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Evaluating IBA and NAA for improved rooting in pot mum cultivation (*Dendranthema grandiflora* Tzvelev.)

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Abstract
The present investigation was conducted from November 2023 to August 2024 under polyhouse conditions at the Department of Floriculture and Landscaping, College of Horticulture, Bengaluru, to evaluate the influence of plant growth regulators on the rooting of cuttings. The experiment was laid out in a Factorial Completely Randomized Design (FCRD) comprising seven treatments with different concentrations of Indole-3-butyric acid (IBA) and Naphthaleneacetic acid (NAA), across five varieties, with three replications. Significant differences were observed among the treatments and varieties for all rooting parameters studied. Early root initiation (7.33 days) was recorded in cuttings of the variety *Camargo* treated with IBA at 400 ppm (T_3V_5), which was statistically on par with NAA at 200 ppm (T_6V_5). The maximum number of roots (49.67) was also obtained in *Camargo* under IBA 400 ppm, indicating the effectiveness of this concentration in stimulating root proliferation. With respect to root length, the highest value (4.98 cm) was observed in *Camargo* cuttings treated with NAA at 250 ppm (T_7V_5). Further, the maximum percentage of rooting (98.10%) was achieved in T_3V_4, signifying varietal differences in response to treatments. The findings clearly demonstrate that both IBA and NAA significantly enhanced rooting attributes, though the magnitude of response varied with variety and concentration. Based on the results, the study recommended the application of IBA at 400 mg L^{-1} or NAA at 200 mg L^{-1} for achieving superior root initiation, higher root number, and enhanced rooting percentage in cuttings, thereby improving propagation efficiency in pot mums.

Keywords: Plant growth regulators, IBA, NAA, pot mums, chrysanthemum

1. Introduction
Chrysanthemum (*Dendranthema grandiflora* Tzvelev.), often called “pot mum” or “garden mum,” is one of the most admired flowering plants grown across the world. Its wide range of vibrant colors, attractive flower shapes and long-lasting blooms make it a favorite among gardeners, florists and flower lovers alike. Belonging to the family *Asteraceae*, chrysanthemums have been cherished for centuries for their ornamental value and are now an essential part of the global floriculture trade (Roopa *et al*., 2018; Teale *et al*., 2006) [16, 22]. Whether used as potted plants for homes and offices or as cut flowers in bouquets and decorations, chrysanthemums continue to hold a special place in both local and international markets.

In commercial cultivation, maintaining the true qualities of the desired variety such as color, shape and blooming time is extremely important (Sevik and Guney, 2013) [18]. Since growing chrysanthemums from seeds often results in plants with mixed traits, growers mostly depend on vegetative propagation using terminal cuttings. This method ensures that every new plant is genetically identical to the parent plant, preserving its uniform appearance and quality (Waseem *et al*., 2011) [24]. However, one of the main challenges in this propagation process is rooting. The success of chrysanthemum cultivation largely depends on how quickly and strongly the cuttings develop roots. Healthy roots help in better absorption of nutrients and water, leading to stronger growth, healthier foliage and more uniform flowering (Guney *et al*., 2021) [5]. Unfortunately, natural root formation can sometimes be slow or uneven, which affects overall plant establishment and productivity.

To overcome this, growers often use plant growth regulators, particularly a group of hormones

known as auxins. Auxins naturally occur in plants and control several key growth processes such as cell division, elongation and differentiation. They play a crucial role in stimulating root initiation, especially in vegetative cuttings (Akhtar *et al*., 2015) [2]. By applying synthetic auxins externally, growers can encourage faster and more uniform root development. This practice has become an essential part of modern propagation techniques in ornamental horticulture.

