Optimizing okra performance through plant growth regulators in the Garhwal Himalayan region

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ABSTRACT

This study explored how plant growth regulators (PGRs) affect okra growth, yield and quality in Uttarakhand's Garhwal Himalayas. The research, conducted during the 2023-2024 kharif season, focused on gibberellic acid (GA_3), naphthalene acetic acid (NAA) and indole acetic acid (IAA) at different concentrations. PGRs significantly improved okra's growth and reproductive traits. GA_3 at 200 ppm achieved 100 per cent germination and increased plant height to 79.65 cm by 90 days after sowing. While NAA at 150 ppm maximized leaf production, GA_3 treatments generally led to earlier flowering. Crucially, GA_3 applications significantly enhanced fruit characteristics and overall yield. GA_3 at 200 ppm resulted in the largest fruits (12.52 cm length, 7.11 cm diameter, 15.60 g weight) and the highest yield per plant (0.21 kg), plot (2.50 kg) and hectare (10.44 tonnes). These benefits are linked to GA_3's ability to boost metabolism, aid cell expansion and efficiently direct nutrients to fruits. In conclusion, while NAA and IAA offered some advantages, GA_3 consistently proved superior for improving okra vigour, accelerating fruit development and substantially increasing fruit size and yield in challenging hilly environments. The study highlights the critical role of GA_3 and NAA in optimizing okra production for better yields.

Keywords: Okra; PGRs; vegetative growth; yield; germination; fruit characteristics

INTRODUCTION

Okra {*Abelmoschus esculentus* (L) Moench}, a beloved vegetable in many cuisines, holds significant economic importance across tropical and sub-tropical regions globally (Swamy 2023). This annual herbaceous plant, a member of the Malvaceae family, is believed to have originated in Ethiopia (Mandal et al 2012). From its African roots, okra historically journeyed far and wide, spreading throughout Asia, into the southern parts of Europe and eventually reaching the Americas (Oyelade et al 2003). While it's now widely cultivated and a staple in India, its true native home lies in tropical and sub-tropical Africa.

India's major okra producing states include Gujarat, West Bengal, Odisha, Bihar and Madhya Pradesh. India leads global production and produced 6,465.6 thousand MT okra on 530.6 thousand hectares with a productivity of 12.2 MT per hectare in the year 2020-21. In the same year in Uttarakhand, 27.73 MT okra was produced from an area of 3.79 thousand hectares with a productivity of 7.31 MT per hectare (Anon 2023).

Okra is incredibly valued in agriculture, not just for its economic importance, but also for its impressive resilience. It's surprisingly easy to cultivate, offers consistent harvests and can adapt to a wide variety of challenging conditions, from different soil types and moisture levels to both droughts and waterlogging. Despite this natural toughness, truly maximizing okra's growth and productivity often calls for a more focused approach. This is precisely where plant growth regulators (PGRs) become crucial. Considered a modern class of agrochemicals, PGRs can profoundly influence a plant's development and visible characteristics even when applied in tiny amounts. They work by stimulating or enhancing the plant's own natural growth systems, affecting everything from a seed's first sprout right through to its final life stage (Farman et al 2019).

Horticulturists already know PGRs are powerful tools for boosting germination rates, improving plant vigour and increasing seed production. When applied at just the right moment and in the correct concentration, various PGRs, including auxins, gibberellins, cytokinins, ethylene, thiourea and ethanol, can all contribute to healthier plant development, higher fruit yields and improved seed output. These regulators essentially strengthen the plant's internal physiological processes, helping it to build and use nutrients more effectively. This enhancement of physiological functions, along with the improved creation and availability of photosynthates (the sugars plants make), can lead to more efficient crop production with visibly better plant traits. Ultimately, by systematically incorporating techniques like the use of growth regulators, both the fruit and seed yield in okra can be significantly increased.

Specifically, naphthalene acetic acid (NAA), a synthetic auxin, plays a vital role throughout several stages of plant growth and development. It actively promotes the division and elongation of cambium cells, which is key for the differentiation of xylem and phloem tissues. NAA is also used to encourage seed germination and boost flowering. Within the plant, it's necessary for operations such as overall cell elongation and division, supporting the dominant apex, aiding in fruit setting, initiating root formation and influencing leaf aging. Because it can control such a broad range of physiological functions, NAA is essential for the general development and growth of the horticulture crops.

