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The impact of auxin on the vegetative and reproductive growth of carrot (*Dacus carota* L.)

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Authors' Contribution **Ali, R. M. A.** conducted collected the data, **A. Manzoor** performed statistical analysis, **M. S. Naveed** and **F. Naz** planted true to type carrot stecklings, **M. Manawar** and **R. Ahmad** designed the experiments and **S. H. Mehfooz** calculated IBA concentration.

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ABSTRACT

Seed is a basic component of every crop species and quality seed is essential for farmers to achieve greater crop production and higher yields. Seed yield can be improved by using the growth hormones. Indole-3-butyric acid (IBA) plays a vital role in reproductive and seed development of crop plant. An investigation is being conducted to determine effect of rooting hormone IBA on reproductive growth that leads to seed developement. Roots treated with three levels of IBA (500 ppm, 1000 ppm and 1500ppm) along with control in a 3 replication. Results showed that roots treated with IBA @ 1500 ppm had taken least number (28.4) of days to flowering with maximum plant height (34.3cm), number of leaves (15.3), leaves length (19.6 cm), number of secondary (10) and tertiary umbels (13.7), diameter of secondary (12.7 cm) and tertiary umbel (4.4), weight of secondary (5.1 g) and tertiary umbel (3.5), seed weight of secondary (4.4 g) and tertiary umbels (1.5 g) and biological weight of the plants (81.0 g) respectively. However, the diameter, weight and seed weight of primary umbel was good in IBA @ 1000 ppm. Thus it is recommended that IBA application at concentration of 1500 ppm can significantly improve growth of carrot seed plants, hence increasing production and seed quality.

Keywords: Indole-3-butyric acid (IBA), quality seed, root growth, umbel diameter, umbel weight.

