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Foliar Application of Indole-3-Butyric Acid and Gibberellic Acid Alters Growth and Yield of Carrot (*Daucus Carota* L.) Cv. "Shidur"

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Abstract

Carrots are a nutritious and well-accepted root crop in Bangladesh, but production is very low at the farmer's field level compared to the other producing countries. Therefore, this study was undertaken to improve the yield of carrots by using different plant growth regulators. To evaluate the influence of the foliar application of indole-3-butyric acid (IBA) and gibberellic acid (GA_3) on the growth and yield of carrots, different concentrations viz., 0, 50, 100, 150 ppm of IBA and GA_3 were sprayed at the vegetative stage of carrot production. Among all the treatments, 150 ppm GA_3 shows better shoot growth with the highest plant height (56.80 cm), number of leaves (10.53), leaf length (56.81 cm), fresh weight of leaves (57.08 g), and dry matter content of leaves (10.95%). Foliar application of 150 ppm IBA significantly increased root traits, including root length (16.20 cm), diameter (3.92 cm), fresh weight per plant (98.45 g), and dry matter content (12.01%). Moreover, gross yield (36.80 tons per ha) and marketable yield (36.21 tons per ha) were the highest when IBA was applied at 150 ppm. Overall results revealed that 150 ppm IBA resulted in better growth and higher yield in carrot cv. "Shidur" compared to other treatments.

Keywords: carrot, growth, GA_3, IBA, plant hormones

Introduction

Carrot (*Daucus carota* L.) is a biennial vegetable root crop that is one of the world's top ten vegetable crops belonging to the family Apiaceae (Que et al., 2019; Muhie et al., 2024). Carrot is cultivated not only in Bangladesh but also throughout the world. China ranked first in the world in production by 17.9 million tons (FAO, 2018), whereas Bangladesh produces 18674 metric tons (BBS, 2020), much lower than the major producing countries. Carrots are abundant with nutritional components including carotenes, anthocyanins, vitamins, plant fibers, and medicinal values (Nagraj et al., 2020; Singh et al., 2021; Nasir et al., 2020; Ikram et al., 2024).

The direct growth and development of carrot taproot indicate the carrot yield. Carrots are one of the most important vegetables in Bangladesh. For that, researchers have focused on enhancing plant growth to increase the yield and quality of this crop. Plant growth, development, cell division, and cell elongation are stimulated by environmental or intrinsic cues, such as plant hormones (Ahammed et al., 2020; Khan et al., 2024). Plant growth regulators have specific targets and quick responses for specific plants that are more cost-effective than other cultural practices. Cultural practices require more time and labor, which is not cost-effective compared to using plant hormones. It is reported that tap root development of carrots is directly related to the application of plant hormones (Wang et al., 2015a; Khadr et al., 2020).

Auxins are a class of phytohormones that control numerous processes of plant growth and development (Gomes and Scortecci, 2021; Sonowski et al., 2023). Indole-3-butyric acid (IBA) is a kind of auxin that occurs naturally in different species of plants and tissues (Skoczynska et al., 2024). The transformation of IBA to IAA is highly correlated (Khadr et al., 2020; Woodward and Bartel, 2005). IBA has a much stronger influence on rooting initiation, stimulates shoot, hypocotyl, and lateral root growth, and is more stable in solutions than IAA (Ludwig-Müller, 2000; Zeng et al., 2023; Pincelli-Souza et al., 2024). IBA application enhanced the taproot length and diameter of carrot (Khadr et al., 2020).

Gibberellic acid (GA) plays a vital role in regulating growth and development through the whole life cycle of plants, including seed germination, stem elongation, flowering, and fruit development (Castro-Camba et al., 2022; Wu et al., 2021). GA promotes cell elongation and expansion in plants. In carrots, the GA content levels in roots are lower than those in petioles and leaf blades (Wang et al., 2015a). Through foliar

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application, exogenous GA_3 promotes the growth of the aboveground part and inhibits the growth of roots (Wang et al., 2015b).

