**Impact of Growth Regulating Substances on Different Varieties of Okra (*Abelmoschus esculentus* L.)**

**Abstract**
A field study was conducted during the summer seasons of 2023–2024 at Guru Kashi University, Punjab, India, to evaluate the impact of plant growth regulators (PGRs) on four okra varieties: Varsha Uphar, Unnat Hisar, Hisar Naveen, and Kashi Chaman. The experiment employed a split-plot design with three replications, assigning varieties to main plots and ten PGR treatments to subplots. Treatments included combinations of gibberellic acid (GA₃: 200, 300, 400 ppm), indole-3-acetic acid (IAA: 10, 15, 20 ppm), naphthalene acetic acid (NAA: 10, 20, 30 ppm), ascorbic acid (250 ppm), and a control. Results demonstrated that **IAA at 20 ppm + ascorbic acid (250 ppm)** significantly enhanced vegetative growth, flowering, and yield parameters. Unnat Hisar treated with IAA 20 ppm + ascorbic acid recorded the highest plant height (9.28 cm at 25 DAS), internodal length (4.84 cm), and branches (20.6). Varsha Uphar under the same treatment achieved the tallest plants at harvest (102.5 cm), maximum leaves (21.88), fruits per plant (22.3), fruit length (13.44 cm), and yield (158.4 q/ha). Earliest flowering occurred in Hisar Naveen with NAA 10 ppm (35.13 days). The synergistic effect of IAA and ascorbic acid optimized growth and yield, particularly in Varsha Uphar and Unnat Hisar, establishing this combination as highly effective for okra cultivation in semi-arid regions.

**Keywords**: Okra, Plant Growth Regulators, IAA, NAA, Yield Enhancement

**Introduction**Okra (*Abelmoschus esculentus* L.), a member of the Malvaceae family (2n=130), is a nutrient-dense vegetable pivotal in tropical and subtropical agriculture. Rich in vitamins (A, C), minerals (calcium: 66 mg/100g), and antioxidants, it serves as food, animal feed, and industrial raw material (Anwar et al., 2009). India, the world’s second-largest vegetable producer (204.96 million tonnes annually), dominates okra cultivation, with Gujarat leading (1.132 million tonnes in 2023–24) (Saxena & Gandhi, 2015; CEIC, 2024). Despite its economic significance, okra yields remain suboptimal due to:

* **Environmental stress:** Okra is highly sensitive to abiotic stresses such as frost, drought, and excessive heat. Optimal growth occurs within a temperature range of 24–28°C, and deviations beyond this can lead to physiological disorders, delayed germination, and reduced fruit development. Drought stress impairs nutrient uptake, while waterlogging reduces oxygen availability to roots, both conditions severely affecting yield and quality.
* **Physiological constraints:** The crop is prone to flower abscission and poor fruit set, especially under high-temperature conditions and hormonal imbalance. Limited assimilate partitioning to reproductive parts due to insufficient sink strength or hormonal signaling leads to decreased pod formation. The excessive drop of buds and immature fruits further reduces marketable yield, necessitating the use of external agents like plant growth regulators to optimize these physiological processes.

**Plant Growth Regulators (PGRs)** offer a sustainable solution by modulating physiological processes:

* **Gibberellic Acid (GA₃):** GA₃ is a diterpenoid hormone that plays a crucial role in stem elongation by degrading DELLA proteins, which are negative regulators of growth (Hedden & Sponsel, 2015). It also enhances cell wall loosening and vascular differentiation, promoting greater nutrient transport efficiency. In okra, foliar application of GA₃ at 50–100 ppm has shown to increase internodal length, early vegetative growth, and flowering. Field trials report a 25–30% increase in yield with GA₃ treatments under both irrigated and rainfed conditions (Kusvuran, 2012).
* **Indole-3-Acetic Acid (IAA):** IAA is a naturally occurring auxin that regulates apical dominance, root development, and fruit set. It enhances root biomass by 40–50%, improving water and nutrient uptake. Moreover, IAA modulates ethylene synthesis, reducing premature flower and fruit drop (Das & Das, 1995; Mukhtar, 2008). Its role in increasing sink strength allows more assimilates to be directed towards developing fruits, thereby improving pod number and size in okra.
* **Naphthalene Acetic Acid (NAA):** As a synthetic auxin analog, NAA accelerates early flowering by inducing ethylene inhibition at lower concentrations, especially under short photoperiods. However, at high concentrations (>30 ppm), it can trigger excessive ethylene biosynthesis, leading to growth inhibition, reduced branching, and early senescence (Taiz & Zeiger, 2010). The dose-dependent response of NAA makes its application highly sensitive and variety-specific.
* **Ascorbic Acid (AA):** As a potent antioxidant, AA plays a dual role—reducing reactive oxygen species (ROS) and enhancing stress tolerance under adverse environmental conditions. It stabilizes cellular membranes, supports chlorophyll biosynthesis, and improves the efficiency of other PGRs when used in combination. AA synergizes particularly well with auxins like IAA to promote sustained vegetative vigor and fruit development by minimizing oxidative damage and enhancing enzymatic activity (Sharma & Singh, 2021).

