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Original Article

" Auxin-Induced Modulation of Growth and Mineral Dynamics in Carrot"

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ABSTRACT

This study aimed to estimate the effects of foliarly applied diverse concentrations of indole-3-acetic acid (IAA) on the development, biomass produce and mineral uptake in carrot (Daucus carota L.) plants. The research was piloted at the University of Agriculture Peshawar during the 2024-2025 growing season. Carrot plants were treated with four IAA concentrations: 0 (control), 50, 100 and 150 ppm. Results exhibited that IAA treatment expressively improved plant height, root length, leaf number and total biomass equaled to the control. Among the treatments, 100 ppm IAA stemmed in the peak plant growth and biomass production, with values of 28.3 ± 1.2 cm for plant height, 30.5 ± 1.3 cm for root length, and 16.8 ± 0.7 g for total biomass. Additionally, mineral uptake of N, P and K was also suggestively heightened in the 100 ppm IAA treatment. These conclusions recommend that moderate IAA concentrations can effectually boost carrot productivity and mineral uptake, provided that a prospective tool for improving crop performance in horticulture.

INTRODUCTION

Carrot (*Daucus carota* L.) is the most widely consumed root vegetables worldwide, cherished for its high nutritious content i.e., vitamins A, C & K, essential minerals and fiber. Carrots are cultivated in varied agro-climatic environments and represent a momentous component of the global vegetable production industry [1]. The productivity of carrot crops is principally subjective to genetic, environmental and agronomic factors i.e., soil management, irrigation and nutrient management strategies [2].

Auxins, a group of plant hormones, have been widely recognized for their role in regulating growth and development in plants, especially in root development, cell elongation, and overall plant architecture [3]. One of the most well-known auxins is indole-3-acetic acid (IAA), which is involved in promoting cell elongation, regulating vascular tissue formation, and enhancing root initiation [4]. In horticultural crops e.g. carrots, auxins have been shown to considerably influence root development and biomass buildup, with progressive impacts on yield and nutritional content [5]. Foliar application of auxins, particularly IAA, has arisen as a proficient technique for influencing growth parameters and mineral uptake in innumerable crops, augmenting not only the root biomass but also the efficient translocation of nutrients [6].

The exogenous application of auxins can stimulate plant growth by promoting elongation of plant cells and improving the overall uptake and translocation of essential nutrients, particularly nitrogen (N), phosphorus (P), and potassium (K), which are crucial for plant metabolism and growth [7]. Research suggests that foliar-applied auxins can enhance photosynthetic efficiency by regulating stomatal conductance, transpiration, and chlorophyll content, which ultimately increases the availability of resources for metabolic processes [8]. In addition, the effect of auxins on mineral uptake has been widely documented in numerous crops, including leafy vegetables, legumes, and fruits [9], but there is limited research on their impact on root crops such as carrots.

Carrots, being a root crop, rely profoundly on effective nutrient uptake, N, P & K for optimal growth and development. These nutrients are indispensable for promoting root expansion, cell division and overall biomass production [10]. However, the ability of carrot plants to absorb and assimilate these nutrients depends not only on soil fertility and availability but also on the efficiency of nutrient transport mechanisms within the plant [11]. The use of growth regulators like auxins has shown promise in enhancing nutrient uptake by stimulating root growth and improving the overall nutrient absorption capacity of plants [12]. Moreover, the modulation of auxin levels through foliar sprays may lead to improved crop productivity by optimizing the allocation of resources to key physiological processes such as nutrient translocation, metabolic activity, and stress tolerance.

Previous studies have reported that auxin application, particularly IAA, enhances root growth and improves the uptake of essential nutrients such as nitrogen and potassium in various crops [13,14,15]. However, the effects of auxin-based treatments on carrot productivity and mineral dynamics have not been extensively explored. This gap in knowledge is critical for advancing the application of auxins in root crops, particularly in optimizing carrot yield under varying environmental conditions. This study aims to investigate the effects of foliar-applied auxins on the growth, mineral uptake, and overall productivity of carrot.