Among synthetic auxins, Indole-3-butyric acid (IBA) and α-Naphthalene acetic acid (NAA) are the two most widely used for promoting root formation in cuttings. IBA is highly preferred because it is stable, effective, and compatible with a wide range of plant species (Kentelky *et al*., 2021) [9]. It promotes the formation of strong and well-developed roots without causing much damage or toxicity. On the other hand, NAA is particularly effective in inducing early root initiation and can increase the number of roots per cutting (Lee *et al*., 2024) [11]. However, at higher concentrations, NAA may lead to callus formation or slow root elongation, which can negatively affect plant growth (Debasis *et al*., 2000) [3]. Therefore, finding the right type and concentration of auxin is crucial to achieving the best rooting results.

In pot mum cultivation, quick and uniform rooting is especially valuable because it saves time during propagation, reduces the risk of transplant shock and ensures more even plant growth later in the season (Suvija *et al*., 2016) [21]. When cuttings root faster and grow more uniformly, growers can produce high-quality plants more efficiently, meeting the market's demand for attractive and healthy ornamentals. For both small nurseries and large-scale commercial farms, improving the rooting process directly translates to better productivity and profitability (Sahoo *et al*., 2025) [17]. Moreover, using optimal hormone treatments can make the entire propagation system more sustainable by reducing losses and improving resource efficiency.

This study focuses on evaluating the effects of different concentrations of IBA and NAA on the rooting performance of chrysanthemum cuttings. It aims to determine which hormone and concentration combination gives the best results in terms of rooting percentage, number of roots per cutting, root length and overall plant growth.

2. Materials and Methods

The Experiment was conducted during November of the year 2023 at the College of Horticulture, Bengaluru to study the effect of IBA and NAA on the rooting of chrysanthemum cuttings at the research polyhouse, Department of Floriculture and Landscape Architecture. The terminal stem cuttings of uniform length (5–7 cm) having one or two buds were excised from the mother plants maintained under artificial lighting. Six auxin formulations were used with different concentrations, with twenty-five cuttings in each treatment and replicated three times. Thereafter, the cut ends were dipped (2-3 min) in rooting hormone solution of IBA (300, 400, 500 ppm) and NAA (150, 200, 250 ppm) individually, initially dissolved in 70% ethanol and made to a volume of 1000 ml with distilled water. The basal part of the cuttings of the control was treated with distilled water. The treated cuttings were planted in the protrays filled uniformly with cocopeat. The trays were placed under a polytunnel provided with sprinklers to maintain optimum moisture and relative humidity (85%) for rooting. The planted cuttings were allowed to root for 30 days. The cuttings were carefully removed from the trays and washed to eliminate any media particles clinging to the roots. Observations related to root and shoot characteristics were recorded, including the number of days taken for root initiation, rooting percentage, root length, number of roots per cutting, shoot length and internodal length. The experiment followed was Factorial Completely Randomised Design (FCRD) with seven treatments and five varieties replicated thrice and statistically analysed.

3. Results and Discussion

3.1 Days taken for root initiation

Minimum days taken for root initiation (8.57 days) was recorded in cuttings treated with IBA@400 ppm (T_3) which was on par with NAA@200 ppm (T_6) (8.56 days) and it was maximum in cuttings treated with Distilled water (T_1) (14.25 days). Among the varieties early rooting was observed in var. Camargo (V_5) (9.42 days) followed by var. Mount Ventox (V_3) (10.21 days). Delayed rooting was recorded in the variety Zizinho Yellow (V_1) (10.34 days). Interaction between the rooting hormone and varieties illustrated that early rooting was recorded in T_3V_5 (7.33 days) which was on par with T_6V_5 (7.93 days). Delayed root initiation was observed in T_1V_2 (15.53 days) (Table 1). Early rooting was driven by endogenous auxin translocation, while exogenous IBA boosted cell proliferation and elongation (Yusnita *et al*., 2017; Ranjbar and Ahmadi, 2016) [25, 15]. Exogenous auxins like IBA and NAA reduced rooting time and enhanced root count compared to controls (Kamal *et al*., 2024) [8].

