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Efficacy of catechol and plant growth regulators on the vegetative growth and flowering of African Marigold (*Tagetes erecta* L. cv. Pusa Narangi Gaiinda)

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ABSTRACT: A field experiment was conducted to evaluate the effects of four plant growth regulators (PGRs)-Gibberellic Acid (GA₃), Naphthalene Acetic Acid (NAA), Triacantanol (TRIA), and Catechol on the vegetative growth and flowering parameters of African marigold (*Tagetes erecta* L. cv. Pusa Narangi Gaiinda). Foliar application of different concentrations of these PGRs significantly influenced plant height, spread, number of branches, leaf count, and floral characteristics. The results revealed that treatments with Catechol at 500 ppm and GA₃ at 200 ppm consistently promoted superior vegetative growth, including increased plant height, spread, branch number, and leaf count. In contrast, treatment with NAA at 30 ppm and NAA at 20 ppm suppressed vegetative growth. Recording the lowest plant height (48.00-51.12 cm and leaf count. Flowering parameters, such as fresh and dry flower weight, flower diameter, and the number of flowers per plant, were also significantly enhanced by Catechol and GA₃ treatments, indicating that Catechol at 1500 ppm and GA₃ at 200 ppm are effective promoters of growth and yield in African marigold.

Keywords: Catechol, Floriculture, GA₃, Marigold, NAA, Triacantanol

Floriculture is a rapidly growing industry in India, driven by increasing demand for flowers for religious, decorative, and allied purposes, viz., beekeeping, landscaping, perfumery, and cosmetic industry. (Singh and Kumar, 2020; Patel and Desai, 2021; Gómez and Rodríguez, 2021; Ahmad and Khan, 2018). The industry has emerged as a significant source of alternative income for farmers in Tamil Nadu, Karnataka, Madhya Pradesh, and West Bengal, owing to its leading position as a marigold producer (Anonymous, 2025). Marigold (*Tagetes* spp.) is one of the most important loose-flower commercial crops, as it is a rich source of lutein and fatty acid esters, accounting for more than 90% of the total carotenoid pigments identified in *Tagetes* spp. (Ahmad and Khan, 2018; Becerra *et al.*, 2020; Yang and Li, 2020). Owing to its economic and ornamental significance, improved plant growth, flowering, and quality traits constitute key areas of research. The plant growth regulators (PGRs), being important and increasingly used tools in modern agriculture, play a crucial role in controlling plant growth and development, promoting flower initiation, and improving various quality characteristics of flowers (Blázquez *et al.*, 1998;

Davies, 2010; Giri *et al.*, 2011; Madhavan *et al.*, 2018; Das *et al.*, 2025). In addition to agronomic management practices and genetic factor modification, plant growth regulators are considered the third key component, influencing plant growth and flowering. Their role in enhancing vegetative growth, regulating flowering and improving overall flower production has been evaluated and confirmed in various crops viz., sugarcane (stem length and yield, grapes (bunch elongation, berry enlargement, and ripening), cotton (prevention of shedding, and improve boll retention), rice and wheat (tillering, lodging prevention, and improve grain filling), fruit crops (fruit set, uniform ripening, and colour development), vegetables (root growth, flowering, and fruit setting) etc. (Nanthakumar *et al.*, 2021; Verma *et al.*, 2024). Triacantanol (TRIA) is a bioactive phytostimulant naturally occurring in plant waxes, first isolated from alfalfa (*Medicago sativa*), and widely applied in several ornamental crops for enhancing cellular physiological efficiency to better express the genetic potential for improved growth and productivity (Naeem *et al.*, 2012; Perveen *et al.*, 2014; Perveen *et al.*, 2016; Maresca *et al.*, 2017; Zaid *et al.*, 2020). On the other hand, Naphthalene Acetic

Acid (NAA), Gibberellic Acid (GA_3), and catechol promote seed germination, stem elongation, and flower quality. They reshape roots *via* redox signaling by regulating cell expansion, flowering time, and environmental adaptation (Saravaiya *et al.*, 2010; Wang *et al.*, 2017). Although research on the specific use of Catechol in marigold is limited, its inclusion in studies represents an innovative shift toward the use of phenolic compounds as growth regulators. Catechol is well known for its role in plant defense and antioxidant pathways, but its potential to influence biomass and flower development opens new possibilities for enhancing ornamental growth (Wang *et al.*, 2017). By modulating physiological activities such as nutrient uptake and water absorption, this compound could serve as a more stable alternative to traditional hormones like GA_3 or NAA. The purpose of this research is to address a significant gap in floriculture and lay a foundation for its effectiveness in optimizing growth parameters. Therefore, examining its dose-dependent effects provides valuable insights into how phenolics can be practically used in modern agriculture.

