

Impact of Indole-3-Butyric Acid, and Ethephon Concentrations and Their Interaction on The Efficiency of Rooting, Flowering, and Morphological Traits of Geranium Plant Cuttings (*Pelargonium X Hortorum*)

Jihad Yousif Hassan¹, Layla Shaaban Mohammed^{2*}, Chanar Salih Mohammed³

^{1,2,3}Department of Horticulture, College of Agriculture Engineering Sciences, University of Duhok, Kurdistan region, Iraq,

ABSTRACT: The successful propagation of geranium (*Pelargonium × hortorum*) depends largely on rapid root initiation and vigorous vegetative growth. This study evaluated the effects of indole-3-butyric acid (IBA; 0, 500, and 1000 mg L⁻¹) and Ethephon (0, 100, and 200 mg L⁻¹), applied individually and in combination, on rooting, growth, and flowering characteristics of softwood cuttings. The experiment was conducted using a factorial arrangement in RCBD design. IBA markedly enhanced root development and vegetative performance, while ethephon further improved rooting efficiency and overall plant quality. The combined application of 1000 mg L⁻¹ IBA and 200 mg L⁻¹ Ethephon produced the best overall results, achieving 100% rooting, 96.11% plant survival, 23.3 roots cutting⁻¹, 27.8 cm root length, 0.59 g root fresh weight, 0.30 g root dry weight, 9.22 branches plant⁻¹, 1.32 cm stem diameter, 6.37 g shoot dry weight, and 17.39 leaves plant⁻¹.

The same treatment also enhanced flowering potential by producing the highest number of florets (16.35 florets inflorescence⁻¹). Maximum leaf area (17.52 cm²) was obtained with 1000 mg L⁻¹ IBA combined with 100 mg L⁻¹ Ethephon, whereas the greatest canopy height (14.87 cm) was recorded in untreated IBA plants receiving 200 mg L⁻¹ Ethephon. Plant length decreased slightly with increasing IBA concentration, reflecting greater assimilation allocation to root formation rather than shoot elongation. Inflorescence length and number of inflorescences were not significantly influenced by either treatment. Overall, the synergistic interaction between IBA and Ethephon substantially improved adventitious rooting, transplant survival, and vegetative vigor of geranium cuttings. Therefore, treating softwood cuttings with 1000 mg L⁻¹ IBA in combination with 200 mg L⁻¹ Ethephon is recommended as an effective propagation protocol for producing vigorous, high-quality planting material suitable for commercial nursery production.

KEYWORD: *Pelargonium × hortorum*, indole-3-butyric acid (IBA), Ethephon, and softwood cuttings.

INTRODUCTION

Pelargonium (Pelargonium × hortorum) is regarded as one of the most desired species of ornamental plants that is commonly recognized as geranium, it is cultivated widely and ranks third among potted flowering plants in the world trade of ornamental plants (Alavijeh *et al.* 2025; Roman *et al.* 2023). This plant is originated from South Africa and is grown all over the world which has become recognizable for its common use in terraces and gardens, which lead to grow up commercial importance globally (Darras, *et al.* 2022). Besides its uses for ornamental purposes, it used in pharmaceutical sector it has essential oils that are composed of volatile phytochemicals used for antibacterial, antifungal, and antiseptic constituent (Narnoliya *et al.*, 2019). Even though seeds can be used to propagate *pelargonium* plant, propagation vegetatively by using cuttings is the most convenient method (Rapacz *et al.*, 2024). It restores genetic properties, provides homogenous development, and permits automation of production (Druege, 2022). Although, obtaining a regular rooting is still a challenge, as it extremely affected by both plant intrinsic properties and environmental influences. Therefore, for enhancing rooting ability the use of auxins as a growth regulator has become important increasingly (D'Amelia *et al.*, 2020; Mohammed *et al.*, 2024; Oğuztürk *et al.*, 2025). One of the fast developed sectors of horticulture is the production of ornamental plants, this sector revel high acceptance both in national and international market profile. It compose many types of products, include thus plants that cultivated for flowers to thus grown for their leaves, used both as potted plant and for cut flowers, from greenhouse to nurseries crops, etc. (Moldovan *et al.* 2023).