This study investigates the influence of the exogenous application of different concentrations of IBA and GA_3 for better plant growth and yield characteristics on carrot cv. "Shidur".

Materials and Methods

The experiment was conducted at the Horticulture Farm of the Bangladesh Agricultural University, Mymensingh, to study the influence of IBA and GA_3 on the growth and yield of carrots. The soil of the experimental area was sandy loam belonging to the Old Brahmaputra Flood Plains Alluvial Tract under the agroecological zone 9. The experiment was eight treatments T_0: Control (0 ppm), T_1: IBA 50 ppm, T_2: IBA 100 ppm, T_3: IBA 150 ppm, T_4: GA_3 50 ppm, T_5: GA_3 100 ppm, T_6: GA_3 150 ppm, T_7: IBA 50 ppm + GA_3 50 ppm; and laid out in randomized complete block design (RCBD) with three replications. Before sowing, the seed was soaked overnight and then covered with a thin cloth before planting. The moistened seeds were spread over polythene sheets to dry out the surface water for two hours. This operation was done to facilitate rapid germination of seeds. Then, the seeds were sown by direct line sowing. The total number of plots was 24. The plots were divided into three blocks. The size of each plot was 1.0 m x 1.0 m. The distance between blocks was 1 m, and between the plots was 0.5 m to facilitate different intercultural operations. Each plot contains 45 plants, and 10 were randomly selected to measure various parameters. First, we prepared the stock solution of the hormone, then diluted it in different required concentrations, and foliar spray was done after 45 days of line sowing.

The land was prepared three times by laddering to obtain good tilth. Manure and fertilizers were applied according to the guidelines of FRG (2018). Plant maintenance includes thinning, weeding, irrigation, and plant protection when needed. Plant height and number of leaves were recorded at 7-day intervals starting from 40 days after sowing up to before harvesting. Harvesting was done 90 days after seed sowing. Harvesting was completed carefully by uprooting the plants plot-wise by hand. The soil and fibrous roots adhering to the conical roots were removed and cleaned. After harvesting, leaf weight and root weight were measured by the analytical balance, leaf length of the largest leaf and Root length by the meter scale, and root diameter by the slide calipers. Leaf and root dry matter were measured by taking 100 g samples of each plant. Leaves and roots were cut into small pieces and sun-dried for 3 days; then, samples were taken in a brown paper bag and placed in an oven for 72 hours at 80°C temperature. After oven drying, the samples were weighed by an electrical balance in grams, and dry matter content was calculated using the following formula.

$$\text{Dry Matter (\%)} = \frac{Dry\ weight}{Fresh\ weight} \times 100$$

An analytical balance was used to measure the gross weight of the harvested roots. The root yield per hectare was computed by converting the per-plot yield and recording it in tones. The data collected from the experimental plots regarding growth and yield were statistically analyzed following the F-variance test with the help of the MSTAT-C program. According to Gomez and Gomez (1984), significance was achieved by the least significant difference (LSD) test at the probability levels of 1% and 5%.

Results and Discussion

The application of different levels of IBA and GA_3 has an influential effect on the height of the plant. The plant height and number of leaves per plant were recorded at 7 days intervals, i.e. 40, 47, 54, 61, 68, 75, 82, and 89 days after sowing (DAS). The plant height and number of leaves increased gradually with the advancement of time (Figures 1, 2). At 89 DAS, the maximum plant height (56.80 cm) and number of leaves per plant (10.53) were recorded. In the case of plant height and number of leaves, when observed 89 days after sowing, all treatments are significantly different from the control except for 50 ppm IBA + 50 ppm (T7).

The fresh leaf length, leaf weight, and dry matter content of leaves were counted accordingly with the treatment. Among them, the most extended leaf length (56.81 cm), highest leaf weight (57.08 g), and maximum (10.95%) dry matter of leaves was measured in 150 ppm GA_3 (T_6) treatment. (Table 1). Abdel, in 2009, also found that GA3 increases the fresh leaf weight and leaf dry matter accumulation in cauliflower. IBA significantly increased root diameter, fresh weight of root, and root length (Khadr et al., 2020). The longer root length (16.20 cm), highest root diameter (3.92 cm), and maximum fresh weight of root per plant (98.45g) were found in 150 ppm of IBA (T_3) treatment (Table 1). All parameters show a significant difference from the control.