Another important plant hormone, gibberellic acid (GA_3), specifically regulates growth and contributes to numerous developmental processes. These include increasing stem length, supporting the germination process, breaking dormancy, encouraging flowering, influencing sexuality expression, inducing enzymes and managing the senescence of leaves and fruits. During germination, GA_3 helps mobilize food reserves for the developing embryo. This phytohormone is widely utilized in both horticulture and agriculture. Gibberellins enhance biological activity by promoting seed germination, early flowering, fruit set and fruit growth, among other functions. While there are 72 known types of gibberellins, GA_3, GA_4 and GA_7 are commonly available for commercial use.

Indole acetic acid (IAA) is another critical player in plant physiology. As a natural auxin, it promotes cell enlargement and stem growth. It stimulates the differentiation of phloem and xylem tissues and significantly impacts the overall growth, quality and yield of vegetable crops. IAA also facilitates the production of longer roots with more lateral roots and root hairs, thereby, improving nutrient uptake. Additionally, IAA encourages cell elongation, delays leaf abscission and triggers flowering and fruiting processes in plants.

While PGRs hold significant promise for enhancing plant growth and yield, their application demands careful planning. Optimal dosage, precise timing, crop specificity and seasonal factors must all be considered (Patil et al 2024). Although many studies have explored PGR effects on okra, limited research exists specifically under the unique hilly conditions of Uttarakhand. Therefore, this study was designed to investigate how PGRs influence the growth, yield and quality traits of okra in the challenging hilly environment of the Garhwal Himalaya.

MATERIAL and METHODS

The study took place during the kharif season of 2023-2024 at the demonstration unit of the Department of Rural Technology, Hemvati Nandan Bahuguna Garhwal University, Uttarakhand. This experimental site is nestled in the Alaknanda valley, a part of the lesser Himalayan region in central Garhwal. It's geographically located at 78°47'30" E longitude and 30°13'0" N latitude, at an elevation of 540 m amsl.

The region is characterized by challenging weather, with harsh winters and dry summers often accompanied by thick fog. Aside from the main rainy season, other months are generally dry, receiving only occasional rain in winter or early spring. Throughout the experimental period, which spanned July to October, the average monthly temperature fluctuated between 15.42 and 36.68°C (Fig 1).

The soil at the experimental site was a sandy loam, with an acidic pH. Notably, it boasted a high organic carbon content of 1.8 per cent, which is actually richer than what you'd typically find in most farmed soils. This richness likely comes from the natural buildup