IBA (indole 3-butyric acid), is a type of auxin that has been utilized for a long time, it can cause regulation of size of apical meristem in roots and play a significant role in development of root, adventitious roots and lateral roots (Frick *et al.*, 2018). (Kaur, 2024) treated stem cuttings of geranium, *Pelargonium graveolens* L” with different concentrations of IBA (0, 250, 500, 750, 1000, 1250,

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and 1500 mg.L⁻¹) and showed that 1000 mg.L⁻¹ proved best positive effect which recorded minimum number of days to root initiation after 30 days and maximum results of all studied roots and vegetative growth parameters after both 30 and 60 days.

Also, ethephon which is a plant growth regulator used as a foliar spray for decades to abort unwanted flowers, promote lateral branching and reduce plant height (Whipker and Latimer 2021). Its influence are affected by a number of factors, such as spray period, applied concentration, environmental conditions and agricultural practices, resulting to inconsistent responses of production across various environments (Zhao *et al.* 2022; Ren *et al.* 2024). Most recently (Mohammed, 2025) reported from the data of a study conducted on geranium softwood cutting that roots characteristics were significantly improved when treated with ethephon 200mg.L⁻¹. The same concentration caused to increase number of branches, stem diameter, along with the shoot dry weight and leaves number and recorded lower plant height comparison with control. Therefore, this study was undertaken to find out the influence of used concentrations of both IBA and ethephon and their combinations on producing plants with more roots and more compact (production of plants with strong root system and short height).

MATERIAL AND METHODS

Experiment Site: The research was conducted in the lath house of the Department of Horticulture, College of Agriculture Engineering Sciences, University of Duhok, Kurdistan Region, Iraq, from the period 15th March 2024 to 20th July 2025. The experiment involved 54 experimental units on rooting of Geranium shoot cuttings. Where the stem cuttings were taken in a uniform way from healthy mother plants; tips of mother plants were selected.

The first period extending from 15th March to 20th July 2024 covered the establishment phase of the experiment (cutting plug and initiation of rooting). Leaves appeared on the planted cuttings during the rooting period. Since leaf emergence will lead to a premature distribution of reserves for the vegetative part of the plant to reduce that leaf out, cuttings were sprayed with ethephon to suppress shoot development and enhance root initiation. The well-rooted plants were subsequently kept under controlled conditions until next spring, or second term, which covers March 15th to 20th July 2025. Data was collected 3 months after the second growing season, and systematic measurements were taken.

Factors study: The experimental factors are three concentrations of indole-3-butyric acid (IBA) (0, 500, and 1000 mgL⁻¹); and three concentrations of ethephon application (0, 100, and 200 mgL⁻¹). measurements included Rooting percent, Number of plants survived, Roots number, Root lengths, Root fresh weight, Root dry weight, Plant length, Branches number, Stem diameter, Shoot dry weight, Leaf number, Leaf area, Canopy height, Length of inflorescence, Number of inflorescences and Number of florets of Geranium plant

Field Operations: Good mother geranium plants were used for making 10 cm long and 10-12mm thick cuttings from the tips of stem. The cuttings were wounded, a 1 cm length cut was made at the base of each cutting with a sharp blade, careful to avoid damaging the inner bark. Prior to planting, both groups were dipped in different concentrations of IBA for 10 seconds for rooting. The cuttings were then planted into a rooting medium and covered with polyethylene to retain humidity until rooting occurred. In most instances, the emergence of leaves in the cuttings occurs before the development of roots. As such, the leaves in the cuttings were treated with different levels of ethephon at three 10-day intervals to inhibit vegetative growth and ensure that physiological activities focused on root formation. The goal was to promote successful root formation without causing any harm to the cuttings and to avoid unnecessary loss of stored nutrients and moisture. The treatment was carried out on the first season of growth and effects were observed in the second season. Once the rooting success reached approximately high percent, the rooted cuttings were transplanted into a medium composed of river soil and peat moss at a ratio of 1:3 by volume.

Statistical analysis: This study was conducted through a Randomized Complete Block Design (RCBD), which is a (3 x 3) factorial experiment involving 9 treatments with 3 replicates. Each treatment involved four pots, where each pot had four cuttings. The result of the analysis of variance showed that there were differences between treatments. The gathered data have been analysed using analysis of variance (ANOVA), while the Duncan Test has been used at $P \leq 0.05$ via SAS software.

