	4.48	4.38	9.23
T ₄	1.01	9.23	0.76	101.65	4.86	4.58	9.74
T ₅	0.84	7.80	0.74	80.35	4.58	3.69	8.26
T ₆	0.84	8.65	0.72	84.85	4.65	3.92	8.56
T ₇	0.87	9.07	0.70	89.35	4.75	4.09	8.83
T ₈	0.88	9.17	0.68	93.85	4.71	4.10	8.71
T ₉	0.83	7.57	0.80	75.50	4.47	3.64	8.11
LSD p ≤ 0.05	0.16	1.07	0.10	6.36	0.34	0.33	0.44

99

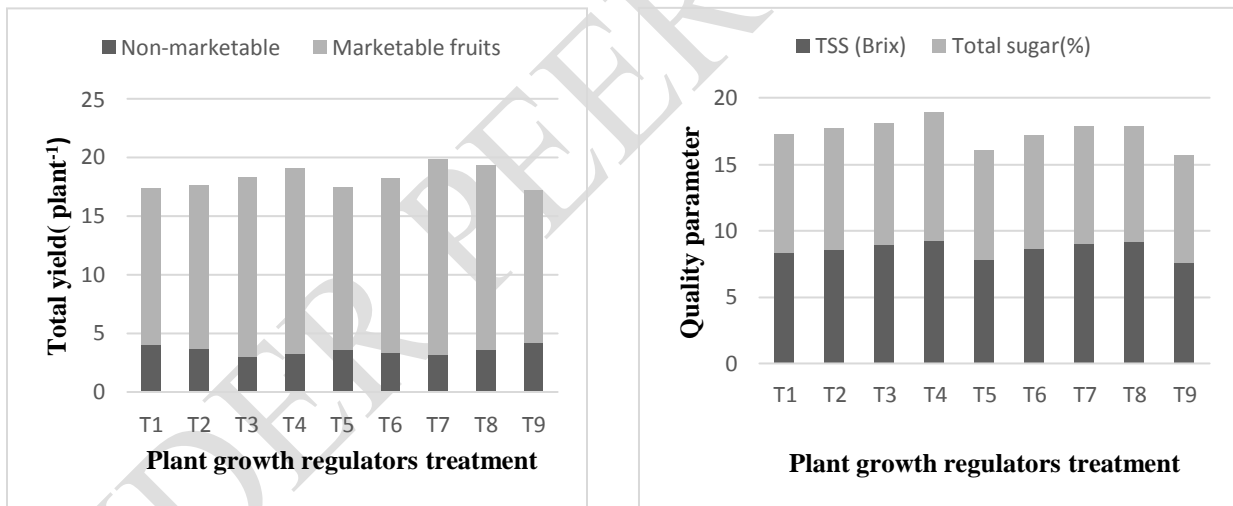


Fig :1 Effect of plant growth regulators on total yield of plant.

CONCLUSION

The findings of this study are highly significant in the present era where the demand for strawberries is increasing rapidly. By utilizing the good characteristics of market-available plant growth regulators that are relatively less expensive, this study aimed to increase strawberry output. The results demonstrate that the application of foliar sprays of 120 mg l⁻¹ GA₃ and 150 mg l⁻¹ NAA at specific growth stages can significantly

enhance the yield and quality of strawberries. These findings have enormous potential to contribute to poverty alleviation among farmers by boosting their crop yield and quality, leading to higher prices and improved livelihoods. Future research should focus on optimizing the concentration and timing of plant growth regulators for strawberry cultivation in different regions to ensure consistent and sustainable yields. This study provides a promising foundation for the development of new strategies to increase strawberry production and enhance farmers' income in the years to come and provide a low-cost production system that can improve the yield and quality of strawberries, potentially contributing to poverty alleviation among farmers in the region.

REFERENCES

- Afrin, S., Gasparrini, M., Forbes-Hernandez, T.Y., Reboredo-Rodriguez, P., Mezzetti, B., Varela-López, A., Giampieri, F. and Battino, M. (2016). Promising health benefits of the strawberry: a focus on clinical studies. *Journal of Agricultural and Food Chemistry*, **64**(22): 4435-4449.
- Bhagariya, D. A., and Prajapati, V. P. (2019). First report of *Pestalotiopsis clavispora* (GF Atk. Steyaert causing crown rot disease on strawberry in India. *International Journal of Economic Plants*, **6**(3):140-142.
- Bisht, T. S., Rawat, L., Chakraborty, B., and Yadav, V. (2018). A Recent Advances in Use of Plant Growth Regulators (PGRs) in Fruit Crops-A Review. *International Journal of Current Microbiology and Applied Sciences*, **7**(5):1307-133.
- Godara, A. K., Sharma, V. K., Panda, A. K., and Tarai, R. K. (2022). Plant Growth Regulators in Strawberry. In *Plant Growth Regulators in Tropical and Sub-tropical Fruit Crops*, :585-624. CRC Press.
- Hedden, P. and Sponsel, V. (2015). A century of gibberellin research. *Journal of Plant Growth Regulation*. **34**(4): 740-760.
- Kafkas, Ebru. (2017). Strawberry growing in Turkey: current status and future prospects. *Acta Horticulturae*. 903-908. 10.17660/ActaHortic.2017.1156.133.
- Shambhu Katel, Honey Raj Mandal, Sujata Kattel, Shubh Pravat Singh Yadav, Baibhav Sharma Lamshal, (2022). Impacts of plant growth regulators in strawberry plant: A review, *Heliyon*, Volume **8**, e11959.
- Khunte, S. D., Kumar, A., 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. *International Journal of Current Microbiology and Applied Sciences*. **9**:1633-1638.