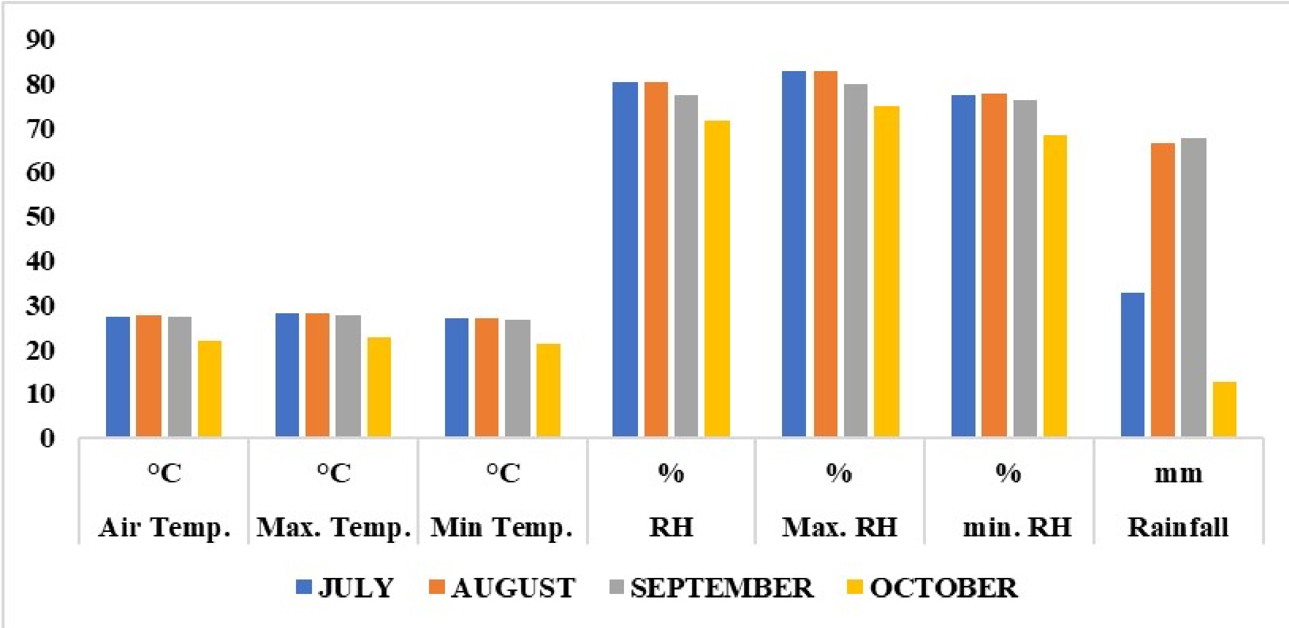

Fig 1. Monthly weather data for the experiment site (July-October 2023)

of leaf litter common in hilly or valley areas. When looked at the nutrients, the nitrogen content was in the medium range (280-560 kg/ha) and potassium was also moderate (120-290 kg/ha). However, phosphorus was relatively low. All in all, the soil's fertility was considered to be medium.

The experiment was conducted using the okra variety Panchpatri and laid out in a randomized block design with three replications per treatment. The experimental field was prepared using a power tiller and laid out into 30 plots (2 × 1.2 m²) with 75 cm × 30 cm spacing, covering a net experimental area of 85.8 m². Sowing was done on 19 July 2023. Recommended fertilizers were applied at the rate of 120 kg per ha nitrogen (urea), 60 kg per ha phosphorus (single super phosphate) and 60 kg per ha potassium (muriate of potash). Half of the nitrogen, along with the full dose of phosphorus and potassium, was applied at sowing, while the remaining nitrogen was top-dressed 30 days after sowing. Weeding and hoeing were done at 15 days interval and irrigation was provided every 4-5 days based on crop needs. Harvesting started 45-50 days after sowing, with fruits hand-picked at tender stages every alternate day.

The experiment consisted of 10 treatments involving three PGRs: GA_3, NAA and IAA, each applied at three different concentrations. GA_3 was applied at 100 ppm (T_1), 150 ppm (T_2) and 200 ppm (T_3); NAA at 100 ppm (T_4), 150 ppm (T_5) and 200 ppm (T_6) and IAA at 30 ppm (T_7), 60 ppm (T_8) and 90 ppm (T_9). A control treatment (T_0) without any PGR was also included for comparison.

First, a stock solution was prepared by weighing 100 mg of the appropriate growth regulator and dissolving it in 100 ml of distilled water in order to manufacture the necessary quantity of growth regulators. The stock solution was then used to create solutions with the required concentration. For instance, 10 ml of the stock solution was taken and dissolved in 100 ml of distilled water to create a 100 ppm GA_3 solution. The seeds were first treated with the prescribed concentration of growth regulator and given a 24 hour rest period, as per the treatment procedure. The process of sowing was completed in a day. Thirty days after sowing (DAS) was the time for the second treatment. During the morning hours, a hand sprayer with compressed air was used to apply an equal volume of spray to each plot. Distilled water was sprayed across the control plot. For data collection, four plants were randomly selected and tagged from each treatment plot. Vegetative growth characteristics of the plant were monitored from planting time to harvest. Germination percentage was calculated by recording the number of germinated plants in each plot using the formula:

$$\text{Germination (\%)} = \frac{\text{Number of germinated seeds}}{\text{Total number of seeds}} \times 100$$

Plant height was measured on the tagged plants at 30, 60 and 90 DAS using a meter scale, from the base to the tip of the tallest leaf and the average height per plant was computed. The number of leaves per plant was recorded at 10 days intervals until harvest by counting the leaves on the tagged four plants in each plot and the mean number of leaves was calculated. Similarly, the number of nodes was manually counted on each tagged plant at 30, 60, and 90 DAS and the average number of nodes per plant was determined. Days till the first blooming was noted by examining the plants from the day of planting and counting the days until the first flower appeared on randomly chosen plants in the row.