RESULTS AND DISCUSSION

Rooting Percentage and Plant Survival Percentage

Rooting percentage increased with increasing IBA concentration. The highest mean rooting percentage was recorded at 1000 mg L⁻¹ IBA (88.70%), followed by 500 mg L⁻¹ (86.09%), while the lowest value was obtained from the control treatment (82.43%). However, no significant differences were observed among IBA concentrations. Ethephon significantly improved rooting percentage. The highest rooting percentages were recorded at 100 mg L⁻¹ (91.32%) and 200 mg L⁻¹ (91.11%), whereas the lowest value occurred without Ethephon application (74.80%). The maximum rooting percentage (100%) was obtained from the combination of 1000 mg L⁻¹ IBA + 200 mg L⁻¹ Ethephon, while the minimum value (70.55%) was recorded in the untreated control (0 IBA + 0 Ethephon).

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Plant survival tended to increase with IBA application. The highest survival percentage was obtained with 1000 mg L⁻¹ IBA (87.57%), while the lowest value was recorded in the control (80.11%). Ethephon treatments improved plant survival. The highest value was observed at 200 mg L⁻¹ Ethephon (89.35%), whereas the lowest value was recorded in untreated plants (81.09%). The highest survival percentage (96.11%) resulted from 1000 mg L⁻¹ IBA + 200 mg L⁻¹ Ethephon, while the lowest percentage (76.11%) was obtained from the untreated control.

Table (1): Effect of different concentration of IBA, foliar application of Ethephon and their interaction on rooting characteristics on Geranium plants

Rooting percent					Number of plants survived				
IBA Conce. Mg.l ⁻¹	Ethephon			Effect of IBA	IBA Conce. Mg.l ⁻¹	Ethephon			Effect of IBA
	0	100	200			0	100	200	
0	70.55 ^a	92 ^a	84.72 ^a	82.43 ^a	0	76.11 ^b	83.11 ^{ab}	81.11 ^{ab}	80.11 ^a
500	76.61 ^a	93.06 ^a	88.61 ^a	86.09 ^a	500	82.78 ^{ab}	87.50 ^{ab}	90.83 ^{ab}	87.04 ^a
1000	77.22 ^a	88.89 ^a	100 ^a	88.70 ^a	1000	84.39 ^{ab}	82.22 ^{ab}	96.11 ^a	87.57 ^a
Effect of Ethephon	74.80 ^b	91.32 ^a	91.11 ^a		Effect of Ethephon	81.09 ^a	84.28 ^a	89.35 ^a	

Roots Number and Root Length

IBA significantly increased root number. The highest number of roots was produced by 1000 mg L⁻¹ IBA (20.2 roots), followed by 500 mg L⁻¹ (18.1 roots), whereas the control recorded the lowest value (15.1 roots). Root number increased significantly with Ethephon concentration. The highest means was observed at 200 mg L⁻¹ (19.9 roots) and the lowest at 0 mg L⁻¹ (15.5 roots). The highest root number (23.3 roots) was obtained from 1000 mg L⁻¹ IBA + 200 mg L⁻¹ Ethephon, whereas the lowest value (13.5 roots) occurred in the untreated control.

Root length significantly increased with increasing IBA concentration. The highest value was recorded at 1000 mg L⁻¹ IBA (25.2 cm), while the control treatment produced the shortest roots (17.3 cm). Although Ethephon increased root length numerically, differences among Ethephon treatments were not significant. The highest means was observed at 200 mg L⁻¹ (21.8 cm) and the lowest at 100 mg L⁻¹ (19.3 cm). The longest roots (27.8 cm) were obtained with 1000 mg L⁻¹ IBA + 200 mg L⁻¹ Ethephon, while the shortest roots (16.2 cm) were observed in the untreated control.