3.2 Number of roots

The maximum number of roots per cutting was observed in cuttings treated with IBA@400 ppm (T_3) (42.53) followed by cuttings treated with NAA@200 ppm (T_6) (41.45) (figure 1). However, the minimum number of roots was recorded in cuttings treated with distilled water (T_1) (20.62). Among varieties the highest number of roots were found in var. Camargo (V_5) (38.58) while the lowest was found in var. Flavio (V_4) (28.67). Interaction between the rooting hormone and variety illustrated that the maximum number of roots (49.67) was found in T_3V_5 which was on par with T_6V_5 (49.40). Whereas, the minimum number of roots per plant was observed in T_1V_4 (15.53) (Table 1). Auxins like IBA and NAA are crucial for the initiation of adventitious root (AR) primordia, as root cell division relies on these hormones. The effectiveness of different auxin concentrations varies by species. Optimal auxin levels promoted rooting by facilitating the synthesis of IBA conjugates, which were beneficial for difficult-to-root plants Radhari *et al*., 2014 [13]. Joel *et al*. (2023) [7] reported that the application of optimal concentrations of IBA significantly enhanced the formation of adventitious roots by promoting cell division and elongation at the basal end of the chrysanthemum cuttings.

3.3 Root length

The maximum root length of (4.71cm) was recorded in cuttings treated with NAA@250 ppm (T_7) followed by IBA@400 ppm (T_3) (4.4 cm) and NAA@200 ppm (T_6) (4.29 cm) in figure 1. However, the minimum root length was found in cuttings treated with distilled water (T_1) (2.74 cm) (Table 1). Among the varieties the maximum root length was recorded in var. Camargo (V_5) (4.58 cm) and the minimum length of roots was observed in the var. Zizinho Yellow (V_1) (3.62 cm). Interaction between the rooting hormone and varieties revealed that increased root length (4.98 cm) was recorded in T_7V_5 followed by T_3V_5 (4.85 cm). Decreased root length was recorded in T_1V_1 (1.81 cm). The significant increase in root length is likely due to auxins enhancing carbohydrate hydrolysis, metabolite accumulation, protein synthesis, cell enlargement, and division

(Strydem and Hartman, 1960; Janakiram *et al*., 2006) [19, 6]. Exogenous synthetic auxins can boost endogenous auxin effects or directly induce root formation (Kralik and Sebahenek, 1980) [10].

3.4 Rooting percentage

The maximum rooting percentage was recorded in cuttings treated with IBA@400 ppm (T_3) (96.47%) which was on par with NAA@200 ppm (T_6) (96.40%). Minimum per cent rooting was registered in terminal cuttings treated with distilled water (T_1) (76.93%). Among the varieties, the maximum rooting percentage was observed in var. Zizinho Yellow (V_1) (90.09%) which was on par with var. Mount Kenya (V_2) (89.76%). However, the rooting percentage was found to be minimal in the var. Mount Ventox (V_3) (88.28%). The interaction between the rooting hormone and the varieties illustrated that the highest rooting percentage was recorded in T_3V_4 (98.10%), which was on par with T_6V_5 (98%) and T_6V_1 (97.60%). It was lowest (74.67%) in T_1V_3 (Table 2). Cuttings treated with IBA at 400 ppm significantly improved rooting. This could be because auxins like IBA and NAA enhance adventitious root formation and regulate root growth, including lateral root development and gravity responses, through auxin transport. In support of these statement, enhanced rooting was reported by Joel *et al*. (2023) [7] in chrysanthemum and (Ghofrani *et al*., 2013; Prince and Beniwal, 2017) [4, 12] in carnation.