This study aimed to assess the effects of GA_3 , NAA, TRIA, and Catechol on the vegetative and flowering characteristics of African marigold cv. *Pusa Narangi Gaiinda* to determine the optimal PGR concentration for maximizing its growth and production.

MATERIALS AND METHODS

The investigation was carried out during the 2024-25 academic year at the Centre for Agricultural Education, Aligarh Muslim University, Uttar Pradesh (27.88° N, 78.20° E), within a semi-arid monsoonal climate. Seeds of *Tagetes erecta* L. cv. Pusa Narangi Gaiinda from IARI, New Delhi, were transplanted on November 16, 2024, into 1.35 m x 1.35 m plots using a Randomized Block Design (RBD) with nine treatments and three replications at a spacing of 45 cm x 30 cm. The details of plant growth regulators and their concentrations used in the experiment are presented in Table 1. Data were collected from five randomly selected plants per plot for vegetative growth (height, spread, branches, number of leaves

plant⁻¹, and fresh and dry biomass plant⁻¹), floral quality (bud initiation, flower appearance, diameter, and stalk length), and yield (fresh/dry flower weight and yield per plant). Various growth and flowering observations were recorded following standard experimental procedures. Plant height was measured from the base of the plant to the apical tip using a measuring scale, whereas flower diameter and flower stalk length were measured at the full bloom stage. Representative experimental observations and field views are presented in Figures 1 and 2.

Statistical analysis was performed using one-way ANOVA in OPSTAT software (Pandey and Rajput, 1993) with treatment significance tested at the 5% level ($P = 0.05$), and mean separation was determined by the Critical Difference (CD) according to Panse and Sukhatme (1985).

Table 1: Plant growth regulators and concentrations evaluated in marigold

Treatment	Plant growth regulator	Concentration
T ₁	Control (water spray)	—
T ₂	Gibberellic acid (GA_3)	100 ppm
T ₃	Gibberellic acid (GA_3)	200 ppm
T ₄	Triacantanol	20 ppm
T ₅	Triacantanol	30 ppm
T ₆	Catechol	1000 ppm
T ₇	Catechol	1500 ppm
T ₈	Naphthalene acetic acid (NAA)	20 ppm
T ₉	Naphthalene acetic acid (NAA)	30 ppm

RESULTS AND DISCUSSION

Effect of Plant Growth Regulators on Vegetative Growth Parameters

Plant growth regulators exerted a significant influence on the vegetative growth of marigold (*Tagetes erecta* L.) cv. *Pusa Narangi Gaiinda* (Tables 2). At 120 days after transplanting (DAT), plant height varied significantly among treatments, ranging from 48.00 cm in NAA at 30 ppm to 79.25 cm in Catechol at 1500 ppm. Similar observations on Gibberellic acid performance were reported by Maurya *et al.* (2023) in marigold. The tallest plants were recorded in Catechol at 1500 ppm (T₇), which was statistically superior to the control and NAA treatments, as the treatment differences exceeded the critical difference (CD) at the 5% level (11.25 cm).

