



RESEARCH ARTICLE

Effect of seedling age, plant growth regulators and pinching on growth, flowering and yield in African marigold (*Tagetes erecta* L.) cv. Pusa Bahar

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Abstract

The present study entitled “Effect of seedling age, plant growth regulators and pinching on growth, flowering and yield in African marigold (*Tagetes erecta* L.) cv. Pusa Bahar” was conducted at the Horticultural Research Farm, Department of Floriculture and Landscape, IGKV, Raipur, Chhattisgarh during rabi seasons 2023–2024 and 2024–2025. The experiment was laid out in a factorial randomized block design (FRBD) with 3 replications and 24 treatment combinations, comprising 2 seedling ages (25 and 35 days), four PGR treatments (Cycocel at 1500 ppm, CCC at 2000 ppm, cytokinin (BA) at 200 ppm, cytokinin (BA) at 250 ppm) and 3 pinching levels (no pinching, single and double pinching). The results were statistically analysed and discussed based on pooled mean. The treatment combination, 25-day-old seedlings × Cycocel at 2000 ppm × single pinching ($S_1G_2P_1$) recorded the highest flower yield plant⁻¹ (628.92 g), flower yield plot⁻¹ (11.38 kg) and flower yield hectare⁻¹ (29.12 t). The treatment 25-day-old seedlings × CCC at 2000 ppm × double pinching ($S_1G_2P_2$) resulted in the minimum plant height (60.88 cm) and the maximum number of flowers plant⁻¹ (79.13). Moreover, the treatment combination 25-day-old seedlings × cytokinin (BA) at 250 ppm × no pinching ($S_1G_4P_0$) recorded the minimum values for all parameters except plant height (106.11 cm). Based on the overall findings, it can be concluded that the combined application of 25-day-old seedlings with CCC at 2000 ppm and single pinching is most effective for optimising growth, flowering and yield of African marigold cv. Pusa Bahar.

Keywords: African marigold; growth; pinching; plant growth regulator; seedling age; yield

Introduction

Marigold (*Tagetes* spp.) of the family Asteraceae is one of the most popular ornamental crops, valued for its bright colours, profuse flowering, easy cultivation and wide use in ornamental, religious and industrial purposes. Because of its short duration, high productivity and adaptability, it has become an important crop in floriculture. Among cultivated species, *Tagetes erecta* L. (African marigold, $2n = 24$) and *Tagetes patula* L. (French marigold, $2n = 48$) are the most widely grown. Marigold is a hardy and photoperiod-insensitive crop that performs well under diverse agro-climatic conditions.

Marigold can be cultivated at any time of year and in every season, but they flower and grow profusely when grown in sunny settings (1). Oil extracted from marigold has an insecticidal property as well as it can be grown in fields as a trap crop against root nematodes (2).

The growth and yield of marigold are influenced by genotype, environment and cultural practices. Among these, seedling age, pinching and plant growth regulators (PGRs) play a major role. Pinching breaks apical dominance, enhances branching and increases flower production. Using seedlings of suitable age improves establishment and uniform flowering. The PGRs such as

cycocel (CCC) and cytokinin (BA) further support vegetative growth and flowering by regulating cell division and hormonal balance. Pinching creates an environment for better use of the hormones in the plant that finally supports overall growth and development of the plant and increases growth and yield parameter (3). Therefore, the present study was undertaken during 2023–2024 and 2024–2025 to evaluate the effects of seedling age, pinching and PGRs on the growth, flowering and yield of marigold.

Materials and Methods

The experiment was conducted at the Horticultural Research cum Instructional Farm, Department of Floriculture and Landscape, College of Agriculture, IGKV, Raipur (Chhattisgarh). The region has a sub-humid climate with hot summers and cool winters. The average annual rainfall in the region is 1200–1400 mm, with most rainfall occurring between June and September. Raipur aggregates up to 1318.90 mm of rainfall throughout the year. The test crop was African marigold (*T. erecta*) cv. Pusa Bahar, grown during the rabi season. The experiment was laid out in a factorial randomized block design (FRBD) with 24 treatment combinations with 3 replications. Each plot measured 1.8 m × 1.2 m and accommodated 16 plants at a spacing of 45 × 30 cm. Treatments consisted of 2

seedling ages (S_1 : 25-day-old, S_2 : 35-day-old), 4 plant growth regulators (G_1 : CCC 1500 ppm, G_2 : CCC 2000 ppm, G_3 : BA 200 ppm, G_4 : BA 250 ppm) and 3 pinching levels (P_0 : no pinching, P_1 : single pinching at 30 days after transplanting (DAT), P_2 : double pinching at 30 and 45 DAT). Observations on growth, flowering and yield attributes were recorded at appropriate developmental stages. The soil was loam in texture (sand 25.84 %, silt 55.97 %, clay 20.67 %). The soil had low available nitrogen (259.12 kg ha⁻¹), medium phosphorus (40.77 kg ha⁻¹) and high potassium (323.01 kg ha⁻¹). The soil reaction was neutral (pH 7.76) with medium organic carbon (0.50 %) and normal electrical conductivity (0.23 dS m⁻¹) and PGRs were applied as foliar spray. Plant growth regulators (CCC at 1500 ppm = 1.5 mL L⁻¹ and 2000 ppm = 2.0 mL L⁻¹; BA at 200 ppm = 200 mg L⁻¹ and 250 ppm = 250 mg L⁻¹ of stock solution) were prepared using standard dilution methods. Foliar application was carried out 4 weeks after transplanting as per treatments, ensuring uniform spray coverage.