3.5 Shoot length

The maximum shoot length was recorded in cuttings treated with NAA@250 ppm (T_7) (7.65 cm) which was on par with IBA@400 ppm (T_3) (7.62 cm) and it was found to be the minimum in cuttings treated with distilled water (T_1) (5.35 cm). Among the varieties the maximum shoot length was recorded in var. Mount Ventox (V_3) (7.61 cm), and the minimum length of the shoot was observed in the var. Camargo (V_5) (6.57 cm). Interaction between the rooting hormone and varieties illustrated that increased shoot length (8.72 cm) was observed in T_7V_3 and it was on par with T_3V_3 (8.16 cm). The shoot length was decreased in T_1V_5 (4.24 cm) (Table 2). An increase in shoot length was observed following the application of auxin-based rooting hormones such as NAA and IBA. The use of these hormones at optimal concentrations (IBA @ 400 ppm and NAA @ 250 ppm) resulted in the longest shoots, enhancing the quality of rooted cuttings, improving their export potential, facilitating easier transplanting and promoting better field establishment after transplantation (Susaj *et al*., 2012) [20]. These findings are in accordance with those of Abrol *et al*. (2018) [1] in chrysanthemum and Ullah *et al*. (2013) [23] in marigold, who also reported significant improvement in shoot growth and overall plant vigor following auxin treatments.

3.6 Internodal length

The perusal data on internodal length is found to be non-significant among the varieties treated with different rooting hormones. Though the maximum internodal length was observed in var. Mount Ventox (V_3) (2.05 cm) and it was found to be the minimum in var. Camargo (V_5) (1.53 cm). Among the rooting hormones the maximum internodal length was recorded in cuttings treated with NAA@250 ppm (T_7) (2.22 cm). Interaction between rooting hormones and varieties revealed that the maximum internodal length of (2.48 cm) was observed in T_7V_4. It was found to be a minimum (0.91 cm) in T_1V_5 (Table 2).

Table 1: Root parameters influenced by different rooting hormones in different pot mum varieties

Treatments	Days taken for root initiation	Number of roots	Root length (cm)
Factor A – Rooting hormone treatment (T)			
T_1 - Control (Distilled water)	14.25 ^{a}	20.62 ^{f}	2.74 ^{g}
T_2 -IBA@300 ppm	10.64 ^{c}	32.58 ^{d}	3.75 ^{f}
T_3 -IBA@400 ppm	8.57 ^{f}	42.53 ^{a}	4.40 ^{b}
T_4 -IBA@500 ppm	9.46 ^{e}	33.53 ^{c}	3.89 ^{e}
T_5 -NAA@150ppm	11.12 ^{b}	27.48 ^{e}	3.98 ^{d}
T_6 -NAA@200ppm	8.56 ^{f}	41.45 ^{b}	4.29 ^{c}
T_7 -NAA@250ppm	9.96 ^{d}	33.76 ^{c}	4.71 ^{a}
SE m ±	0.057	0.103	0.022
CD@ 5%	0.159	0.29	0.061
Factor B - Variety (V)			
V_1- Zizihno yellow	10.34 ^{a}	34.23 ^{c}	3.62 ^{e}
V_2- Mount kenya	11.17 ^{c}	35.21 ^{b}	3.94 ^{c}
V_3- Mount Ventox	10.21 ^{d}	28.98 ^{d}	3.67 ^{d}
V_4- Flavio	10.70 ^{b}	28.67 ^{e}	4.01 ^{b}
V_5- Camargo	9.42 ^{e}	38.58 ^{a}	4.58 ^{a}
SE m ±	0.047	0.087	0.018
CD@ 5%	0.131	0.245	0.052
Interaction (T×V)			
T_1V_1	14.60 ^{b}	20.87 ^{v}	1.81 ^{A}
T_1V_2	15.53 ^{a}	23.33 ^{u}	2.64 ^{y}
T_1V_3	13.60 ^{c}	19.13 ^{w}	2.17 ^{z}
T_1V_4	14.67 ^{b}	15.53 ^{x}	3.18 ^{w}
T_1V_5	12.87 ^{d}	24.27 ^{t}	3.89 ^{opq}
T_2V_1	10.60 ^{f}	31.13 ^{mn}	3.32 ^{v}
T_2V_2	11.40 ^{e}	39.73 ^{ef}	3.70 ^{rst}
T_2V_3	11.73 ^{e}	28.60 ^{p}	3.56 ^{tu}
T_2V_4	10.13 ^{g}	26.33 ^{r}	3.80 ^{qrs}
T_2V_5	9.33 ^{ij}	37.13 ^{h}	4.34 ^{ijk}
T_3V_1	8.40 ^{kl}	46.27 ^{c}	4.07 ^{mn}