Plant spread in both East-West (E-W) and North-South (N-S) directions was significantly enhanced by catechol and GA₃ applications. The maximum E-W (46.58 cm) spread was recorded under Catechol at 1000 PPM (T₆), and the maximum N-S (45.67 cm) spread was recorded under Catechol at 1000 PPM; these values were significantly higher than those of the control and NAA treatments, as indicated by the respective CD values. This pattern confirmed the findings of Bairwa and Mishra (2017b), who emphasized NAA's stronger association with floral induction and root growth than with shoot or canopy expansion. Though limited literature exists on Catechol's role in marigold cultivation, the current results resonate with Narute *et al.* (2020c), who emphasized the efficacy of GA₃ in enhancing vegetative biomass, suggesting that Catechol would have acted through complementary pathways. Also, a dose-dependent effect of catechol on enhancing root growth was reported in tobacco seedlings by Wang *et al.* (2017). This enhancing plant spread under catechol may be linked to improved cell elongation and stimulation of lateral growth. As far as the number of branches was concerned, the increase in the number and leaves was observed due to GA₃ at 200 ppm, as it produced the maximum number of branches (18.22 plant⁻¹), which was significantly higher than the control (12.11 plant⁻¹), exceeding the CD (5%) value of 2.80. The highest leaf number was recorded with Catechol at 1500 ppm (415.11 leaves plant⁻¹), followed by Catechol at 1000 ppm, indicating enhanced photosynthetic surface area. In contrast, NAA treatments recorded the lowest values for these traits, suggesting a suppressive effect on vegetative growth at higher

concentrations. This promoter effect of growth regulators, in general, and GA and NAA in particular, has been reported by various workers; however, Bhuneshwar (2022) reported that salicylic acid outperformed GA₃ and NAA in *Calendula officinalis*. This supports the findings of Mishra *et al.* (2018) and Bairwa and Mishra (2017a), which reported that NAA has greater effects on root development and flower induction than on vegetative branching. The present findings clearly demonstrate that GA₃ at 200 ppm is the most effective treatment for increasing branch number in African marigold, followed by Catechol at 1000-1500 ppm and Triacntanol at 20-30 ppm. These PGRs stimulate vegetative growth by influencing hormonal pathways, promoting bud development, and enhancing physiological efficiency. NAA, while beneficial for other traits such as root growth and flowering, proved less effective for branching, underscoring the need for crop and trait-specific PGR selection to achieve the desired horticultural outcome. The effect on fresh and dry biomass accumulation differed significantly among treatments (Table 2). The maximum fresh weight (190.37 g plant⁻¹) was obtained with Catechol at 1500 ppm, followed closely by Catechol at 1000 ppm. These treatments were statistically superior to the control, as the differences exceeded the CD (5%) value of 24.91 g. Similarly, the highest dry matter accumulation (22.70 g plant⁻¹) was recorded under Catechol 1000 ppm, reflecting improved assimilate production and partitioning. The comparatively lower biomass recorded in NAA-treated plants may be attributed to hormonal imbalance leading to restricted vegetative expansion. The superior

Table 3: Ranking of plant growth regulators based on growth, flowering, and yield performance of *Tagetes erecta* L. cv. Pusa Narangi Gaiinda

Treatment	Overall Performance	Rank
Catechol 1500 ppm (T ₇)	Highest growth, biomass, and flower yield	1
Catechol 1000 ppm (T ₆)	Best floral quality and earliness	2
GA ₃ 200 ppm (T ₃)	Maximum branches, good yield	3
GA ₃ 100 ppm (T ₂)	Early flowering	4
TRIA 30 ppm (T ₅)	Moderate improvement	5
TRIA 20 ppm (T ₄)	Slight improvement	6
Control (T ₁)	Baseline	7
NAA 30 ppm (T ₉)	Poor growth	8
NAA 20 ppm (T ₈)	Lowest performance	9

Table 2: Effect of plant growth regulators on growth, flowering, and yield attributes of marigold (*Tagetes erecta* L.) cv. Pusa Narangi Gainda