This study investigated:

1. The interaction between PGRs and high-yielding okra varieties.
2. The suitability of varieties for southwestern Punjab’s agro-climate.
3. The efficacy of GA₃, IAA, and NAA in improving growth and yield.

**Materials and Methods**

**Experimental Site**: The study was conducted at the Vegetable Research Farm, Guru Kashi University, Talwandi Sabo, Bathinda, Punjab (21.5°N, 70.5°E; 60 m altitude). This location lies in the south-western agro-climatic zone of Punjab and is characterized by a semi-arid subtropical climate. The region experiences hot summers and mild winters, with annual rainfall ranging between 718–1087 mm—most of which occurs during the southwest monsoon season (July–September). During the cropping period, average temperatures fluctuate between 24°C and 28°C, which is within the optimal range for okra growth, development, and reproductive performance. The soil of the experimental field was medium-black, deep, and alluvial in nature, with good moisture retention and moderate infiltration rate. It was neutral in reaction (pH 7.2), low in organic carbon content (0.86%), and moderately fertile. Soil testing before sowing revealed available nitrogen at 240 kg/ha, phosphorus at 22 kg/ha, and potassium at 380 kg/ha, making it suitable for the cultivation of short-duration vegetable crops like okra.

**Experimental Design**: A split-plot design with three replications was used:

* **Main plots**: Four varieties—Varsha Uphar, Unnat Hisar, Hisar Naveen, Kashi Chaman.
* **Subplots**: Ten PGR treatments (Table 1).

**Table 1: PGR Treatments Evaluated**

|  |  |
| --- | --- |
| **Treatment** | **Composition** |
| T1 | GA₃ 200 ppm + Ascorbic acid 250 ppm |
| T2 | GA₃ 300 ppm + Ascorbic acid 250 ppm |
| T3 | GA₃ 400 ppm + Ascorbic acid 250 ppm |
| T4 | IAA 10 ppm + Ascorbic acid 250 ppm |
| T5 | IAA 15 ppm + Ascorbic acid 250 ppm |
| T6 | IAA 20 ppm + Ascorbic acid 250 ppm |
| T7 | NAA 10 ppm |
| T8 | NAA 20 ppm |
| T9 | NAA 30 ppm |
| T10 | Control (distilled water) |

**Agronomic Practices**:

* **Seed Treatment**: Seeds soaked in PGR solutions for 8 hours, air-dried, and sown.
* **Sowing**: Manual dibbling at 2–3 cm depth (45 cm × 10 cm spacing) during summer.
* **Fertilization**: 100 kg N/ha (50% basal, 50% top-dressed at first picking).
* **Irrigation**: Light post-sowing irrigation, followed by need-based scheduling.
* **Harvesting**: Fruits picked at physiological maturity.

**Data Collection**:

* **Growth Parameters**: Plant height (25, 50, 75 DAS, harvest), internodal length, leaves/plant, branches/plant.
* **Reproductive Traits**: Days to flowering initiation, 50% flowering.
* **Yield Attributes**: Fruit length, fruits/plant, yield (q/ha).
* **Statistical Analysis**: Split-plot ANOVA; means compared via CD (\*p\* ≤ 0.05).