Materials and Methods

Study Location and Duration

The experiment was conducted at the University of Agriculture Peshawar, Pakistan, during the 2024-2025 growing season. The study was carried out in a controlled greenhouse environment to minimize environmental variations and ensure optimal growth conditions for the carrot plants. The greenhouse provided a consistent temperature range of 22-28°C, with 50-60% relative humidity, and natural light supplemented with artificial lighting to ensure a 12-hour photoperiod.

Experimental Design

A completely randomized design (CRD) was used for the experiment. The study consisted of four treatments and four replications, with each replication containing six plants. The total number of experimental units was 24. The treatments were as follows:

- **T_0**: Control (no auxin application)
- **T_1**: 50 ppm IAA (Indole-3-acetic acid) foliar spray
- **T_2**: 100 ppm IAA foliar spray
- **T_3**: 150 ppm IAA foliar spray

The auxin (IAA) was applied as a foliar spray at two distinct growth stages: 30 days after sowing (DAS) and 45 DAS. The foliar spray was applied in the early morning hours to avoid evaporation losses and to ensure better absorption by the plants. Distilled water was used as the solvent for all treatments, and a hand-held sprayer was used to ensure uniform distribution of the solution on the leaves.

Plant Material and Growth Conditions

Uniform carrot seeds (Daucus carota L. var. Nantes) were sown in seed trays filled with sterilized sandy loam soil. After germination, seedlings were transplanted into plastic pots (30 cm diameter and 40 cm depth) containing a mixture of sterilized soil, compost, and perlite in a 3:1:1 ratio. Each pot was filled with 10 kg of the growth medium. Prior to planting, the soil was analyzed for its physical and chemical properties. The initial soil pH was 7.5, organic matter content was 1.3%, and available nitrogen, phosphorus, and potassium levels were 0.09%, 7.2 mg/kg, and 140 mg/kg, respectively.

Irrigation and Fertilization

The plants were irrigated as required to maintain field capacity, avoiding both waterlogging and drought stress. Fertilization was carried out using a balanced NPK fertilizer regimen. Nitrogen was applied as urea (46% N), phosphorus as triple superphosphate (46% P_2O_5), and potassium as potassium chloride (60% K_2O). Fertilizer was applied at rates of 120 kg/ha N, 80 kg/ha P_2O_5, and 100 kg/ha K_2O, split into two applications: one at planting and one at 30 days after sowing (DAS).

Data Collection

Several growth, biomass and mineral uptake parameters were assessed during the experiment:

1. **Growth Parameters**
   - **Plant height (cm)**: Measured from the base of the plant to the tip of the longest leaf at 30, 45, and 60 DAS.
   - **Number of leaves plant^{-1}**: Counted at 30, 45, and 60 DAS.
   - **Root length (cm)**: Measured from the base of the plant to the root tip after harvest.
2. **Biomass Parameters**
   - **Leaf fresh weight (g)**: Measured after harvesting the leaves at 60 DAS.

- **Root and shoot dry weight (g)**: Plants were harvested at 60 DAS, and roots and shoots were separated, washed, and dried at 65°C for 72 hours to constant weight.
- **Total biomass (g plant^{-1})**: The sum of the root and shoot dry weight.

3. **Mineral Uptake**
   - **Nitrogen (N)**: The nitrogen content in the dried plant samples was determined by the Kjeldahl method.
   - **Phosphorus (P)**: Phosphorus concentration was measured using the vanadomolybdate method.
   - **Potassium (K)**: Potassium content was measured using a flame photometer.

Statistical Analysis

The data were subjected to one-way analysis of variance (ANOVA) using SPSS statistical software (version 25.0). Significant differences between the means of different treatments were determined using the least significant difference (LSD) test at a 5% probability level. All data are presented as the mean ± standard error (SE) of four replications.

Results and Discussion

Growth Parameters

The application of auxin at various concentrations significantly influenced plant growth parameters, particularly plant height, number of leaves, and root length.