The number of days from seeding to the first blossom appearing on 50 per cent of the plants was counted to find the number of days required for 50 per cent flowering in each plot. Four mature fruits were randomly selected from each treatment in every replication to record fruit characters. Fruit length was measured using a measuring tape from the stem end to the blossom end, while diameter was recorded at the mid-point of each fruit using a centimetre measuring scale. The average values for both parameters were calculated.

Additionally, the average number of days to first fruiting was determined by recording the number of days from sowing to the maturity of the first fruit. Fruit weight was determined by taking average of fruits using a weighing scale. The average number of fruits per plant was calculated and the total number of fruits gathered from the sample plants was recorded. The total weight of fruits harvested from each plot was recorded to determine the fruit yield per plot. To estimate the total yield per hectare, the average fruit yield per plant was multiplied by the number of plants that can be grown in one hectare based on the given spacing.

The experimental data were subjected to statistical analysis using the randomized block design as described by Panse and Sukhatme (1989) and OP-STAT software. Analysis of variance (ANOVA) was performed to test the significance of differences among treatments using the F-test. Where significant differences were observed, the critical difference at the 5 per cent level of significance was calculated and treatment means were compared for all observed parameters.

RESULTS and DISCUSSION

Effect of PGRs on vegetative characteristics of okra: Data in Table 1 show the effect of PGRs on vegetative characteristics of okra.

Treatments T_3 (GA_3 200 ppm) (100.00%), T_1 (GA_3 100 ppm) (97.20%), T_2 (GA_3 150 ppm) (97.20%), T_7 (IAA 30 ppm) (97.20%), T_5 (NAA 150 ppm) (94.40%), T_8 (IAA 60 ppm) (94.40%) and T_9 (IAA 90 ppm) (94.40%) resulted in maximum germination and were at par and minimum germination was recorded in T_0 (Control) (80.50%).

At 30 DAS, higher plant height was observed in T_3 (26.50 cm), T_2 (23.30 cm), T_1 (21.21 cm) and T_4 (NAA 100 ppm) (20.85 cm), which were at par as compared to 14.49, 16.80, 17.60, 17.80, 18.60 and 19.35 cm in T_0, T_6 (NAA 200 ppm), T_5, T_9, T_8 and T_7 respectively, which were also at par. At 60 DAS, maximum plant height of 38.86, 37.39, 33.87 and 33.35 cm was exhibited by T_3, T_2, T_1 and T_4 respectively, which were at par and minimum in T_0 (22.67 cm) and T_6 (27.29 cm), the two being at par. There was slight deviation in plant height under different treatments at 90 DAS. T_3, T_2, T_4 and T_7 resulted in higher plant height of 79.65, 79.17, 72.69 and 67.40 cm respectively as compared to rest of the treatments T_0 (50.10 cm), T_6 (61.62 cm), T_5 (61.70 cm), T_1 (62.50 cm), T_8 (62.74 cm) and T_9 (63.90 cm), which were at par with one another.

From 30 to 90 DAS, the number of branches increased as the plants grew older. At 30 DAS, higher number of leaves per plant was observed in T_5 (7.60), T_4 (7.41) and T_7 (7.25) which were at par, than T_0 (6.34), T_6 (6.41), T_1 (6.50), T_3 (6.50) and T_8 (6.60) which were at par. However, at 60 DAS, T_5 (16.41) produced maximum number of leaves per plant as compared to minimum in T_3 (12.91), T_0 (13.00), T_2 (13.15), T_1 (13.25), T_7 (13.41), T_6 (13.58) and T_8 (13.58), being statistically at par. This trend almost remained same even at 90 DAS; T_5 showed maximum number of leaves (28.58) as compared to minimum in T_0 (22.50), T_2 (23.25), T_3 (23.40), T_9 (23.58), T_1 (23.83), T_7 (24.00), T_6 (24.30) and T_8 (24.83), all being at par.