**Results and Discussion**

**Growth Parameters**

This table details plant height (cm) across four growth stages (25, 50, 75 DAS, and harvest) under various plant growth regulator treatments. The application of IAA 20 ppm combined with ascorbic acid 250 ppm consistently resulted in the most pronounced increase in plant height across all varieties, with Varsha Uphar reaching a maximum of 102.5 cm at harvest—approximately 37% taller than its untreated control. This indicates enhanced cell division and elongation facilitated by the synergistic effect of auxin and antioxidant support. Unnat Hisar and Kashi Chaman also responded well, reaching 99.28 cm and 99.18 cm, respectively, reflecting the consistency of this treatment across genotypes. In contrast, GA₃ treatments, particularly at 400 ppm, promoted moderate growth, improving height by 12–15% over control, likely due to DELLA protein degradation but with diminishing returns at higher concentrations. NAA 10 ppm showed minimal impact, and plants under control conditions exhibited stunted growth, with Kashi Chaman recording the lowest final height of 66.14 cm. These findings emphasize that optimal concentrations of IAA combined with ascorbic acid not only enhance elongation but also support sustainable height progression through critical vegetative phases, particularly in genetically vigorous cultivars like Varsha Uphar.

**Table 2: Plant Height (cm)**

| **Treatment** | **Variety** | **25 DAS** | **50 DAS** | **75 DAS** | **At Harvest** |
| --- | --- | --- | --- | --- | --- |
| **IAA 20ppm + AA 250ppm** | **Varsha Uphar** | 7.26 | 72.67 | 92.67 | 102.50 |
| **Unnat Hisar** | 9.28 | 74.26 | 91.24 | 99.28 |
|  | **Hisar Naveen** | 8.82 | 73.46 | 89.82 | 100.90 |
|  | **Kashi Chaman** | 8.78 | 74.26 | 89.18 | 99.18 |
| **IAA 15ppm + AA 250ppm** | **Varsha Uphar** | 5.74 | 60.21 | 78.11 | 79.59 |
|  | **Unnat Hisar** | 7.02 | 60.53 | 76.78 | 79.14 |
|  | **Hisar Naveen** | 7.27 | 60.37 | 75.44 | 79.37 |
| **Kashi Chaman** | 6.95 | 60.03 | 72.71 | 79.17 |
| **GA₃ 400ppm + AA 250ppm** | **Varsha Uphar** | 6.53 | 55.83 | 74.42 | 76.58 |
| **Unnat Hisar** | 7.14 | 56.04 | 72.84 | 73.48 |
| **Hisar Naveen** | 6.44 | 55.93 | 71.27 | 75.03 |
| **Kashi Chaman** | 7.57 | 55.23 | 69.84 | 74.12 |
| **NAA 10ppm** | **Hisar Naveen** | 6.30 | 47.76 | 63.30 | 68.69 |
| **Varsha Uphar** | 4.28 | 47.24 | 67.39 | 69.00 |
| **Control** | **Kashi Chaman** | 7.47 | 47.00 | 61.03 | 66.14 |
| **Varsha Uphar** | 5.67 | 46.49 | 65.46 | 66.89 |
| **CD (0.05%)** |  | 0.40 | 1.38 | 2.72 | 1.48 |

**Table 3: Internodal Length (cm) and Branching at Harvest**

| **Treatment** | **Variety** | **Internodal Length** | **Branches/Plant** |
| --- | --- | --- | --- |
| **IAA 20ppm + AA 250ppm** | **Unnat Hisar** | 4.84 | 20.6 |
|  | **Kashi Chaman** | 4.79 | 19.8 |
|  | **Varsha Uphar** | 4.39 | 16.4 |
| **IAA 15ppm + AA 250ppm** | **Unnat Hisar** | 3.84 | 18.3 |
| **Kashi Chaman** | 3.81 | 17.1 |
| **NAA 30ppm** | **Unnat Hisar** | 3.79 | 13.4 |
| **Control** | **Unnat Hisar** | 3.47 | 7.2 |
| **CD (0.05%)** |  | NS | 1.80 |

This table highlights the comparative influence of plant growth regulators on internodal elongation and branch development. The treatment involving IAA 20 ppm + ascorbic acid 250 ppm proved most effective, with Unnat Hisar achieving the longest internodes (4.84 cm) and the highest branching (20.6 branches/plant). Similar improvements were observed in Kashi Chaman and Varsha Uphar, underscoring the treatment’s broad efficacy. The improved branching enhances canopy spread and light interception, which is essential for optimizing photosynthetic activity. In contrast, NAA at 30 ppm moderately increased internode length (3.79 cm) but reduced branching (13.4 branches), indicating a trade-off. Control plants performed poorly (3.47 cm, 7.2 branches), confirming the crucial role of PGRs in lateral growth stimulation under semi-arid conditions.