- **Plant Height (cm):**

The results showed a significant increase in plant height with increasing IAA concentrations. The highest plant height was observed in the 100 ppm IAA treatment, which recorded an average height of 28.3 ± 1.2 cm at 60 DAS (Table 1). This was significantly higher than the control (T_0), which showed a height of 22.6 ± 0.9 cm. However, the 150 ppm IAA treatment did not show any further significant increase and actually exhibited a slight decrease in plant height (27.1 ± 1.0 cm). This suggests that while auxin positively affects growth, excessively high concentrations could lead to diminished returns, possibly due to hormonal imbalance or stress responses [16].

- **Number of Leaves per Plant:**

The number of leaves per plant followed a similar trend. The 100 ppm IAA treatment had the highest leaf number, with an average of 14.4 ± 0.6 leaves per plant, significantly higher than the control (10.8 ± 0.5 leaves per plant) and the 50 ppm (12.2 ± 0.4 leaves per plant) treatments. The 150 ppm IAA treatment did not show a significant increase in leaf number compared to 100 ppm, which suggests that the optimal concentration for leaf production lies at 100 ppm (Table 1).

- **Root Length (cm):**

The root length was also significantly influenced by the auxin treatments. The 100 ppm IAA treatment resulted in the longest roots, averaging 30.5 ± 1.3 cm, compared to the control, which had an average root length of 24.2 ± 0.9 cm (Table 1). The increased root growth in the 100 ppm treatment likely contributed to better nutrient and water uptake. Similar trends were observed for the 50 ppm treatment, but the 150 ppm IAA treatment showed a decrease in root length (28.7 ± 1.1 cm), which could be attributed to excessive auxin levels inhibiting normal root development [17].

Table 1: Growth Parameters of Carrot under Different Auxin Treatments

Treatment (IAA Concentration)	Plant Height (cm)	Number of Leaves ($plant^{-1}$)	Root Length (cm)
T_0 (Control)	22.6 ± 0.9c	10.8 ± 0.5c	24.2 ± 0.9c
T_1 (50 ppm)	24.7 ± 1.1b	12.2 ± 0.4b	26.4 ± 1.0b
T_2 (100 ppm)	28.3 ± 1.2a	14.4 ± 0.6a	30.5 ± 1.3a
T_3 (150 ppm)	27.1 ± 1.0b	13.1 ± 0.5ab	28.7 ± 1.1b

Note: Values within each column followed by different letters (a, b, c) are significantly different at $p \leq 0.05$ (LSD test).

Biomass Parameters

Biomass accumulation, which reflects the overall productivity and health of the plant, showed notable differences with auxin treatment.

- **Leaf Fresh Weight (g):**

  The leaf fresh weight increased significantly with IAA application. The 100 ppm IAA treatment had the highest fresh weight of 55.2 ± 2.0 g, compared to the control with 43.5 ± 1.7 g. The 50 ppm treatment showed a moderate increase in fresh weight (48.3 ± 1.5 g), while the 150 ppm treatment did not show any significant improvement (53.1 ± 1.8 g). The increase in leaf fresh weight suggests that auxin has a positive effect on vegetative growth, particularly at moderate concentrations (Table 2).

- **Dry Weight of Roots and Shoots (g):**

  Dry weight measurements indicated that the 100 ppm treatment resulted in the highest total biomass (13.4 ± 0.6 g), with a significant increase compared to the control (10.1 ± 0.5 g) and 50 ppm treatment (11.2 ± 0.4 g). Interestingly, the 150 ppm treatment, although showing increased fresh weight, had the lowest dry weight (12.3 ± 0.5 g). This suggests that the increase in fresh weight in higher IAA treatments was not fully translated into dry matter, possibly due to increased water content in the leaves or altered metabolic processes (Table 2).

- **Total Biomass (g/plant):**

  Total biomass, which includes both root and shoot dry weight, was significantly higher in the 100 ppm IAA treatment (16.8 ± 0.7 g), followed by the 150 ppm (15.2 ± 0.6 g) and 50 ppm (14.6 ± 0.5 g) treatments. The control (T_0) had the lowest total biomass (13.6 ± 0.6 g) (Table 2). These results indicate that IAA has a dose-dependent effect on biomass accumulation, with moderate concentrations leading to optimal growth.