- Kirschbaum, D.S., Jerez, E.F., Salazar, S.M., Borquez, A.M., Meneguzzi, N.G., Agüero, J.J. Conci, V.C., Conci, L.R., Salame, T.P. and Santos, B.M. (2014). Causes of non-marketable fruit production throughout the strawberry harvest season in subtropical environments. *Acta Horticulturae*. 1049: 887-892.
- Kumra, R., Saravanan, R. S., Bakshi, P., Kumar, A., Singh, M., and Kumar, V. (2018). Influence of plant growth regulators on strawberry: A review. *International Journal of Chemical Studies*, **6**(1):1236-1239.
- Rakesh, K., Jasrotia, S. S., Parshant, B., Rafiq, S., and Vishal, R. (2014). Influence of gibberellic acid and blossom removal on flowering and yield of strawberry (*Fragaria* × *ananassa* Duch.) cv. Belrubi. *International Journal of Agricultural Sciences*, **10**(1):272-275.
- Massetani, F., and Neri, D. (2016). Plant architecture in different cultivation systems. In *Strawberry: growth, development and diseases*, :99-118. Wallingford UK: CABI.
- Palei, S., Das, K., Sahoo, K., Dash, D. K., and Swain, S. (2016). Influence of plant growth regulators on strawberry (*Fragaria* × *ananassa*) cv. Chandler under Odisha condition. *International Journal of Recent Scientific Research*. **7**(4):9945-9948.
- Rajbhar, Y. P., Bhagat, S., Gopal, S., Singh, D. K., and Mukesh, K. (2015). Studies on the effect of growth regulator and vermicompost on growth and yield of different cultivars of strawberry (*Fragaria* × *ananassa* Duch). *Asian Journal of Horticulture*, **10**(2):222-231.
- 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* × *ananassa* Duch.) cv. winter dawn under open field conditions of South Gujarat. *Agricultural Science Digest - A 206 Research Journal*, **41**(2):323-333.
- 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):1720-172
- 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), 1694-1699.

- Singh, A., Singh, R. D., Piloo, N., Singh, N. O., Devi, N. S., and Singh, S. R. (2022). Effect of GA₃ and NAA on yield and benefit: cost ratio of strawberry (*Fragaria x ananassa* Duch.) cv. Chandler under the open condition of Manipur. *Journal of Agriculture and Ecology*, **14**:93-98.
- 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):1149-1154.
- Sood, M. K., Kachawaya, D. S., and Singh, M. C. (2018). Effect of bio-fertilizers and plant growth regulators on growth, flowering, fruit ion content, yield and fruit quality of strawberry. *International Journal of Agriculture, Environment and Biotechnology*, **11**(3): 439-449.
- Thakur, S., Mehta, K., and Sekhar, R. S. (2015). Effect of GA₃ and plant growth promoting rhizobacteria (PGPR) on growth, yield and fruit quality of strawberry, (*Fragaria x ananassa*Duch) cv Chandler. *International Journal of Advanced Research*, **3**(11):312-317.
- Ullah, A., Sajid, M., Zakirullah, H., Alamgir Khan, Z. J., and Shah, Z. (2022). Effect on yield and qualitative characteristics of strawberry (*Fragaria ananassa*) cv. chandler to foliar application of gibberellic acid and zinc. *Pure and Applied Biology*. **12**(1):555-559.
- Vishal, V. C., Thippesha, D., Chethana, K., Maheshgowda, B. M., Veeresha, B. G., and Basavraj, A. K. (2016). Effect of various growth regulators on vegetative parameters of strawberry (*Fragaria x ananassa* Duch.) cv. Sujatha. *Research Journal of Chemical and Environmental Sciences*, **4**(4):68-71.
- Yadav, I., Singh, J., Meena, B., Singh, P., Meena, S., Neware, S., and Patidar, D. K. (2017). Strawberry Yield and Yield Attributes after Application of Plant Growth Regulators and Micronutrients on Cv. Winter Dawn. *Chemical Science Review and Letters*, **6**(21):589-594.

UNDER PEER REVIEW