INTRODUCTION: Carrot (*Daucus carota* L.; 2n = 2x = 18) is a biennial plant, that belongs to family Umbellifereae. It is an Asian native grown as a winter vegetable in many countries throughout the world Carrot has high nutritional values therefore, it is used in cooked, canned and as a raw form (Noor *et al.*, 2020a). It is a rich source of vitaman A particularly (α and β carotene), B1, B2, and vitamin C that increase its demand worldwide (Rasheed *et al.*, 2022). It is found in different colors like red, orange, purple, black and yellow due to the presence of the photopigments like lycopene, B-carotene, Xenthophyllas and anthocyanin (Shibaya *et al.*, 2022). In the world carrot is ranked in top ten vegetables crop. In 2019, 2447.62 million tons of carrots were harvested across the world on an area of 11.2 million ha. China is the largest producer of the carrot with 24.5 million tons of production on an area of 0.42 million hectares in 2019 (FAO, 2021). In Pakistan carrot ranked 3rd among the cool season vegetable's crops. Its total production is 0.25 million tons by cultivating on 0.014 million ha and it is having a 2.9% share in total vegetable production. Carrot is produced in all provinces, but significant harvest is produced in Punjab on an area of 0.013 million hactare with 0.47 million tons production (MNFSR, 2021).
The principal purpose for low productivity of carrot in Pakistan as compared to other countries is unavailability of seed with high quality attributes, in most cases studies has been achieved on enhancing crop production, however but no interest is given in enhancing quality of seed (Mohammad *et al.*, 2013). As a result, a significant portion of the carrot seed available in the market is imported due to the poor quality of locally produced seed (Noor *et al.*, 2020a). Imported seeds are typically pricey and sometimes unavailable. Additionally, private seed producers are benefiting from this condition and charging farmers higher prices for imported hybrid seed (Kumar *et al.*, 2013). Lack of optimum seed production technology for vegetable crops, from seed planting to harvesting and postharvest treatment of seed, can be blamed for both decreased productivity and unsatisfactory quality (Ziaf *et al.*, 2017).
Production of high-quality seed is essential for increasing local carrot yield. However, in Pakistan only 5% of local enterprises produce their own seeds whie the rest is imported through international companies (Rana, 2014). In 2019-20, Pakistan imported 425.3 metric tons of carrot seed of value 150. Million (FSC&RD, 2020). Seed Quality is directly influenced the crop growth and yield (Kumar *et al.*, 2020). Quality seed having a higher germination rate and crop establishment makes them able to achieve their optimum potential (Bose *et al.*, 2018). Plant growth regulators play a vital role in growth, flowering and seed formation resulting in good crop establishment, due to its source sink relationship and stimulation of translocation of photo assimilates (Amanullah *et al.*, 2010). A growth regulator directly influences the developmental processes and fundamental growth in plants (Zhang *et al.*, 2022). Roots are the main part of the plants that are essential for the plant fixation, nutrients and water uptake. Primary roots and lateral roots make up the majority of plant root systems (Sun *et al.*, 2018). Endogenous hormone levels are intimately correlated with root development, nutrition absorption, and transportation by roots (Wang *et al.*, 2015). There are many types of growth promoting phytohormones like auxins, cytokinins and brassinosteroids are regarded essential signaling molecules in seed development and are frequently utilised to maximize seed production (Sun *et al.*, 2010). According to research, plant hormones are essential for the development of carrot taproot (Wang *et al.*, 2015; Khadr *et al.*, 2020). Auxins are a group of phytohormones that regulate a variety of plant growth and maturation processes (Davies, 2013).
The primary function of auxins is to promote cell elongation. They also promote root initiation, vascular development, and embryonic development. An important auxin in plants, indole-3-acetic acid (IAA) is primarily generated in the meristematic tissues of early leaves (Kaya *et al.*, 2010). A kind of auxin known as indole-3-butyric acid (IBA) can be found in numerous plant species and tissues in nature (Epstein and Ludwig-Müller, 1993). The possibility of IBA being converted to IAA and likewise reveals that the two auxins' genetic makeups are closely connected. IBA has the unique auxin potential of polar cell-to-cell transfer, though most likely via a different route than IAA (Rashotte *et al.*, 2003). IBA is significantly more influential on initiating rooting than IAA and is more resilient in solutions (Chhun *et al.*, 2003). IBA possesses auxin activity in several biomarkers and has a more pronounced impact on the rooting process in different plant species than IAA (Štefančič *et al.*, 2005). IBA modulates growth and has an impact on several developmental processes, such as cell division, stem elongation, early root development, lateral root development, root hair development, callus development, flower enhancement, enzyme induction and fruit and leaves aging (Mustafa and Khan, 2016). Due to its extraordinary effects it is used in many crops for root initiation (Bhupathireddy *et al.*, 2022). It is most commonly used plant hormone for encouraging root growth of cuttings and producing new roots in many crops like in, watermelon (EL-Eslamboly, 2014). Cucumber (Astrit and Glenda, 2017) tomato (Ludwig-Müller, 2000; Kachru *et al.*, 2017) and bell pepper (Dogra and Sharma, 2022).
In the world, carrot seeds are produced with two methods: i.e., root to seed, and seed to seed. In Pakistan commonly used root to seed method. The root to seed method is mostly used in Pakistan for the commercial seed production of carrots since the approach enables the selection of roots that are healthy and true to type for replanting stecklings (Manzoor *et al.*, 2021). The quality and yield of carrots are directly influenced by the growth and development of the carrot taproot. According to research, plant hormones are important for the growth of carrot taproot (Khadr *et al.*, 2020). Root development and growth are closely connected to maximizing the crop potential. Without strong roots, a plant cannot grow vigorously since they are the main supply of water and nutrients (Gewin, 2010). Due to their source and sink relationship plant growth regulator play a vital role

in reproductive and seed development of crop plants (Rademacher, 2015). According to research, auxin: indole butyric acid (IBA) is a very productive synthetic hormone that induces root and has effective results as compared to others.

OBJECTIVES: The current study was conducted with an aim to study effect of different concentrations of IBA on carrot root development and its results on vegetative and reproductive growth that leads to quality seed production.

MATERIALS AND METHODS: **Research description:** During 2020-2021, the experiment was carried out in the Barani Agricultural Research Institute's (BARI) Chakwal vegetable research area (72° longitude, 32° latitude, and 575m altitude). Seeds of approved variety carrot cv. T-29 were collected from Vegetable Section, BARI, Thoa bahadur, Chakwal. Seed were sown (12kg/acre) on to the both sides of rows prepared 30 cm row to row distance in mid-September. After 90 days from sowing, carrots were prepared for steckling. Healthy standard-sized roots (25–30 cm long and 7–9 cm in diameter) were chosen to prepare stecklings for experiment. Off-type (poorly coloured) and small-sized roots as well as cracked, wounded, sick, and forked roots were rejected. Steckling were sown with 45 cm plant to plant distance on both sides of raised beds prepared 75 cm apart. Experimental treatments contain different concentrations of the Indole Butyric Acid (IBA) as follow T_1: 0 ppm (control), T_2: 500 ppm, T_3: 1000 ppm, T_4: 1500 ppm. The prepared stecklings were dipped in respective concentrations for 60 seconds. After the treatment, the stecklings were dried at room temperature and then transplanted in to the soil at recommended distance.