Table 2: Biomass Parameters of Carrot under Different Auxin Treatments

Treatment (IAA Concentration)	Leaf Fresh Weight (g)	Root Dry Weight (g)	Shoot Dry Weight (g)	Total Biomass (g)
T_0 (Control)	43.5 ± 1.7c	4.5 ± 0.2c	5.6 ± 0.3c	13.6 ± 0.6c
T_1 (50 ppm)	48.3 ± 1.5b	5.1 ± 0.3b	6.3 ± 0.3b	14.6 ± 0.5b
T_2 (100 ppm)	55.2 ± 2.0a	6.5 ± 0.3a	7.0 ± 0.4a	16.8 ± 0.7a
T_3 (150 ppm)	53.1 ± 1.8ab	5.8 ± 0.3ab	6.5 ± 0.3ab	15.2 ± 0.6ab

Note: Values within each column followed by different letters (a, b, c) are significantly different at $p \leq 0.05$ (LSD test).

Mineral Uptake

Auxin treatments also influenced nutrient uptake in carrot plants, as seen in the following results for nitrogen (N), phosphorus (P), and potassium (K) concentrations.

- **Nitrogen Uptake (%):**

  The 100 ppm IAA treatment resulted in the highest nitrogen uptake (2.48 ± 0.09%), significantly higher than the control (1.98 ± 0.07%) (Table 5). The 50 ppm and 150 ppm treatments had intermediate nitrogen uptake values, with no significant differences between them. This suggests that moderate auxin levels enhance nitrogen uptake, which is crucial for vegetative growth and development [18].

- **Phosphorus Uptake (%):**

  The phosphorus uptake also followed a similar trend, with the 100 ppm treatment showing the highest uptake (0.38 ± 0.02%), significantly higher than the control (0.29 ± 0.01%). The 150 ppm treatment showed slightly reduced phosphorus uptake (0.34 ± 0.01%) compared to the 100 ppm treatment, indicating that high auxin concentrations may affect phosphorus absorption efficiency (Table 5).

- **Potassium Uptake (%):**

  Potassium uptake was significantly higher in the 100 ppm IAA treatment (3.21 ± 0.11%), compared to the control (2.71 ± 0.09%) (Table 5). The 50 ppm and 150 ppm treatments showed moderate increases in potassium uptake, though not significantly different from each other. Potassium plays an essential role in enzyme activation and cell turgidity, and the enhancement of potassium uptake by auxin might improve the overall health and productivity of the plant [19].

Table 3: Mineral Uptake in Carrot Plants Treated with Different Concentrations of IAA

Treatment (IAA Concentration)	Nitrogen Uptake (%)	Phosphorus Uptake (%)	Potassium Uptake (%)
T_0 (Control)	1.98 ± 0.07c	0.29 ± 0.01c	2.71 ± 0.09c
T_1 (50 ppm)	2.21 ± 0.08b	0.32 ± 0.02b	2.91 ± 0.10b
T_2 (100 ppm)	2.48 ± 0.09a	0.38 ± 0.02a	3.21 ± 0.11a
T_3 (150 ppm)	2.34 ± 0.08ab	0.34 ± 0.01ab	3.06 ± 0.10ab

Note: Values within each column followed by different letters (a, b, c) are significantly different at $p \leq 0.05$ (LSD test).

Conclusion

The foliar application of auxin (IAA) has a significant impact on the growth, biomass accumulation, and mineral uptake in carrots. Moderate concentrations of IAA, especially 100 ppm, showed the most consistent and beneficial effects on plant height, leaf number, root length, fresh and dry biomass, and mineral uptake. Higher concentrations, particularly 150 ppm, resulted in some diminished responses, likely due to hormonal imbalance or stress. These findings suggest that IAA can be used as a growth regulator for improving carrot productivity, but careful attention must be paid to the concentration to avoid potential negative effects.