At 30 DAS, more nodes per plant were recorded in T_5 (5.50), T_1 (5.41), T_2 (5.40), T_8 (5.16), T_0 (5.08), T_7 (5.08), T_4 (5.00) and T_3 (4.91), all being at par, as compared to T_9 (4.30) and T_6 (4.50) which

Table 1. Impact of plant growth regulators on vegetative and flowering characters of okra cv Panchpatri

Treatment	Germination (%)	Plant height (cm)			Number of leaves/plant			Number of nodes/plant			Days to 1st blossoming	Days to 50% flowering
		30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS		
T_0: Control	80.50	14.49	22.67	50.10	6.34	13.00	22.50	5.08	7.58	14.00	37.00	40.00
T_1: GA_3 100 ppm	97.20	21.21	33.87	62.50	6.50	13.25	23.83	5.41	8.25	14.58	34.30	37.30
T_2: GA_3 150 ppm	97.20	23.30	37.39	79.17	7.00	13.15	23.25	5.40	8.30	12.75	34.67	37.60
T_3: GA_3 200 ppm	100.00	26.50	38.86	79.65	6.50	12.91	23.40	4.91xxx	7.91xxx	11.83	33.65	37.00
T_4: NAA 100 ppm	88.83	20.85	33.35	72.69	7.41	14.25	25.08	5.00	8.16	13.00	36.30	39.30
T_5: NAA 150 ppm	94.40	17.60	29.20	61.70	7.60	16.41	28.58	5.50	8.42	15.00	34.30	37.30
T_6: NAA 200 ppm	88.86	16.80	27.29	61.62	6.41	13.58	24.30	4.50	7.25	12.30	36.00	39.00
T_7: IAA 30 ppm	97.20	19.35	31.95	67.40	7.25	13.41	24.00	5.08	7.60	12.58	34.70	37.60
T_8: IAA 60 ppm	94.40	18.60	31.56	62.74	6.60	13.58	24.83	5.16	7.50	13.00	35.30	38.30
T_9: IAA 90 ppm	94.40	17.80	30.14	63.90	7.08	13.91	23.58	4.30	7.34	13.00	35.60	38.67
$CD_{0.05}$	8.31	5.77	6.28	14.32	0.35	0.84	2.48	0.65	0.72	1.94	1.62	1.45
SE(m)	2.77	1.93	2.13	4.79	0.18	0.28	0.83	0.22	0.24	0.65	0.54	0.48

were also at par with T_3 (4.91). At 60 DAS, higher number of nodes per plant was observed in T_5 (8.42), T_2 (8.30), T_1 (8.25), T_4 (8.16) and T_3 (7.91), which were at par, compared to T_6 (7.25), T_9 (7.34), T_8 (7.50), T_0 (7.58) and T_7 (7.60) which were also at par and also at par with T_3 (7.91). When observed at 90 DAS, T_5 (15.00), T_1 (14.58) and T_0 (14.00) exhibited more number of nodes per plant and were at par. In contrast, T_3 (11.83), T_6 (12.30), T_7 (12.58), T_2 (12.75), T_4 (13.00), T_8 (13.00) and T_9 (13.00) had minimum number of nodes per plant and were at par.

PGRs are incredibly important for helping plants grow. Take GA_3, for instance; it's a real game-changer for seeds. It helps them soak up water, which is a big deal for kicking off germination. When seeds can absorb enough water, they basically wake up from their sleep and start to sprout, as long as the conditions are right. Interestingly, a study by Zhu et al (2019) even found that GA_3 can help seeds handle salty conditions, making it easier for them to absorb water and germinate even when there's a lot of salt around.

Similar observations were made earlier by Shahid et al (2013) and Ravat and Makani (2015), specifically in okra. GA_3 encourages plant cells to divide and stretch out, which lengthens the spaces between leaves and ultimately makes the plant taller. This hormone helps stems grow by allowing cells to expand, leading to taller, stronger plants. Natesh et al (2005), Patil and Patel (2010) and Bhagure and Tambe (2013) all reported similar findings. This happens because the plant redirects energy from developing fruits and seeds towards its growing tips, resulting in increased plant height. NAA, another type of plant hormone, also boosts plant growth by promoting both cell division and expansion. What's more, NAA improves how efficiently plants perform photosynthesis and absorb nutrients, which means more leaves. That's why NAA often leads to a greater number of leaves compared to GA_3 and IAA, which don't have the same broad impact on leaf development.