Data of different vegetative and reproductive growth were recorded i.e., A total number of 10 plants were selected randomly and number of leaves, leaves length (cm), plant height (cm), days to flower, number of secondary and tertiary umbel, diameter of primary, secondary and tertiary umbel (mm), weight of primary, secondary and tertiary umbel (g), seed weight of primary secondary and tertiary umbel (g), biological weight (g) (Gul *et al.*, 2009; Noor *et al.*, 2020b). The number of leaves of each plant was counted at completion of vegetative growth leave length is measured from base to apex in cm with the help of measuring scale. Similarly, plant height was measured from the base of the roots to the tip of the leaf before bolting in cm. Days to flowering are counted from the first day of sproutig until the umbel formation. At harvest, the average values of all secondary and tertiary umbels from five randomly selected plants in each replication were measured. The plant's seed was harvested from its primary, secondary and tertiary umbels, windowed to eliminate interior materials and weighted on a digital weighing scale. The average seed weight of five plants was measured. Biological weights were taken separately of each plant. The umbels were separated from the plant and weighed the remaining plant with root to measure the biological weight.

Statistical analysis: The experiment used a randomized complete block design (RCBD) with 3 replications, each of which contained 40 plants. A computer-based tool Statistix 8.1, the analysis of variance (ANOVA) approach was used to collect and statistically analyse the data. Differences between means were compared by using Least Significant difference (LSD) test at 5% probability (Steel *et al.*, 1997).

RESULTS AND DISCUSSION: In a current study, findings for analysis of variance (ANOVA) found a great variation for vegetative growth traits across various treatments at 5% level of significance. Among the treatment, maximum increase in number of leaves 15.9, leave length 19.6 cm, plant height 34.3 cm was recorded at T_4 (1500 ppm IBA) as compared to control plants as presented in table 1 and figure 1. Plant growth regulators, that are chemical compounds used to modulate plant growth, are essential for increasing agricultural production by altering endogenous hormone levels in various plant organs and throughout the plant's life cycle (Somers *et al.*, 2004). Auxin is a one of the main plant hormone that enhances plant development and growth due to its role in cell division and expansion (Korasick *et al.*, 2013). One of these processes is the controlled input of the pool of active auxin [indole-3-acetic acid (IAA)] from the auxin precursor indole-3-butyric acid (IBA) (Frick and Strader, 2018). In agriculture, IBA has long been used for root development and plant growth. IBA promotes primary root development and trigger adventitious root initiation (Jiang *et al.*, 2017). This property of IBA was tested to develop roots in carrot seed crop. Stimulation of cell division and cell elongation at shoot apex together with an improvement in photosynthetic efficiency is due to the increase activity of exogenously treatment with IBA which finally resulted increased in plant height, leaves length and number of leaves reported in carrot (Khadr *et al.*, 2020). Increased in number of leaves, leaves length and plant height due to IBA was also observed in apple (*Malus pumila)* cuttings (Khandaker *et al.*, 2022). Increased in number of leaves, leaves length and plant height due to IBA was also observed in apple (*Malus pumila)* cuttings (Khandaker *et al.*, 2022).

Figure 1: Effect of different concentration of IBA on vegetative growth of carrot stecklings, a: T_1 (control; 0 ppm), b: T_2 (500 ppm), c: T_3 (1000 ppm), d: T_4 (1500 ppm).

Floral traits were also positively affected by IBA concentration. Minimum number of days to flowering was also noted at T_4, which takes 6.6 % less time as compared to control (table 1). Along with other aspects, umbel position affects the quality of carrot seeds (Pereira *et al.*, 2008). Because primary, secondary, tertiary, and quaternary umbels develop in alternation, the blooming time for carrots is prolonged. Additionally, each umbel's blossoming time ranges from 7 to 15 days. The seeds generated in umbels of various orders mature unevenly as a result of the prolonged flowering time, resulting in physiological quality variations (Gomes *et al.*, 2012). Thus, root treatment with IBA at 1500 ppm induced early anthesis. Influence of earlier anthesis is due to the mobilization of photo-assimilates from vegetative phase to reproductive is mightily in the presence of the high exogenous level of the IBA (Sanodiya *et al.*, 2017). These outcomes also support the conclusions of (Ranpise *et al.*, 2004) who noticed that IBA treatment on cuttings at 2000 ppm induced chrysanthemum flowering to start earlier than normal.