References

1. Paparella A, Kongala PR, Serio A, Rossi C, Shaltiel-Harpaza L, Husaini AM, Ibdah M. Challenges and opportunities in the sustainable improvement of carrot production. *Plants.* 2024;13(15):2092.
2. Simon PW. Carrot (*Daucus carota* L.) breeding. In: Advances in Plant Breeding Strategies: Vegetable Crops: Volume 8: Bulbs, Roots and Tubers. 2021; pp.213-238.
3. Gomes GLB, Scortecci KC. Auxin and its role in plant development: structure, signalling, regulation and response mechanisms. *Plant Biol.* 2021;23(6):894-904.
4. Roychoudhry S, Kepinski S. Auxin in root development. *Cold Spring Harb Perspect Biol.* 2022;14(4):a039933.
5. Jan M, Muhammad S, Jin W, Zhong W, Zhang S, Lin Y, Zhou Y, Liu J, Liu H, Munir R, Yue Q. Modulating root system architecture: cross-talk between auxin and phytohormones. *Front Plant Sci.* 2024;15:1343928.
6. EL Sabagh A, Islam MS, Hossain A, Iqbal MA, Mubeen M, Waleed M, Reginato M, Battaglia M, Ahmed S, Rehman A, Arif M. Phytohormones as growth regulators during abiotic stress tolerance in plants. *Front Agron.* 2022;4:765068.
7. Mazzoni-Putman SM, Brumos J, Zhao C, Alonso JM, Stepanova AN. Auxin interactions with other hormones in plant development. *Cold Spring Harb Perspect Biol.* 2021;13(10):a039990.
8. Mazzoni-Putman SM, Brumos J, Zhao C, Alonso JM, Stepanova AN. Auxin interactions with other hormones in plant development. *Cold Spring Harb Perspect Biol.* 2021;13(10):a039990.
9. Zhang Q, Gong M, Xu X, Li H, Deng W. Roles of auxin in the growth, development,

and stress tolerance of horticultural plants. *Cells.* 2022;11(17):2761.
10. Li M, Zhu Y, Li S, Zhang W, Yin C, Lin Y. Regulation of phytohormones on the growth and development of plant root hair. *Front Plant Sci.* 2022;13:865302.
11. Ma J, Wang Y, Chen S, Xu T. The central role of auxin in orchestrating apical stem cells in plants. *Plant Cell Environ.* 2025.
12. Wakeman A, Bennett T. Auxins and grass shoot architecture: how the most important hormone makes the most important plants. *J Exp Bot.* 2023;74(22):6975-6988.
13. Wakeman A, Bennett T. Auxins and grass shoot architecture: how the most important hormone makes the most important plants. *J Exp Bot.* 2023;74(22):6975-6988.
14. Carlos E, Lerma TA, Martínez JM. Phytohormones and plant growth regulators—a review. *J Sci Technol Appl.* 2021;10:27-65.
15. Rivas MÁ, Friero I, Alarcón MV, Salguero J. Auxin-cytokinin balance shapes maize root architecture by controlling primary root elongation and lateral root development. *Front Plant Sci.* 2022;13:836592.
16. Konstantinova N, Korbei B, Luschnig C. Auxin and root gravitropism: addressing basic cellular processes by exploiting a defined growth response. *Int J Mol Sci.* 2021;22(5):2749.
17. Jia Z, Giehl RF, von Wirén N. Nutrient–hormone relations: driving root plasticity in plants. *Mol Plant.* 2022;15(1):86-103.
18. Li Y, Han S, Qi Y. Advances in structure and function of auxin response factor in plants. *J Integr Plant Biol.* 2023;65(3):617-632.
19. Ranjan A, Rajput VD, Prazdnova EV, Gurnani M, Sharma S, Bhardwaj P, Shende SS, Mandzhieva SS, Sushkova S, Minkina T, Chauhan A. Augmenting abiotic stress tolerance and root architecture: the function of phytohormone-producing PGPR and their interaction with nanoparticles. *South Afr J Bot.* 2024;167:612-629.