T_3V_2	9.13 ^{j}	37.53 ^{h}	4.41 ^{hij}
T_3V_3	8.60 ^{k}	34.20 ^{j}	4.03 ^{no}
T_3V_4	8.73 ^{k}	39.87 ^{e}	4.61 ^{def}
T_3V_5	7.33 ^{n}	49.67 ^{a}	4.85 ^{ab}
T_4V_1	9.33 ^{ij}	33.53 ^{k}	4.28 ^{jkl}
T_4V_2	10.40 ^{fg}	35.20 ^{i}	3.96 ^{nop}
T_4V_3	9.40 ^{hij}	30.60 ^{no}	2.97 ^{x}
T_4V_4	9.67 ^{hi}	29.20 ^{p}	3.53 ^{u}
T_4V_5	8.53 ^{kl}	39.13 ^{fg}	4.70 ^{cde}
T_5V_1	11.47 ^{e}	27.60 ^{q}	3.83 ^{pqr}
T_5V_2	11.67 ^{e}	32.27 ^{l}	4.18 ^{lm}
T_5V_3	10.73 ^{f}	25.47 ^{s}	3.61 ^{tu}
T_5V_4	11.53 ^{e}	20.53 ^{v}	3.76 ^{qrs}
T_5V_5	10.20 ^{g}	31.53 ^{m}	4.53 ^{fgh}
T_6V_1	8.53 ^{kl}	47.07 ^{b}	3.68 st
T_6V_2	9.33 ^{ij}	41.20 ^{d}	4.21 ^{klm}
T_6V_3	8.20 ^{lm}	34.47 ^{j}	4.44 ^{ghi}
T_6V_4	9.47 ^{hij}	40.27 ^{e}	4.34 ^{ijk}
T_6V_5	7.93 ^{m}	49.40 ^{a}	4.79 ^{bc}
T_7V_1	9.47 ^{hij}	33.20 ^{k}	4.72 ^{bcd}
T_7V_2	10.73 ^{f}	37.27 ^{h}	4.47 ^{ghi}
T_7V_3	9.20 ^{j}	30.40 ^{o}	4.56 ^{efg}
T_7V_4	10.67 ^{f}	29.00 ^{p}	4.83 ^{bc}
T_7V_5	9.73 ^{h}	38.93 ^{g}	4.98 ^{a}
SE m ±	0.12	0.23	0.04
CD@ 5%	0.34	0.64	0.13

Table 2: Rooting percentage, shoot length and internodal length in rooted terminal cuttings treated with different rooting hormones