During evaluation of different concentration of IBA, significant difference was observed in reproductive growth of carrot. Statistical analysis of reproductive growth showed that 1500 ppm (T_4) concentration performed better among other concentration in terms of number of secondary (10.0) and tertiary umbels (13.7) and diameter of secondary (12.7 cm) and tertiary umbels (4.4 cm) respectively. But primary umbel diameter shows non-significant interaction with respect to T_4 treatment as maximum diameter (14.3 cm) was attained at T_3 (1000 ppm) treatment (table 2). Treatment T_4 produced significantly less weight of primary umbel (5.9 g) as compared to T_3 (6.5 g) while, highest weight of secondary (5.1 g) and tertiary umbel (3.5 g) were found in T_4 respectively. However, a significant reduction in weight of primary, secondary and tertiary umbel was found in (T_2:500 ppm) and (T_1: 0 ppm) respectively (table 3). A reproductive stalk produced by carrot seed plant. A primary umbel is produced at the end of the main flower stem. This primary flowering stalk also has multiple laterals and sub-laterals, which have secondary and tertiary umbels at their tips, respectively (George, 2009). Root treatment with 1500 ppm produced the highest number of secondary and tertiary umbels.

Table 1: Impact of different concentration of IBA on plant vegetative and floral growth.

Treatment	Parameters			
	No of leaves	Leave length (cm)	Plant height (cm)	Days to flowering
T_1 (0 ppm)	7.7 ± 1.15 c	9.7 ± 0.80 c	25.7 ±4.16 c	35 ± 4.0 a
T_2 (500 ppm)	9.0 ± 1.0 bc	13.4 ± 0.9 b	27 ± 3.0 bc	33.4± 3.65 b
T_3 (1000 ppm)	11.3 ± 0.57 b	15.3± 0.8 b	28.7± 4.04 b	31.4± 3.2 c
T_4 (1500 ppm)	15.9 ± 2.0 a	19.6± 1.01 a	34.3 ±3.60 a	28.4 ± 3.0 d

*Mean values ± SE followed by different letter(s) are significantly different at $p \leq 0.05$ according to least significant different (LSD) test. Mean = 30 (10 plants × 3).

Table 2: Impact of different concentration of IBA on plant reproductive growth.

Treatment	Umbel growth parameters				
	No of secondary umbel	No of tertiary umbel	Primary umbel diameter (cm)	Secondary umbel diameter (cm)	Tertiary umbel diameter (cm)
T_1 (0 ppm)	5.3 ± 0.57 c	7.0 ±1.41 d	10.1 ± 1.0 d	6.2 ± 1.0 b	3.2 ± 0.15 c
T_2 (500 ppm)	6.7 ± 0.57 bc	9.2 ± 1.52 c	11.3 ± 1.0 c	8.2 ± 0.05 b	3.4 ± 0.15 bc
T_3 (1000 ppm)	7.5 ± 0.57 b	11.4 ± 1.52 b	16.8 ± 2.0 a	8.6 ± 0.83b	3.6 ± 0.05 b
T_4 (1500 ppm)	10 ± 1.0 a	13.7 ± 2.08a	14.3 ± 1.52 b	12.7± 2.0 a	4.4 ± 0.2 a

*Mean values ± SE followed by different letter(s) are significantly different at $p \leq 0.05$ according to least significant different (LSD) test. Mean = 30 (10 plants × 3).

Table 3: Impact of different concentration of IBA on umbel weight.

Treatment	Umbel weight parameters (g)		
	Primary umbel weight	Secondary umbel weight	Tertiary umbel weight
T_1 (0 ppm)	4.6 ± 0.26 c	3.4 ± 0.21 c	2.4± 0.22 c
T_2 (500 ppm)	4.9 ± 0.50 bc	3.5 ± 0.28 c	2.5 ± 0.18 c
T_3 (1000 ppm)	6.5 ± 0.42 a	4.3 ± 0.25 b	2.9 ± 0.25 b
T_4 (1500 ppm)	5.9± 0.86 b	5.1 ±0.29 a	3.5 ± 0.37 a

*Mean values ± SE followed by different letter(s) are significantly different at $p \leq 0.05$ according to least significant different (LSD) test. Mean= 30 (10 plants × 3).