**Table 4: Leaf Development**

|  |  |  |  |
| --- | --- | --- | --- |
| Treatment | Variety | Leaves at 25 DAS | Leaves at Harvest |
| **IAA 20ppm + AA 250ppm** | **Varsha Uphar** | **3.59** | **21.88** |
|  | **Unnat Hisar** | **4.55** | **21.57** |
|  | **Kashi Chaman** | **4.23** | **21.72** |
| **GA₃ 300ppm + AA 250ppm** | **Unnat Hisar** | **4.45** | **18.87** |
| **Control** | **Varsha Uphar** | **3.77** | **16.92** |
| **CD (0.05%)** |  | **0.20** | **1.01** |

Leaf count data reveals a significant enhancement in foliar development under the IAA 20 ppm + ascorbic acid 250 ppm treatment, which boosted leaf production by approximately 29% over the control. Varsha Uphar exhibited the highest leaf count at harvest (21.88 leaves/plant), while Unnat Hisar and Kashi Chaman also produced over 21 leaves, indicating the consistency of this treatment across multiple genotypes. At the early vegetative stage (25 DAS), Unnat Hisar recorded 4.55 leaves—20% more than the control—demonstrating early initiation of leaf primordia and accelerated vegetative growth. The increase in leaf number enhances total leaf area, thus improving light capture and photosynthetic efficiency, which are directly correlated with biomass accumulation and yield potential.

While GA₃ 300 ppm + ascorbic acid also encouraged early leaf emergence (4.45 leaves at 25 DAS in Unnat Hisar), its effect plateaued in later stages, with final leaf counts lower than those under the IAA treatment. This suggests that IAA not only supports rapid early growth but also sustains leaf development throughout the crop cycle. The persistent impact of IAA combined with the antioxidative properties of ascorbic acid creates a stable internal environment for continuous cell division and expansion, critical for productivity in semi-arid agroclimatic conditions.

**Table 5: Reproductive Parameters**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatment** | **Variety** | **Days to Flowering** | **Fruit Length (cm)** |
| **NAA 10ppm** | **Hisar Naveen** | 35.13 | 10.05 |
|  | **Varsha Uphar** | 39.83 | 10.48 |
| **IAA 20ppm + AA 250ppm** | **Varsha Uphar** | 45.00 | 13.44 |
|  | **Kashi Chaman** | 43.83 | 13.27 |
| **Control** | **Hisar Naveen** | 39.12 | 10.12 |
| **CD (0.05%)** |  | 0.49 | 1.00 |

Naphthalene Acetic Acid (NAA) at 10 ppm effectively induced the earliest flowering across treatments, particularly in Hisar Naveen, which flowered in just 35.13 days. While this early initiation is beneficial for quick crop cycles, it was associated with lower yield performance. In contrast, the combination of Indole-3-Acetic Acid (IAA) at 20 ppm and ascorbic acid at 250 ppm significantly improved fruit development parameters. Varsha Uphar exhibited the longest fruit length (13.44 cm) and the highest number of fruits per plant (16.4), nearly twice that of the control. Thus, while NAA promoted earliness, the IAA-AA synergy optimized fruit size, number, and overall productivity.

**Table 6: Yield Performance**

|  |  |  |
| --- | --- | --- |
| **Treatment** | **Variety** | **Fruit Length (cm)** |
| **IAA 20ppm + AA 250ppm** | Varsha Uphar | 158.4 |
|  | Kashi Chaman | 148.8 |
|  | Unnat Hisar | 150.6 |
|  | Unnat Hisar | 138.3 |
| **NAA 10ppm**  | Hisar Naveen | 110.7 |
| **Control** | Varsha Uphar | 98.5 |
| **CD (0.05%)** |  | 2.5 |

Yield data (q/ha) demonstrates IAA 20ppm + ascorbic acid’s dominance: Varsha Uphar produced 158.4 q/ha—61% higher than control. Kashi Chaman and Unnat Hisar also exceeded 148 q/ha under this treatment. NAA 10ppm yielded poorly (110.7 q/ha in Hisar Naveen), reinforcing that early flowering alone does not guarantee high productivity. IAA-ascorbic acid’s yield advantage stems from enhanced vegetative growth and fruit retention.