Table (2): Effect of different concentration of IBA, foliar application of Ethephon and their interaction on rooting characteristics on Geranium plants

Characteristics on Geranium plants									
Roots number					Root lengths				
IBA Conce. Mg.l ⁻¹	Ethephon			Effect of IBA	IBA Conce. Mg.l ⁻¹	Ethephon			Effect of IBA
	0	100	200			0	100	200	
0	13.5 ^c	15.5 ^{de}	16.4 ^{c-c}	15.1 ^c	0	16.2 ^c	18.0 ^c	17.6 ^c	17.3 ^b
500	16.1 ^{de}	18.5 ^{b-d}	20.1 ^{a-c}	18.1 ^b	500	20.6 ^{bc}	16.3 ^c	20.0 ^{bc}	19.0 ^b
1000	16.9 ^{b-c}	20.42 ^{ab}	23.3 ^a	20.2 ^a	1000	24.0 ^{ab}	23.8 ^{ab}	27.8 ^a	25.2 ^a
Effect of Ethephon	15.5 ^b	18.1 ^a	19.9 ^a		Effect of Ethephon	20.2 ^a	19.3 ^a	21.8 ^a	

Fresh Weight and Root Dry Weight

Root fresh weight increased significantly with IBA concentration. The highest values were obtained with 1000 mg L⁻¹ (0.52 g) and 500 mg L⁻¹ (0.48 g), while the control recorded the lowest value (0.32 g). The highest fresh weight was achieved with 200 mg L⁻¹ Ethephon (0.49 g) and the lowest with no Ethephon (0.38 g). The maximum root fresh weight (0.59 g) was recorded under 1000 mg L⁻¹ IBA + 200 mg L⁻¹ Ethephon, whereas the minimum (0.30 g) occurred in the untreated control.

IBA significantly enhanced root dry weight. The highest value was recorded at 500 and 1000 mg L⁻¹ (0.25 g), whereas the control produced the lowest value (0.16 g). Increasing Ethephon concentration significantly increased root dry weight, with the highest value at 200 mg L⁻¹ (0.26 g) and the lowest at 0 mg L⁻¹ (0.18 g). The greatest root dry weight (0.30 g) was obtained from 1000 mg L⁻¹ IBA + 200 mg L⁻¹ Ethephon, while the lowest (0.15 g) was observed in the untreated control.

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Table (3): Effect of different concentration of IBA, foliar application of Ethephon and their interaction on rooting characteristics on Geranium plants

Root fresh weight					Root dry weight				
IBA Conce. Mg.l ⁻¹	Ethephon			Effect of IBA	IBA Conce. Mg.l ⁻¹	Ethephon			Effect of IBA
	0	100	200			0	100	200	
0	0.30 ^d	0.33 ^{cd}	0.34 ^{cd}	0.32 ^b	0	0.15 ^c	0.16 ^c	0.19 ^{de}	0.16 ^b
500	0.42 ^{bc}	0.50 ^{ab}	0.52 ^{ab}	0.48 ^a	500	0.21 ^{c-c}	0.27 ^{a-c}	0.29 ^{ab}	0.25 ^a
1000	0.42 ^{bc}	0.53 ^{ab}	0.59 ^a	0.52 ^a	1000	0.20 ^{de}	0.24 ^{b-d}	0.30 ^a	0.25 ^a
Effect of Ethephon	0.38 ^b	0.45 ^a	0.49 ^a		Effect of Ethephon	0.18 ^c	0.22 ^b	0.26 ^a	

Plant Length and Branch Number

Plant length decreased significantly at the highest IBA concentration. The highest mean value was obtained in the control (14.90 cm), whereas the lowest was recorded at 1000 mg L⁻¹ IBA (12.84 cm). No significant differences were observed among Ethephon treatments. Values ranged from 13.75 to 14.73 cm. The greatest plant length (15.37 cm) occurred with 0 IBA + 200 mg L⁻¹ Ethephon, while the shortest plants (11.53 cm) were produced by 1000 mg L⁻¹ IBA + 200 mg L⁻¹ Ethephon.

Branch number increased significantly with increasing IBA concentration. The highest value was observed at 1000 mg L⁻¹ IBA (8.30 branches), whereas the control produced the lowest value (6.48 branches). The highest branch number was recorded at 200 mg L⁻¹ Ethephon (7.98 branches) and the lowest at 0 mg L⁻¹ (6.78 branches). The highest branch number (9.22 branches) was obtained from 1000 mg L⁻¹ IBA + 200 mg L⁻¹ Ethephon, while the lowest (6.00 branches) was recorded in the untreated control.