The findings on highest number of flowers are consistent with Sao *et al.* (2021) in dahlia (*Dahlia pinnata)*. The numbers of branches present to the plants are highly connected with the number of flowers over plant. The conclusions of this study also closely match those of research on French marigold (*Tagetes patula*) (Singh, 2004). The observation of umbel diameter clearly shows that primary, secondary and tertiary umbels were significantly different after root treatment with IBA at 1000 ppm. At 1000 ppm, the primary umbel had the largest diameter produced, while secondary and tertiary umbel developed at 1500 ppm had the largest diameter. These results are the evidence with findings of Sao *et al.* (2021) who observed that at 1000 ppm, dahlia (*Dahlia variabilis*) attains maximum flower size. The larger size of the flower may be a result of the increased diameter being caused by an increase in cell elongation, rapid translation, and storage of metabolites. The findings regarding flower diameter are consistent with those of Gupta *et al.* (2001) for chrysanthemums. It is clear from the data that rooting hormones had a significant impact on carrot seed plants and their interactions with umbel weight. Untreated plants had the lowest umbel weight, but plants treated with IBA had the largest primary, secondary and tertiary umbel weight at different concentrations. This may have been caused by more photosynthesis activity around the sink i.e flowering as a result of enhanced photosynthesis rate in leaves and a rise in chlorophyll content within the leaves. The findings concur with (Khuriwal *et al.*, 2018) findings on dahlia (*Dahlia pinnata)* (Ranpise *et al.*, 2004) on chrysanthemums (Ullah *et al.*, 2013) and on marigolds (*T. erecta*). Among seed related parameters, the highest weight of secondary and tertiary umbel was attained by T_4 that is 4.4 g and 1.5 g respectively. Minimum weight of secondary and tertiary umbel was found in T_3 which attained (3.1 g and 0.5 g) followed by T_2 (2.5 g and 0.3 g) and T_1 (1.6 g and 0.1 g) respectively. With respect to primary umbel statistical analysis showed that maximum weight was observed with treatment T_3 that is 5.7 followed by T_4 (5.1 g), T_2 (2.8 g) and T_1 (1.9 g) respectively (table 4).

Table 4: Effect of different concentration of IBA on seed and biological weight

Treatment	Umbel seed weight (g)			Biological weight (g)
	Seed weight of primary umbel	Seed weight of secondary umbel	Seed weight of tertiary umbel	
T_1 (0 ppm)	1.9 ± 0.18 d	1.6 ± 0.13 d	0.1 ± 0.01 d	30.7 ± 1.23 d
T_2 (500 ppm)	2.8 ± 0.23 c	2.5 ± 0.42 c	0.3 ± 0.02 b	46.3 ± 2.33 c
T_3 (1000 ppm)	5.7 ± 0.55 a	3.1 ± 0.45 b	0.5 ± 0.03 c	59.6 ± 1.76 b
T_4 (1500 ppm)	5.1 ± 0.34 b	4.4 ± 0.72 a	1.5 ± 0.09 d	81.0 ± 1.73 a

*Mean values ± SE followed by different letter(s) are significantly different at $p \leq 0.05$ according to least significant different (LSD) test. Mean = 30 (10 plants × 3).

Growth regulators improved seed production. The results on umbel seed weight that was significantly impacted by altering rooting hormone IBA concentrations, while untreated plants result lowest umbel weight. Sun *et al.*, (2018) observations, which showed that over-expression of the Auxin Response Factor 19 gene improved seed output in Arabidopsis thaliana and Jatropha curcas give support to this assumption. This higher mobilization of reserved food from source to sink, as observed in okra (*Abelmoschus esculentus*) can be related to the enhanced seed output and seed quality with growth regulators (Sanodiya *et al.*, 2017).

The total dry matter accumulation of the plant, including the leaves, stems, roots, and any other above-ground or below-ground plant tissue, is referred to as the biological yield/weight of a plant system. The dry matter accumulation is an indicator of the biomass of the plant and can be used to determine the yield of the plant in terms of weight or volume (Noor *et al.*, 2020). Significant differences were recorded for biological weight among different treatments and statistical analysis showed that maximum biological weight (81.0 g) was found with the application of concentration 1500 ppm in T_4. While treatment T_1 (0 ppm) took significantly the lowest value of biological weight (30.7 g) due to the effect of the IBA concentration. According to Gul *et al.* (2009) higher plant height, leaf area, leaf count, and root biomass may have all helped to increase biological yield (table 4).

CONCLUSION: The rooting hormone IBA with a 1500 concentration was shown to be the most successful at increasing carrot plant seed yield. In order to improve the reproductive stage of the carrot seed plant, IBA may be used as a root-promoting hormone at 1500 ppm for quality seed production.

CONFLICT OF INTEREST: Authors have no conflict of interest.

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