Hormonal treatments of IBA and GA_3 significantly decreased the damaged percentage of branched roots, cracked roots, and rotten roots. The findings represent that application can reduce the rate of cracked and rotten roots in carrots. The highest

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percentage of branched roots, cracked roots, and rotten roots were observed from the control (T0) treatment, viz. i.e., 4.81 %, 3.87 %, and 1.76 % (Table 2). A wide range of significant variation was found among the different treatments on marketable roots yield per ha. The maximum yield (36. 21 t.ha^{-1}) was obtained from the application of 150 ppm IBA (T_3) treatment, which was statistically significant than other treatments, and the control (T_0) treatment produced the minimum (18.33 t.ha^{-1}) marketable yield per hectare (Table 2).

Plant growth regulators play a vital role in growth, development, and crop establishment due to their source-sink relationship and stimulation of translocation of photoassimilates (Amanullah et al., 2010). Plant hormones are essential for the development of plants and taproots of carrots (Wang

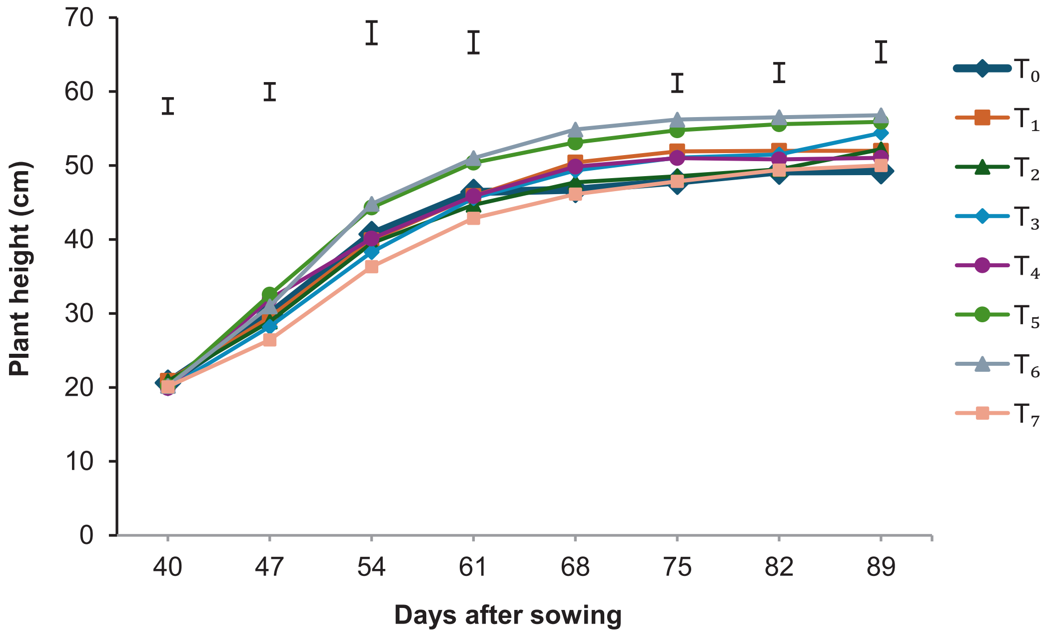

Figure 1. Effect of IBA and GA_3 on plant height at different days after carrot sowing. Vertical bars represent LSD at a 1% level of significance. T_0; Control, T_1 ;50 ppm IBA, T_2;100 ppm IBA, T_3; 150 ppm IBA, T_4; 50 ppm GA_3, T_5; 100 ppm GA_3, T_6; 150 ppm GA_3, T_7 ;50 ppm IBA + 50 ppm.