Treatment	Plant height (cm)	Plant spread		No. of branches (120 DAT)	Leaves plant ⁻¹	Days to flower appearance	Flower diameter (mm)	Flower plant ⁻¹	Fresh weight (g plant ⁻¹)	Dry weight (g plant ⁻¹)	Flower Count	Flower Yield (g Plant ⁻¹)
		E-W (cm)	N-S (cm)									
Control	57.00	37.89	36.00	12.11	263.44	60.33	58.05	35.60	169.9	20.38	35.60	387.17
GA ₃ 100 ppm	71.22	39.67	36.95	13.44	315.44	62.04	61.5	38.25	185.17	19.23	38.25	418.17
GA ₃ 200 ppm	75.44	44.44	45.33	18.22	322.67	62.28	61.44	38.73	187.17	21.01	38.73	420.17
TRIA 20 ppm	52.33	35.89	35.22	14.11	278.22	62.87	59.44	29.70	170.13	20.42	29.70	316.5
TRIA 30 ppm	54.33	37.44	37.55	13.44	295.00	62.87	58.56	30.05	172.16	21.56	30.05	318.67
CAT 1000 ppm	71.33	46.58	45.67	16.11	386.33	58.03	65.48	40.8	189.17	22.70	40.80	420.44
CAT 1500 ppm	79.25	43.56	42.11	15.77	415.11	58.16	64.02	41.12	190.37	22.48	41.12	424.83
NAA 20 ppm	51.12	35.56	36.22	12.55	186.11	65.20	56.28	28.42	110.47	13.26	28.42	369.00
NAA 30 ppm	48.00	39.33	40.78	13.33	218.89	65.37	57.31	28.9	108.83	13.06	28.90	375.11
S.E	3.19	1.56	1.35	0.96	20.33	0.86	1.04	0.13	10.78	1.22	0.13	8.56
CD ($p < 0.05$)	11.25	4.54	3.12	2.8	59	1.99	2.39	0.4	24.91	2.8	0.4	25.65

S.E= Standard Error; C.D= critical difference

performance of Catechol at higher concentrations may be due to its phenolic compounds, which enhance physiological activity, water absorption, and nutrient uptake, thereby contributing to better biomass accumulation. Similarly, the positive role of GA₃ in increasing fresh weight was supported by Acharya *et al.* (2021) and Narute *et al.* (2020b), who attributed such results to enhanced cell division and elongation.

Effect of Plant Growth Regulators on Floral Quality Parameters

Flowering behavior was significantly influenced by the application of plant growth regulators (Table 2). Catechol at 1000 ppm induced the earliest flower appearance (58.03 days after transplanting), which was significantly earlier than the control (60.33 days) and NAA treatments, as the difference exceeded the CD (5%) value of 1.99 days. Catechol application accelerates metabolic activity, leading to early floral initiation. Delayed flowering observed under NAA treatments may be attributed to prolonged vegetative growth, driven by auxin-mediated regulation. This delay is consistent with the findings of Kumar *et al.* (2011), who reported that NAA treatments, particularly at higher concentrations, delayed floral development by enhancing vegetative growth and delaying the transition to the reproductive phase.

The effects on floral quality traits varied significantly among treatments, including flower diameter, stalk length, and flower weight (Table 2). Catechol at 1000 ppm produced the largest flowers (65.48 mm diameter) and the longest stalks (9.77 cm), which were statistically better than the control and NAA treatments, as indicated by the respective CD values. Similarly, the maximum fresh (190.37 g) and dry (22.48g) flower weights were recorded under Catechol at 1500 ppm, with results closely matching those under Catechol 1000 ppm, indicating improved sink strength and enhanced translocation of assimilates toward floral organs. This suggests that catechol application boosts physiological and metabolic activity in plants, leading to increased water retention and cell expansion, thereby improving flower weight. Meanwhile, the number of flowers per plant varied significantly, as shown in Table 2. Catechol at 1500 ppm produced the highest flower yield (41.12 flowers per plant), which was statistically superior to the control (35.60 flowers per plant) and NAA treatments, since the difference exceeded the CD (5%) value of 0.40.

Effect of Plant Growth Regulators on Yield Parameters

The highest average number of flowers per plant was recorded in the Catechol at 1500 ppm treatment (41.12), which was



Fig 1. a) Measuring the height of the marigold plant. b) Overview of the planted field of African Marigold cv. Pusa Gaienda at CAE, Agriculture farm



Fig. 2: Measurement of a) Flower Diameter; b) Flower stalk

statistically equivalent to Catechol 1000 ppm (40.80), followed by GA₃ at 200 ppm (38.73) and GA₃ at 100 ppm (38.25). The minimum number of flowers per plant was recorded in NAA-treated plants at 20 ppm (28.42). Regarding flower yield per plant (g), the maximum yield was obtained in Catechol at 1500 ppm (424.83 g) treatment, which was statistically at par with Catechol at 1000 ppm (420.44 g) and GA₃ at 200 ppm (420.17 g). However, the lowest flower yield was recorded in plants treated with TRIA at 20 ppm (316.50 g).