Statistical analysis

The recorded data were analysed using ANOVA as per the procedure for FRBD to determine the significance of treatment effects. Results were interpreted based on pooled means of 2 years (2023–2024 and 2024–2025).

Results and Discussion

Vegetative characters

The data on vegetative growth parameters, viz. plant height (cm), plant spread (cm), number of primary branches, number of secondary branches, stem diameter (mm) and chlorophyll content (SPAD meter), were recorded and analysed. All data related to vegetative growth parameters are systematically presented in Tables 1 and 2.

The effect of seedling age on plant height was found to be non-significant. Among the plant growth regulators, foliar application of BA at 250 ppm (G_4) recorded the maximum plant height (85.83 cm), whereas the minimum plant height (74.05 cm) was observed under CCC at 2000 ppm (G_2). The results indicated that plant height was positively correlated with increasing concentrations of cytokinin (BA), which stimulates cell division, elongation and shoot proliferation (4–6). Pinching significantly influenced plant height, where P_0 resulted in the maximum height (95.15 cm), while P_2 recorded the minimum plant height (66.05 cm). The reduction in height due to pinching is attributed to the removal of the apical bud, which disrupts apical dominance and redirects assimilates toward lateral branch development instead of vertical growth (7, 8). The combination S_1G_4 ($S_1 \times$ BA at 250 ppm) produced the tallest plants (87.10 cm), whereas S_2G_2 ($S_2 \times$ CCC at 2000 ppm) resulted in the shortest plants (74.02 cm). The interaction between PGR and pinching ($G \times P$) indicated that G_4P_0 (BA at 250 ppm $\times$ P_0) produced the tallest plants (103.14 cm), while G_2P_2 (CCC at 2000 ppm $\times$ P_2) recorded the shortest (61.73 cm). Among the three-way interactions, $S_1G_4P_0$ ($S_1 \times$ BA at 250 ppm $\times$ P_0) produced the maximum plant height (106.11 cm pooled mean), whereas $S_1G_2P_2$ ($S_1 \times$ CCC at 2000 ppm $\times$ P_2) recorded the minimum (60.88 cm). The combination $S_1G_4P_0$ ($S_1 +$ BA 250 ppm + P_0) showed superiority because younger seedlings generally establish faster and produce more vigorous early growth due to their higher metabolic activity and better root-shoot synchronization. The application of Benzyladenine (BA) at 250 ppm, a cytokinin, further enhances

growth by promoting cell division, cell elongation and branching, resulting in increased vegetative development. Additionally, no pinching (P_0) allows the plant to maintain apical dominance, enabling uninterrupted vertical growth and leading to maximum plant height. These combined physiological advantages contribute to overall superior plant performance.

The effect of seedling age on number of primary branches was found to be non-significant experimentation. It was observed that maximum primary branching (13.02) was recorded under G_2 (CCC at 2000 ppm), was statistically comparable to G_1 (CCC at 1500 ppm; 12.72 cm) and the lowest number of primary branches (12.08) noted under G_4 (BA at 250 ppm). Pinching exhibited a significant influence on primary branches the data revealed that the maximum number of primary branches was consistently recorded in treatment P_2 , which produced 13.84 branches, whereas the minimum number of primary branches was observed under treatment P_0 , which recorded only 11.29. All the interaction effects on primary branches in African marigold were statistically non-significant.

The effect of seedling age on number of secondary branches was found to be non-significant. The highest number of secondary branches (38.75) was observed in treatment G_2 (CCC at 2000 ppm), whereas the lowest number of secondary branches (26.95) was recorded under G_4 (BA 250 ppm). In this experiment, application of CCC at 2000 ppm markedly influenced branch formation. The probable reason behind this result may attributed to CCC, a growth retardant, inhibits gibberellin biosynthesis, which suppresses excessive stem elongation and promotes compact growth and axillary shoot formation. This makes plants bushier and allows greater allocation of resources to branch development rather than vertical growth (9–12). Secondary branches (40.43) were highest under P_2 . The minimum number of secondary branches (32.06) was recorded under P_0 . Pinching significantly increased branches. The reason may be attributed to the removal of the apical bud, which disrupts apical dominance by lowering auxin concentration at the shoot tip. This physiological change redirects assimilates and growth hormones, particularly cytokinin's, towards axillary bud outgrowth, thereby enhancing the production of lateral branches (13, 14). The interaction between seedling age and PGRs exerted a significant influence on the number of secondary branches, S_2 treated with CCC at 2000 ppm (S_2G_2) produced the highest number of secondary branches (35.00) on par with S_1 with CCC at 2000 ppm (S_1G_2) with 34.58 branches. The lowest number of branches (26.59) was recorded in S_1 treated with BA at 250 ppm (S_1G_4). Evidence from data indicated that G_2P_2 (CCC at 2000 ppm combined with S_2) resulted in the maximum secondary branching (45.26), whereas G_4P_0 (BA at 250 ppm with P_0) produced the minimum number of secondary branches (16.14). The data showed that a significant interaction between seedling age, plant growth regulators and pinching influenced the number of secondary. Triple interaction, $S_2G_2P_2$ (S_2 treated with CCC at 2000 ppm combined with P_0) consistently resulted in the highest branching (46.57), while $S_1G_4P_0$ (S_1 treated with BA at 250 ppm without pinching) showed the lowest number of secondary branches (15.02).