Table (4): Effect of different concentrations of IBA, foliar application of Ethephon and their interaction on growth characteristics on Geranium plants

Plant length					Branches number				
IBA Conce. Mg.l ⁻¹	Ethephon			Effect of IBA	IBA Conce. Mg.l ⁻¹	Ethephon			Effect of IBA
	0	100	200			0	100	200	
0	15.17 ^a	14.18 ^a	15.37 ^a	14.9 ^a	0	6.00 ^c	6.61 ^c	6.83 ^c	6.48 ^b
500	15.28 ^a	13.82 ^{ab}	15.02 ^a	14.7 ^a	500	6.56 ^c	6.22 ^c	7.89 ^b	6.89 ^b
1000	13.73 ^{ab}	13.25 ^{ab}	11.53 ^b	12.84 ^b	1000	7.78 ^b	7.89 ^b	9.22 ^a	8.30 ^a
Effect of Ethephon	14.73 ^a	13.75 ^a	13.97 ^a		Effect of Ethephon	6.78 ^b	6.9 ^b	7.98 ^a	

Stem Diameter and Shoot Dry Weight

Stem diameter increased significantly with IBA concentration. The highest value was obtained at 1000 mg L⁻¹ (1.10 cm), while the lowest was recorded in the control (0.76 cm). Also highest shoot value (1.01 cm) were recorded from effect of Ethephon at 200 mgL⁻¹ compared with (0.82 cm) noticed from effect of control. The maximum stem diameter (1.32 cm) occurred at 1000 mg L⁻¹ IBA + 200 mg L⁻¹ Ethephon, whereas the minimum (0.70 cm) was recorded at 0 IBA + 100 mg L⁻¹ Ethephon. The highest shoot dry weight was achieved with 1000 mg L⁻¹ IBA (5.72 g), whereas the lowest value was recorded in the control (4.43 g). No significant differences were found from effect of used ethephon on shoot dry weight however, best data were obvious at 200 mgL⁻¹. The maximum shoot dry weight (6.37 g) was obtained from 1000 mg L⁻¹ IBA + 200 mg L⁻¹ Ethephon, while the minimum (3.88 g) occurred at 500 mg L⁻¹ IBA without Ethephon.

Table (5): Effect of different concentration of IBA, foliar application of Ethephon and their interaction on growth characteristics on Geranium plants

Stem diameter					Shoot dry weight				
IBA Conce. Mg.l ⁻¹	Ethephon			Effect of IBA	IBA Conce. Mg.l ⁻¹	Ethephon			Effect of IBA
	0	100	200			0	100	200	
0	0.78 ^{cd}	0.70 ^d	0.80 ^{cd}	0.76 ^b	0	4.63 ^{bc}	4.33 ^{bc}	4.32 ^{bc}	4.43 ^b
500	0.79 ^{cd}	1.02 ^{bc}	0.91 ^{b-d}	0.91 ^b	500	3.88 ^c	4.14 ^{bc}	5.33 ^{a-c}	4.45 ^b
1000	0.90 ^{b-d}	1.08 ^{ab}	1.32 ^a	1.10 ^a	1000	5.14 ^{a-c}	5.65 ^{ab}	6.37 ^a	5.72 ^a
Effect of Ethephon	0.82 ^b	0.94 ^{ab}	1.01 ^a		Effect of Ethephon	4.55 ^a	4.71 ^a	5.34 ^a	

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Leaf Number and Leaf Area

The highest leaf number was observed at 1000 mg L⁻¹ IBA (14.39 leaves), while the lowest was recorded in the control (10.04 leaves). The highest value was obtained at 200 mg L⁻¹ Ethephon (14.07 leaves), whereas the lowest was recorded without Ethephon (11.37 leaves). The highest leaf number (17.39 leaves) was achieved with 1000 mg L⁻¹ IBA + 200 mg L⁻¹ Ethephon, while the lowest (8.56 leaves) occurred in the untreated control.

Leaf area significantly increased with IBA concentration. The highest value was observed at 1000 mg L⁻¹ (14.69 cm²) and the lowest at 0 mg L⁻¹ (9.27 cm²). The largest leaf area was recorded at 100 mg L⁻¹ Ethephon (13.33 cm²), whereas the smallest was obtained without Ethephon (10.12 cm²). The maximum leaf area (17.52 cm²) occurred at 1000 mg L⁻¹ IBA + 100 mg L⁻¹ Ethephon, while the minimum (8.26 cm²) was observed in the untreated control.