The average range of flower yield per plant (316.50 g to 424.83 g) indicated a wide variation among treatments. The highest flower yield (424.83 g/plant) at both concentrations of Catechol at 1500 ppm and 1000 ppm, also coincides with the highest number

of flowers per plant. The superior performance of Catechol might be attributed to its role in enhancing physiological processes such as respiration, photosynthesis, and overall metabolic activity, which ultimately support better flowering and yield. Among gibberellic acid treatments, both GA₃ concentrations at 200 ppm and at 100 ppm showed remarkably higher yields (420.17 g/plant and 418.17 g/plant, respectively). This promotive effect of GA₃ on flowering and yield might be due to its influence on cell elongation, flower initiation, and improved source-sink relationship, as supported by the findings of Markam (2017), Wadgave (2016), and Narute *et al.* (2020a). Although TRIA is known to enhance photosynthetic efficiency and nutrient uptake, its effect was less than that of Catechol and GA₃. TRIA is reported to enhance adenylate cyclase activity and

photosynthesis, which may explain its moderate improvement in leaf count and biomass in the present study (Naeem *et al.*, 2012). These results aligned with those of Verma *et al.* (2022), who noted moderate improvements in yield components under TRIA application in marigold. The lowest flower yields were recorded in NAA treated and control plots. Though NAA slightly increased flower yield compared with the control, the increase was marginal and not statistically significant. The low performance of NAA could be due to its auxinic effect, which primarily favors vegetative growth rather than enhancing floral yield components. Similar findings were reported by Mishra (2018) and Sharma (2023), who observed minimal effect of NAA on marigold flower yield. The study suggested that Catechol at 1500 ppm was the most effective treatment for enhancing flower yield, followed by GA₃ at 200 ppm, supporting the efficacy of both Catechol and GA₃ in improving floral productivity in African marigold. Based on the overall performance of different plant growth regulators on vegetative growth, flowering behaviour, and yield parameters, the treatments were comparatively ranked and presented in Table 3. Among all treatments, Catechol at 1500 ppm (T₆) secured the first rank owing to its superior influence on plant height, biomass accumulation, flower number, and flower yield. Catechol at 1000 ppm (T₅) ranked second due to its excellent floral quality and earliness, while GA₃ at 200 ppm (T₄) occupied the third position because of its pronounced effect on branching and yield improvement. In contrast, NAA treatments exhibited comparatively poor performance and were placed at lower ranks. The ranking clearly indicated that Catechol and GA₃ treatments were more effective than TRIA and NAA for enhancing growth and floral productivity in African marigold cv. *Pusa Narangi Gaiinda*.

CONCLUSION

The present study conclusively demonstrated that foliar application of plant growth regulators, particularly Catechol and GA₃, significantly enhanced vegetative growth, flowering behaviour, and flower yield in African marigold (*Tagetes erecta*

L.) cv. *Pusa Narangi Gaiinda*. Among the treatments, Catechol at 1500 ppm showed the most pronounced effect, markedly improving plant height, canopy spread, branching, leaf production, biomass accumulation, and floral yield. These responses may be attributed to the phenolic nature of catechol, which enhanced metabolic activity, photosynthetic efficiency, and assimilate translocation. GA₃, especially at 200 ppm, promoted stem elongation, branching, and floral development, thereby establishing its role in stimulating cell division and elongation. Flowering was accelerated and floral quality improved under Catechol and GA₃ treatments. In contrast, NAA delayed flowering and reduced shoot and floral growth, likely because it preferentially affects rooting and early establishment. Triacantanol showed moderate effectiveness, performing better than NAA and control but inferior to Catechol and GA₃. Catechol at 1500 ppm was the most effective treatment, followed by Catechol 1000 ppm and GA₃ at 200 ppm. It is therefore recommended that catechol at 1500 ppm be applied as a foliar spray to maximize marigold growth and flower yield under the semi-arid agro-climatic conditions of Aligarh, Uttar Pradesh.

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