Bhattarai et al (2021) conducted an experiment using only plant hormones (NAA and GA_3) and micronutrients (boron and zinc) on brinjal (eggplant) plants. They discovered that spraying with GA_3 (25 ppm) significantly improved various growth factors like plant height, the number of leaves, leaf size, plant canopy and root length. It also enhanced yield factors such as the number of fruits per plant, fruit weight and overall fruit yield. Interestingly, NAA (20 ppm) proved more effective for increasing the number of branches, stem thickness, main root length and fruit weight. Both GA_3 and NAA play a vital role in boosting the growth and yield of vegetable crops. GA_3 is a key growth promoter that aids in the overall development of many plants by encouraging cell elongation and division. NAA, on the other hand, influences various physiological processes, speeds up maturity and even improves the quality of fruits, as noted by Tomar et al (2020).

Effect of PGRs on blossoming of okra: The data in Table 1 show that minimum number of days for 1st blossoming 33.65, 34.30, 34.30, 34.67 and 34.70 was taken by T_3, T_1, T_5, T_2 and T_7 respectively, which were at par and maximum was taken by control T_0 (37.00), T_4 (36.30), T_6 (36.00) and T_9 (35.60), which were at par. The treatments T_3 (37.00), T_1 (37.30), T_5 (37.30), T_2 (37.60), T_7 (37.60) and T_8 (38.30) took minimum number of days for 50 per cent flowering and were at par, as against maximum 40.00, 39.30, 39.00 and 38.67 days in T_0, T_4, T_6 and T_9 respectively, which were at par. GA_3 enhances apical dominance. This may have led to accelerated flower bud initiation and opening compared to other growth regulators like NAA and IAA. Similar findings were noted in the studies of Singh et al (2012), Thomson et al (2015) and Raj et al (2016).

Effect of PGRs on fruit characteristics of okra: The data concerning effect of PGRs on fruit characteristics of okra are given in Table 2.

Maximum fruit length was recorded in case of treatments T_3 (12.52 cm) and T_4 (11.65 cm) which were at par and minimum in T_0 (8.42 cm) and T_9 (8.70 cm), the two being at par. Maximum fruit diameter was observed in T_3 (7.11 cm) and minimum in T_0 (3.84 cm). T_3 (41.00), T_1 (41.60) and T_2 (42.60) took minimum number of days for first fruiting and were at par. Maximum number of days was taken by T_0 (45.00), T_4 (43.60), T_7 (43.60) and T_9 (43.60), all being at par. T_3 (15.60 g) excelled in fruit weight as compared to all other treatments and T_0 produced lightest fruits (9.40 g). Fruit yield per plant was maximum in T_3 (0.21 kg), T_2 (0.19 kg) and T_1 (0.18 kg), all being at par. It was minimum in T_0 (0.11 kg), T_7 (0.12 kg), T_9 (0.12 kg) and T_8 (0.14 kg), the treatments being at par. The yield per plot and per hectare was recorded maximum in T_3 which was 2.50 kg per plot and 10.44 tonnes per hectare respectively. The yield was lowest in T_0 (1.04 kg/plot and 4.34 tonnes/ha) and T_9 (1.23 kg/plot and 5.15 tonnes/ha), the two treatments being at par.

GA_3 really boosts the plant's metabolism, helping with things like photosynthesis and moving nutrients around, which are all crucial for fruit growth. This sped-up metabolism means bigger and longer fruits. Kokare et al (2006), Patil and Patel (2010) and Shahid et al (2013) all saw similar results.