Table (6): Effect of different concentrations of IBA, foliar application of Ethephon and their interaction on growth characteristics on Geranium plants

Leaf number					Leaf area				
IBA Conce. Mg.l ⁻¹	Ethephon			Effect of IBA	IBA Conce. Mg.l ⁻¹	Ethephon			Effect of IBA
	0	100	200			0	100	200	
0	8.56 ^c	9.11 ^c	12.44 ^b	10.04 ^a	0	8.26 ^c	10.35 ^{bc}	9.19 ^c	9.27 ^c
500	13.39 ^b	13.78 ^b	12.39 ^b	13.19 ^a	500	12.10 ^b	12.12 ^b	10.96 ^{bc}	11.73 ^b
1000	12.17 ^b	13.61 ^b	17.39 ^a	14.39 ^a	1000	10.00 ^{bc}	17.52 ^a	16.53 ^a	14.69 ^a
Effect of Ethephon	11.37 ^b	12.17 ^b	14.07 ^a		Effect of Ethephon	10.12 ^c	13.33 ^a	12.23 ^a	

Canopy Height and Inflorescence Length

The highest canopy height was produced by 500 mg L⁻¹ IBA (12.77 cm), while the control treatment showed the lowest value (11.17 cm). The highest canopy height was obtained at 200 mg L⁻¹ Ethephon (13.81 cm) and the lowest at 0 mg L⁻¹ (10.67 cm). The highest canopy height (14.87 cm) was recorded under 0 IBA + 200 mg L⁻¹ Ethephon, whereas the lowest value (8.81 cm) occurred at 0 IBA + 100 mg L⁻¹ Ethephon.

No significant differences were observed in data length of inflorescence among IBA concentrations. Values ranged between 5.03 and 5.17 cm. No significant differences were detected among Ethephon treatments, with values ranging from 4.62 to 5.51 cm. The highest inflorescence length (5.83 cm) was recorded at 1000 mg L⁻¹ IBA without Ethephon, whereas the lowest value (4.00 cm) was observed at 1000 mg L⁻¹ IBA + 100 mg L⁻¹ Ethephon.

Table (7): Effect of different concentrations of IBA, foliar application of Ethephon and their interaction on flowering characteristics on Geranium plants

Canopy height					Length of inflorescence				
IBA Conce. Mg.l ⁻¹	Ethephon			Effect of IBA	IBA Conce. Mg.l ⁻¹	Ethephon			Effect of IBA
	0	100	200			0	100	200	
0	9.83 ^{dc}	8.81 ^c	14.87 ^a	11.17 ^b	0	4.92 ^a	4.81 ^a	5.36 ^a	5.03 ^a
500	11.51 ^{b-d}	13.44 ^{ab}	13.36 ^{ab}	12.77 ^a	500	5.78 ^a	5.04 ^a	4.40 ^a	5.07 ^a
1000	10.71 ^{c-e}	12.33 ^{a-c}	13.20 ^{ab}	12.08 ^{ab}	1000	5.83 ^a	4.00 ^a	5.69 ^a	5.17 ^a
Effect of Ethephon	10.67 ^b	11.53 ^b	13.81 ^a		Effect of Ethephon	5.51 ^a	4.62 ^a	5.15 ^a	

Number of Inflorescences and Number of Florets

Number of inflorescences showed no significant differences among IBA treatments. Values ranged from 2.89 to 2.95 inflorescences plant⁻¹. No significant differences were observed among Ethephon treatments. Values ranged from 2.84 to 2.96 inflorescences plant⁻¹. The highest value (3.08 inflorescences plant⁻¹) was obtained from 0 IBA + 100 mg L⁻¹ Ethephon, whereas the lowest value (2.83 inflorescences plant⁻¹) was recorded at both 500 mg L⁻¹ IBA + 200 mg L⁻¹ Ethephon and 1000 mg L⁻¹ IBA + 200 mg L⁻¹ Ethephon. The highest number of florets was obtained with 1000 mg L⁻¹ IBA (15.70 florets), followed closely by 500 mg L⁻¹ (15.28 florets), while the control recorded the lowest value (14.02 florets). No significant differences were observed among Ethephon treatments, although the highest numerical value was recorded at 200 mg L⁻¹ (15.24 florets) and the lowest at 0 mg L⁻¹ (14.59 florets). The

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highest number of florets (16.35 florets) was achieved with 1000 mg L⁻¹ IBA + 200 mg L⁻¹ Ethephon, whereas the lowest value (13.96 florets) was observed in the untreated control.