Treatments	Rooting percentage	Shoot length (cm)	Internodal length (cm)
Factor A – Rooting hormone treatment (T)			
T_1 -Control (Distilled water)	76.93 ^{f}	5.35 ^{e}	1.23
T_2 -IBA@300 ppm	85.27 ^{e}	7.57 ^{a}	2.02
T_3 -IBA@400 ppm	96.47 ^{a}	7.62 ^{a}	1.88
T_4 -IBA@500 ppm	92.67 ^{b}	7.28 ^{b}	1.65
T_5 -NAA@150ppm	85.87 ^{d}	7.02 ^{c}	2.02
T_6 -NAA@200ppm	96.40 ^{a}	6.65 ^{d}	1.42
T_7 -NAA@250ppm	91.93 ^{c}	7.65 ^{a}	2.22
SE m ±	0.18	0.08	0.31
CD@ 5%	0.51	0.25	NS
Factor B - Variety (V)			
V_1- Zizihno yellow	90.09 ^{a}	6.87 ^{c}	1.57
V_2- Mount kenya	89.76 ^{ab}	6.95 ^{bc}	1.65
V_3- Mount Ventox	88.28 ^{d}	7.61 ^{a}	2.05
V_4- Flavio	89.04 ^{c}	7.09 ^{b}	1.81
V_5- Camargo	89.61 ^{b}	6.57 ^{d}	1.53
SE m ±	0.15	0.07	0.26
CD@ 5%	0.43	0.21	NS
Interaction (T×V)			
T_1V_1	78.67 ^{p}	5.42 ^{p}	1.20
T_1V_2	77.33 ^{q}	5.48 ^{p}	1.20
T_1V_3	74.67 ^{r}	5.87 ^{op}	1.37
T_1V_4	78.33 ^{pq}	5.73 ^{p}	1.49
T_1V_5	75.67 ^{r}	4.24 ^{q}	0.91
T_2V_1	86.00 ^{kl}	7.33 ^{defghi}	1.96
T_2V_2	86.67 ^{jk}	7.93 ^{bc}	2.09
T_2V_3	81.67 ^{o}	7.74 ^{bcde}	2.16
T_2V_4	84.33 ^{mn}	7.52 ^{cdefgh}	2.03
T_2V_5	87.67 ^{j}	7.31 ^{efghij}	1.89
T_3V_1	97.33 ^{ab}	7.24 ^{efghijk}	1.84
T_3V_2	96.00 ^{c}	7.53 ^{cdefgh}	1.77
T_3V_3	96.30 ^{bc}	8.16 ^{ab}	2.34
T_3V_4	98.10 ^{a}	7.67 ^{bcdef}	1.78
T_3V_5	94.67 ^{d}	7.50 ^{cdefgh}	1.66
T_4V_1	92.67 ^{fg}	7.31 ^{efghi}	1.63
T_4V_2	93.33 ^{ef}	6.98 ^{hijklm}	1.45
T_4V_3	94.33 ^{de}	7.88 ^{bcd}	2.23
T_4V_4	91.67 ^{gh}	7.14 ^{fghijkl}	1.53

T_4V_5	91.33 ^{hi}	7.09 ^{ijklmn}	1.41
T_5V_1	86.67 ^{jk}	7.13 ^{ghijkl}	1.36
T_5V_2	85.67 ^{kl}	6.75 ^{jklmn}	1.26
T_5V_3	85.33 ^{lm}	7.59 ^{cdefg}	1.66
T_5V_4	84.00 ^{n}	6.87 ^{ijklmn}	1.31
T_5V_5	87.60 ^{j}	6.73 ^{klmn}	1.38
T_6V_1	97.60 ^{a}	6.52 ^{mn}	1.26
T_6V_2	96.33 ^{bc}	6.45 ^{mn}	1.21
T_6V_3	95.33 ^{cd}	7.29 ^{efghij}	1.95
T_6V_4	94.67 ^{d}	6.64 ^{lmn}	1.42
T_6V_5	98.00 ^{a}	6.33 ^{no}	1.25
T_7V_1	91.67 ^{gh}	7.13 ^{fghijkl}	1.73
T_7V_2	93.00 ^{f}	7.56 ^{cdefg}	2.10
T_7V_3	90.30 ^{i}	8.72 ^{a}	2.34
T_7V_4	92.33 ^{fgh}	8.05 ^{bc}	2.48
T_7V_5	92.33 ^{fgh}	6.78 ^{ijklmn}	1.46
SE m ±	0.41	0.19	0.70
CD@ 5%	1.15	0.56	NS