When researchers applied 200 ppm of GA_3 (that's treatment T_3), they noticed the fruit diameter increased. This is likely because GA_3 encourages the

Table 2. Effect of PGRs on fruit characteristics of okra cv Panchpatri

Treatment	Fruit length (cm)	Fruit diameter (cm)	Days to first fruiting	Fruit weight (g)	Fruit yield /plant (kg)	Fruit yield /plot (kg)	Fruit yield (tonnes/ha)
T_0: Control	8.42	3.84	45.00	9.40	0.11	1.04	4.34
T_1: GA_3 @ 100 ppm	9.63	5.58	41.60	11.60	0.18	1.98	8.25
T_2: GA_3 @ 150 ppm	9.60	6.10	42.60	14.80	0.19	2.14	8.95
T_3: GA_3 @ 200 ppm	12.52	7.11	41.00	15.60	0.21	2.50	10.44
T_4: NAA @ 100 ppm	11.65	6.45	43.60	13.20	0.16	1.73	7.23
T_5: NAA @ 150 ppm	11.07	5.70	43.30	14.39	0.17	1.92	8.01
T_6: NAA @ 200 ppm	9.80	6.09	43.00	13.70	0.16	1.75	7.29
T_7: IAA @ 30 ppm	10.17	5.61	43.60	10.50	0.12	1.46	6.11
T_8: IAA @ 60 ppm	11.45	4.80	43.30	12.56	0.14	1.63	6.80
T_9: IAA @ 90 ppm	8.70	4.96	43.60	10.27	0.12	1.23	5.15
$CD_{0.05}$	1.05	0.43	1.62	0.41	0.03	0.20	0.83
SE(m)	0.39	0.14	0.54	0.14	0.01	0.07	0.28

production of enzymes that loosen and expand cell walls, leading to larger fruits. The overall increase in fruit size, both length and diameter, comes down to the growth regulators helping cells enlarge and elongate. By influencing cell division and elongation, GA_3 can actually speed up the development of flower buds, meaning fruits set earlier. This hormone also makes the plant grow faster and become more vigorous, helping it reach the fruiting stage sooner. Singh et al (2012), Thomson et al (2015) and Raj et al (2016) have all reported similar findings.

Applying GA_3 really improves various aspects of yield, like increasing both the number of flowers and fruits per plant. More flowers mean more potential for fruits to set, which directly leads to heavier fruits. According to Meena et al (2017), GA_3 treatments significantly increase the number of fruits and seeds per fruit, contributing to heavier fruits. GA_3 also kickstarts seed hydrolase activity, which helps convert stored nutrients into sugars and amino acids. This process promotes seed development and fruit growth, providing the necessary nutrition for developing fruits, resulting in larger and heavier okra fruits.

These findings are consistent with what Patil and Patel (2010), Sanodiya et al (2017) and Bagale et al (2022) found.

While auxins mostly focus on root development and branching, GA_3 has a stronger effect on the parts of the plant above ground. This means it directly boosts the growth of yield-contributing parts, like the fruits. GA_3 increases the yield per plant by encouraging fruit set, making fruits bigger, improving photosynthesis and how nutrients are distributed and working with the plant's natural characteristics, all of which lead to a higher fruit yield per plant.

GA_3 specifically promotes cell division and elongation within developing okra fruits. This makes the fruits longer and bigger overall, directly contributing to a higher yield because larger fruits weigh more. GA_3 also improves how nutrients and food are sent to the developing okra fruits. By directing more resources to the fruits, GA_3 ensures they develop better, leading to more robust and heavier fruits. The use of several growth regulators really impacted okra yield, showing how important these chemicals are for boosting yield potential by changing many growth and yield characteristics. Patil and Patel (2010) also reported similar results.

CONCLUSION

This study clearly demonstrates the significant positive impact of plant growth regulators (PGRs), particularly gibberellic acid (GA_3) and naphthalene acetic acid (NAA), on improving the growth, yield and quality of okra, especially under the challenging hilly conditions of the Garhwal Himalaya.

The findings show that GA_3 at 200 ppm was exceptionally effective across multiple parameters, leading to higher germination rates, increased plant height, accelerated flowering, larger and heavier fruits and ultimately, a substantial boost in overall yield. This efficacy is attributed to GA_3's role in stimulating essential metabolic activities, promoting cell expansion and ensuring efficient nutrient distribution to the developing fruits. While NAA (specifically at 150 ppm) also showed notable benefits, particularly in increasing leaf production, GA_3 consistently proved to be a more comprehensive enhancer for okra development and productivity.

The results underscore the critical importance of judiciously applying these PGRs to unlock the full potential of okra cultivation in similar challenging environments. By optimizing their use, farmers can significantly enhance both the quantity and quality of their okra harvests.

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