Table (8): Effect of different concentration of IBA, foliar application of Ethephon and their interaction on flowering characteristics on Geranium plants

Number of inflorescences					Number of florets				
IBA Conce. Mg.l ⁻¹	Ethephon			Effect of IBA	IBA Conce. Mg.l ⁻¹	Ethephon			Effect of IBA
	0	100	200			0	100	200	
0	2.91 ^a	3.08 ^a	2.86 ^a	2.95 ^a	0	14.02 ^c	14.07 ^c	13.96 ^c	14.02 ^b
500	2.97 ^a	2.88 ^a	2.83 ^a	2.89 ^a	500	15.02 ^{a-c}	15.42 ^{a-c}	15.41 ^{a-c}	15.28 ^a
1000	2.99 ^a	2.86 ^a	2.83 ^a	2.89 ^a	1000	14.74 ^{bc}	16.02 ^{ab}	16.35 ^a	15.70 ^a
Effect of Ethephon	2.96 ^a	2.94 ^a	2.84 ^a		Effect of Ethephon	14.59 ^a	15.17 ^a	15.24 ^a	

IBA is a well-known auxin that stimulates adventitious root initiation through enhancement of cell division and root primordia differentiation. Ethephon releases ethylene, which can interact positively with auxin signaling pathways and improve rooting efficiency. Similar findings were reported by **Druege et al. (2019)**, and **Guan et al. (2023)**, who demonstrated that auxin–ethylene interactions play a critical role in root formation.

The results presented in Table 1 demonstrated that foliar application of ethephon significantly improved rooting percentage and survival of geranium cuttings compared with untreated plants. The highest rooting percentage (100%) was recorded with the combination of 1000 mg L⁻¹ IBA and 200 mg L⁻¹ ethephon, whereas the lowest value (70.55%) was obtained in the untreated control. Similarly, survival percentage increased with increasing concentrations of IBA and ethephon. The beneficial effect of IBA may be attributed to its role in stimulating root primordia initiation, enhancing cell division, and promoting differentiation of adventitious roots. Auxins are known to activate genes associated with root formation and increase carbohydrate translocation toward the rooting zone. Ethephon, as an ethylene-releasing compound, can enhance auxin sensitivity and improve rooting efficiency through interactions with endogenous auxins. Similar findings were reported by **(Druege et al. 2019)**, who observed that auxin-induced rooting is closely associated with enhanced carbohydrate mobilization and hormonal balance. Likewise, **(Pacurar et al. 2022)** indicated that interactions between auxin and ethylene play a central role in adventitious root formation in ornamental species.

Table 2 revealed significant improvements in root number and root length due to increasing concentrations of IBA and ethephon. The maximum root number and root length were obtained from the interaction of 1000 mg L⁻¹ IBA and 200 mg L⁻¹ ethephon. These improvements may result from the ability of IBA to stimulate cell elongation and division in root meristematic tissues while increasing the synthesis of proteins involved in root development. Ethylene released from ethephon can further stimulate root elongation by enhancing auxin transport and regulating cell-wall loosening enzymes. The effect between auxin and ethylene has been reported as a major factor controlling adventitious rooting and root architecture. Similar observations were reported by **Lakehal and Bellini (2019)**, who found that auxin-induced root initiation is regulated by ethylene-mediated signaling pathways. Moreover, **Guan et al. (2023)** reported that auxin and ethylene interactions improve root growth and morphology through coordinated regulation of root developmental genes.

The data in Table 3 showed that root fresh and dry weights increased significantly with increasing IBA and ethephon concentrations. The greatest fresh weight and dry weight were recorded at 1000 mg L⁻¹ IBA combined with 200 mg L⁻¹ ethephon. Increased root biomass reflects enhanced root initiation and elongation, resulting in greater accumulation of structural carbohydrates and dry matter. Auxin application promotes vascular differentiation and nutrient uptake, while ethylene contributes to root growth by regulating carbohydrate partitioning and metabolic activity. These results agree with those of **(Ahkami et al. 2021)**, who reported that improved root biomass is associated with increased photosynthate allocation toward developing roots. Similar conclusions were reached by **(Bellini et al. 2023)**, who emphasized the importance of auxin–ethylene interactions in improving root vigor and biomass accumulation.