**Discussion 4.1.**

Vegetative Growth Enhancement IAA 20 ppm + AA 250 ppm treatment notably outperformed other treatments by:

* + Stimulating cell elongation: IAA activates the TIR1/AFB-Aux/IAA-ARF signaling pathway, promoting cell division and elongation, thus substantially enhancing plant height, internodal length, and overall biomass (Vanneste & Friml, 2009).
	+ Enhancing root architecture: The improved root system significantly increases water and nutrient uptake efficiency, crucial for supporting vigorous vegetative growth, especially under semi-arid conditions (Das & Das, 1995).
	+ Mitigating oxidative stress: AA effectively scavenges reactive oxygen species (ROS), stabilizing cellular membranes during rapid growth phases, which maintains plant vigor and resilience against abiotic stresses (Sharma & Singh, 2021).

Varsha Uphar exhibited superior vegetative response, attaining a height of 102.5 cm at harvest, likely due to its intrinsic genetic vigor and resistance to yellow vein mosaic virus (YVMV), maximizing the effectiveness of the IAA and AA application. GA₃ 400 ppm combined with AA demonstrated synergy, as GA₃ promoted vegetative growth via DELLA protein degradation (Hedden & Sponsel, 2015), while AA reduced GA₃ photodegradation, slightly enhancing growth. However, this combination increased plant height by only 12% over control, proving less effective than IAA-based treatments. High concentrations (>30 ppm) of NAA limited vegetative growth by promoting ethylene synthesis, leading to early senescence and reduced vigor (Taiz & Zeiger, 2010).

**4.2. Reproductive Efficiency**

• **NAA 10 ppm:** Accelerates flowering via ethylene suppression in floral abscission zones, enabling earlier bloom initiation, particularly in Hisar Naveen (35.13 days) (Mukhtar, 2008). However, early flowering may lead to reduced vegetative growth, limiting biomass accumulation and negatively affecting potential yield.

• **IAA 20 ppm + AA 250 ppm:** Slightly delays flowering but significantly enhances reproductive efficiency by:

* Improving carbohydrate allocation, channeling more assimilates to fruit development, thus enhancing pod size and uniformity (Singh et al., 2018).
* Reducing flower and fruit abscission by approximately 20–25% through ethylene inhibition (Mukhtar, 2008).
* **Yield outcomes:** Varsha Uphar achieved a yield of 158.4 q/ha, consistent with Kumar et al. (2020), who reported 25–30% yield increases with auxin-based treatments.

**4.3. Practical Implications**

* **Semi-arid regions:** IAA 20 ppm + AA 250 ppm enhances root development, optimizing water and nutrient use efficiency, vital for crop resilience under stress conditions.
* **Variety selection:** Varsha Uphar and Unnat Hisar demonstrate strong positive responses to IAA-AA treatments, making them ideal candidates for regions prone to abiotic stress.
* **Economic evaluation:** NAA's limited yield benefits necessitate careful cost-benefit analysis, whereas the substantial yield increases from the IAA-AA combination justify its broader adoption for enhanced productivity and profitability.

**Conclusion**

Indole-3-Acetic Acid (IAA) at 20 ppm and ascorbic acid (AA) at 250 ppm improve okra growth, production, and quality, notably in Varsha Uphar and Unnat Hisar. This synergistic combination boosts plant height, intermodal length, branch proliferation, and leaf development. IAA boosts root development, which enhances nutrient and water intake in semi-arid southern Punjab. Ascorbic acid also reduces oxidative stress by scavenging reactive oxygen species, preserving cellular integrity, and improving photosynthetic efficiency, allowing plants to develop rapidly after IAA. This treatment significantly boosts marketable production, fruit length, and consistent pod quality by improving flower retention and reducing fruit abscission. Semi-arid farmers should apply this integrated method to boost production and resource efficiency, making okra cultivation more adaptable to environmental pressures. The molecular and biochemical processes of the IAA-AA synergy should be investigated to increase horticultural production and quality.

**Author Disclaimer**

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of this manuscript

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