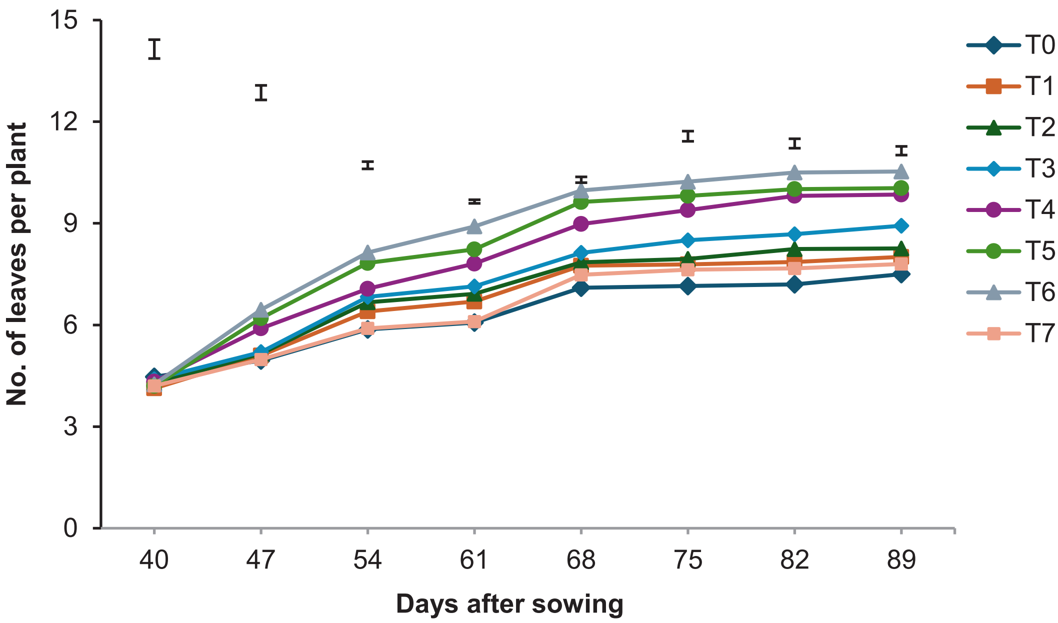

Figure 2. Effect of IBA and GA_3 on the number of leaves per plant on different days after carrot sowing. Vertical bars represent LSD at a 1% level of significance. T_0; Control, T_1 ;50 ppm IBA, T_2;100 ppm IBA, T_3; 150 ppm IBA, T_4; 50 ppm GA_3, T_5; 100 ppm GA_3, T_6; 150 ppm GA_3, T_7 ;50 ppm IBA + 50 ppm.

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et al., 2015a; Khadr et al., 2020). Plant height is one of the important characteristics of carrot growth. The foliar application of prepared 50 ppm, 100 ppm, and 150 ppm of IBA and GA3 hormonal solution significantly affects plant shoot and root growth. IBA mainly increases the taproot growth of carrots, whereas GA3 increases the shoot-growing parameters from applying GA_3 150 ppm (T_6) treatment and the lowest from the control (Fig. 1,2). Malek et al. (2010) also found that GA_3 increases the plant height, similar to our results. Mohanta et al., (2015) also recorded that plant height and number of leaves were increased from GA_3 treatment. GAs has essential roles during carrot growth and development, e.g., Wang et al., (2015b) reported that GA_3 content is higher in leaf blades and petioles than in roots. Thus, exogenous application of GA_3 promotes the plant growth of the aboveground part and inhibits the root growth (Wang et al., 2015a). The present result agrees with the findings of Ghani et al. (2021) and Ashraf et al. (2018) found in radish. That IBA increases the root length, fresh and dry weight, and yield. IBA increased the yield of cauliflower than the GA_3 (Abdel, 2015). The maximum diameter of the root was recorded at 150 ppm IBA ($T_{3),}$ which is significantly higher than the other treatments. The findings were similar to Abdel's experiment (2009). The maximum (12.01%) dry matter content of the root was recorded at T_3 treatment, and the minimum (8.57%) was found in T_0 (control). The result of the experiment was

Table 1. Effects of foliar application of IBA and GA_3 on shoot and root parameters of carrot