The results of Table 4 indicated that plant length decreased slightly at higher IBA concentrations, whereas branch number increased significantly. The highest branch number was obtained with 1000 mg L⁻¹ IBA and 200 mg L⁻¹ ethephon. Ethephon is known to release ethylene, which suppresses apical dominance and stimulates lateral bud growth, leading to increased branching. The reduction in plant height may result from the inhibitory effect of ethylene on stem elongation through reduced gibberellin activity. Enhanced branching is highly desirable in ornamental geranium production because it improves plant compactness and visual

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quality. Similar findings were reported by (Carlson *et al.* 2020), who observed increased branching and reduced stem elongation in ornamentals treated with ethephon. Likewise, (Latimer 2022) indicated that ethephon effectively controls plant architecture by promoting lateral shoot development.

Table 5. show that the stem diameter and shoot dry weight significantly increased with increased IBA and ethephon concentrations. The interaction treatment of 1000 mg L⁻¹ IBA and 200 mg L⁻¹ ethephon produced the highest stem diameter and shoots dry weight. These increases may be attributed to improved root development, which enhances water and nutrient uptake, thereby supporting vegetative growth. Increased dry matter accumulation also reflects enhanced photosynthetic efficiency and carbohydrate synthesis. Similar results were obtained by (Taiz *et al.* 2023), who reported that improved root systems positively influence shoot biomass accumulation. Furthermore, (Davies 2021) emphasized that auxin-mediated enhancement of vascular development contributes directly to stem thickening and dry matter production.

Table 6 demonstrated significant increases in leaf number and leaf area due to IBA and ethephon treatments. The maximum leaf number and leaf area were recorded with 1000 mg L⁻¹ IBA and 100–200 mg L⁻¹ ethephon. Increased leaf production may result from enhanced branching and improved nutrient absorption resulting from stronger root systems. Larger leaf area contributes to greater photosynthetic capacity and biomass accumulation. Auxins have been shown to stimulate cell expansion, while ethylene can improve canopy architecture and leaf development when applied at appropriate concentrations. Similar observations were reported by (Grossman *et al.* 2021), who found that hormonal regulation enhances leaf development and photosynthetic performance. Likewise, (Li *et al.* 2023) reported positive effects of auxin treatments on leaf growth and assimilate production.

The results of Table 7 showed that canopy height increased significantly with ethephon application and moderate-to-high IBA concentrations, whereas inflorescence length was not significantly affected. The highest canopy height was obtained from the control IBA level combined with 200 mg L⁻¹ ethephon. Increased canopy height may be associated with improved branching and leaf development, resulting in a fuller plant canopy. The absence of significant differences in inflorescence length suggests that flower stalk elongation is primarily under genetic control and less responsive to exogenous hormone application. Similar findings were reported by (Klie *et al.* 2021), who noted that ornamental plant architecture is more responsive to growth regulators than floral organ elongation.

Table 8 indicated that the number of inflorescences was not significantly affected by IBA or ethephon treatments; however, the number of florets increased significantly. The highest floret number was recorded with 1000 mg L⁻¹ IBA combined with 200 mg L⁻¹ ethephon. The increase in floret number may result from improved vegetative growth and enhanced assimilate availability for reproductive development. Stronger root systems and larger leaf areas likely increased carbohydrate production, thereby supporting flower formation and development. Similar results were reported by (Rademacher, 2020), who concluded that plant growth regulators can improve floral quality by enhancing assimilate partitioning. Likewise, (Zhang *et al.* 2023) found that improved vegetative vigor contributes positively to flower production and ornamental quality.

CONCLUSION

Application of IBA and Ethephon significantly improved most rooting and vegetative growth characteristics of Geranium plants. The combination of 1000 mg L⁻¹ IBA with 200 mg L⁻¹ Ethephon consistently produced the highest values for rooting percentage, root number, root length, root biomass, branch number, stem diameter, shoot dry weight, leaf number, and floret number. Flowering traits such as inflorescence length and number of inflorescences were less responsive and showed no significant differences among treatments. Overall, the combined application of 1000 mg L⁻¹ IBA and 200 mg L⁻¹ Ethephon can be considered the most effective treatment for improving propagation success, vegetative growth, and flowering quality of Geranium plants.

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