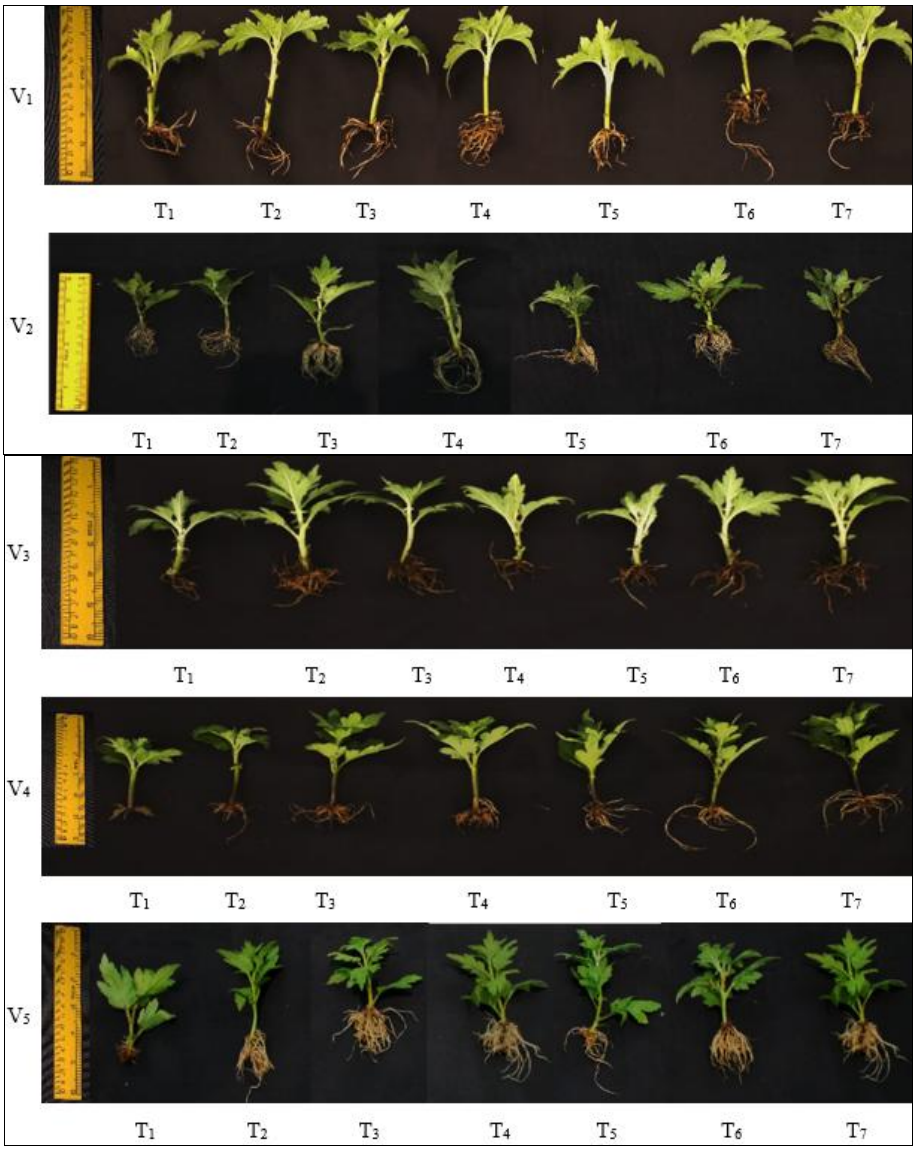

Fig 1: Comparison of root characters with different rooting hormones in five varieties

4. Conclusion

The study demonstrated that exogenous application of IBA@400 ppm and NAA@200 ppm significantly enhanced rooting performance in chrysanthemum cuttings. These treatments induced early root initiation, higher root number, greater root length and superior rooting percentage compared to the control. Among the varieties tested, Camargo exhibited the best rooting response, highlighting genotypic influence. The findings suggested that adopting optimum concentrations of IBA or NAA can improve propagation efficiency, uniformity and establishment of pot mums under polyhouse conditions.

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Conflict of Interests
The authors have declared that no conflicts of interest exist.

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