Treatments	Leaf length (cm)	Leaf weight (g)	Leaf dry matter (%)	Root length (cm)	Root diameter (cm)	Root weight (g)	Root dry matter (%)
T_0; Control	49.10	50.15	7.85	12.57	2.06	45.53	8.57
T_1; 50 ppm IBA	52.13	53.26	8.15	15.00	3.16	85.16	9.95
T_2; 100 ppm IBA	52.43	53.49	8.89	15.39	3.68	92.32	11.23
T_3; 150 ppm IBA	52.81	54.01	9.23	16.20	3.92	98.45	12.01
T_4; 50 ppm GA_3	55.75	55.37	9.76	14.27	2.98	62.27	9.53
T_5; 100 ppm GA_3	55.85	56.08	10.35	14.53	3.07	83.85	10.09
T_6; 150 ppm GA_3	56.81	57.08	10.95	15.35	3.71	90.17	10.85
T_7; 50 ppm IBA + 50 ppm	50.21	52.17	8.10	13.53	2.40	49.13	9.07
$LSD_{0.05}$	0.67	1.01	0.23	0.45	0.06	1.14	0.14
$LSD_{0.01}$	0.93	1.40	0.32	0.62	0.08	1.58	0.20
Level of significance	**	**	**	**	**	**	**

Notes: ** = Significant at 1% level of probability.

Table 2. The main effect of foliar application of IBA and GA_3 on % branched root, % cracked root, % rotten root, gross and marketable carrot yields

Treatments	Branched roots (%)	Cracked roots (%)	Rotten roots (%)	Gross yield ($t.ha^{-1}$)	Marketable yield per plot ($kg.m^2$)	Marketable yield per ha ($t.ha^{-1}$)
T_0; Control	4.81	3.87	1.76	25.70	1.833	18.33
T_1; 50 ppm IBA	2.38	1.85	1.09	30.90	2.739	27.33
T_2; 100 ppm IBA	2.00	1.30	0.30	34.80	3.275	32.75
T_3; 150 ppm IBA	1.00	0.60	0.00	36.80	3.621	36.21
T_4; 50 ppm GA_3	3.01	2.25	1.07	30.30	2.57	25.7
T_5; 100 ppm GA_3	2.50	1.32	0.59	31.00	2.964	29.64
T_6; 150 ppm GA_3	1.09	0.90	0.80	32.90	3.109	31.09
T_7 ;50 ppm IBA + 50 ppm	3.50	0.90	1.40	26.80	2.009	20.09
$LSD_{0.05}$	0.21	0.17	0.10	1.19	0.09	9.00
$LSD_{0.01}$	0.29	0.23	0.14	1.65	0.12	12.00
Level of significance	**	**	**	**	**	**

Notes: ** = Significant at 1% level of probability.

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supported by the findings of Karimi et al. (2012). The maximum root weight per hectare of 36.80 tons was recorded from the T3 (150 ppm IBA) treatment, which was statistically significant compared to the other treatments and increased by 49% to the control (T_0). Abdel (2007) also found that with the increase in the IBA application rate, the marketable rate of radish increased linearly. In this study, we applied very low concentrations of the growth regulator to the foliage so that the residual effects, if any, would be minimized. IBA is classified as a biochemical with negligible human and environmental risks when applied at low rates, due to its rapid metabolism to naturally occurring compounds like indole-3-acetic acid (USEPA, 1992).

Conclusions

Different levels of IBA and GA_3 treatments significantly improved the growth and yield of contributing characteristics of carrots. Bangladesh farmers generally cultivate crops according to their conception and mainly use chemical fertilizers as the source of nutrients, which may affect the soil health. The appropriate combination of hormonal treatment can be used as an alternative to nutrient management. The system enhances appropriate hormonal uses instead of harmful chemical uses, maintains soil health, improves yield, and reduces the cost of cultivation. The highest gross carrot "Shidur" yield (36.80 $t.ha^{-1}$) and marketable yield (36.21 $t.ha^{-1}$) was from treatment with 150 ppm IBA. Effectivity of IBA and GA_3 treatments, including the residual effects of the plant growth regulators, could further be tested in other agroecological zones.

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