No significant difference was observed for seedling age on stem diameter. All the levels of plant growth regulators significantly influenced stem diameter, the superior performance of G_2 (16.05 mm) in terms of stem diameter, which was Statistically at par with G_1 (15.18 mm), while G_4 recorded the lowest value (12.99 mm). The

Table 1. Effect of seedling age, plant growth regulators and pinching on plant height (cm), Number of primary branches, number of secondary branches, stem diameter (mm), chlorophyll content (SPAD meter) and 50 % flowering in African marigold cv. Pusa Bahar

Treatment	Plant height (cm)			Number of primary branches			Number of secondary branches			Stem diameter (mm)			Chlorophyll content (SPAD value)			50 % flowering		
	2023-24	2024-25	Pooled mean	2023-24	2024-25	Pooled mean	2023-24	2024-25	Pooled mean	2023-24	2024-25	Pooled mean	2023-24	2024-25	Pooled mean	2023-24	2024-25	Pooled mean
S ₁ S ₂ SEm (±) CD (5 %)	80.27	79.79	80.00	12.57	12.66	12.61	31.84	30.60	31.22	15.04	14.30	14.67	35.85	36.40	36.13	70.96	71.11	71.04
	79.77	79.57	79.70	12.47	12.50	12.49	31.45	30.26	30.85	14.87	14.10	14.48	35.00	35.57	35.28	70.25	70.67	70.46
	0.39	0.38	0.27	0.25	0.21	0.15	0.27	0.29	0.27	0.22	0.22	0.22	0.58	0.46	0.39	0.83	0.82	0.83
	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	77.22	77.01	77.12	12.72	12.71	12.72	33.11	31.87	32.49	15.59	14.76	15.18	31.61	32.02	31.82	72.85	73.11	72.98
G ₁ G ₂ G ₃ G ₄	74.20	73.91	74.05	13.01	13.07	13.02	35.35	34.23	34.79	16.41	15.69	16.05	33.97	34.44	34.21	71.57	71.86	71.71
	82.62	82.19	82.41	12.29	12.46	12.37	30.54	29.30	29.92	14.50	13.66	14.08	36.82	37.66	37.24	69.59	70.00	69.80
	86.04	85.62	85.83	12.05	12.12	12.08	27.57	26.33	26.95	13.31	12.67	12.99	39.29	39.82	39.55	68.40	68.61	68.50
	0.32	0.31	0.22	0.35	0.29	0.22	0.22	0.24	0.22	0.31	0.32	0.27	0.83	0.66	0.56	1.17	1.17	1.17
	0.93	0.89	0.63	NS	NS	0.62	0.63	0.69	0.63	0.89	0.90	0.88	2.36	1.88	1.59	3.34	3.32	3.32
P ₀ P ₁ P ₂	94.96	95.33	95.15	11.27	11.31	11.29	21.25	20.01	20.63	10.98	10.61	10.79	24.59	24.27	24.43	63.00	63.07	63.04
	78.65	78.06	78.35	12.50	12.53	12.52	32.67	31.44	32.06	15.24	14.26	14.75	35.86	36.99	36.43	69.50	69.77	69.63
	66.45	66.75	66.05	13.77	13.90	13.84	41.00	39.85	40.43	18.63	17.72	18.18	45.82	46.70	46.26	79.30	79.85	79.58
	0.39	0.38	0.27	0.30	0.25	0.19	0.27	0.29	0.27	0.27	0.27	0.27	0.71	0.57	0.46	1.02	1.01	1.01
	1.13	1.08	0.77	0.86	0.72	0.54	0.77	0.85	0.78	0.77	0.78	0.77	2.04	1.63	1.38	2.90	2.87	2.88
SEm (±) CD (5 %)	77.36	76.94	77.15	12.82	12.79	12.81	33.59	32.36	32.98	15.69	15.14	15.22	31.77	31.50	31.50	73.22	73.31	73.27
	77.09	76.99	77.09	12.63	12.63	12.63	32.62	31.38	32.00	15.50	14.78	15.14	32.00	32.26	32.13	72.48	72.90	72.69
	74.39	73.79	74.09	13.02	13.09	13.06	35.19	33.96	34.58	16.45	16.10	16.10	34.66	35.15	34.90	71.88	71.97	71.92
	74.00	74.03	74.02	13.00	12.98	12.99	35.50	34.50	35.00	16.37	15.63	16.00	33.29	33.73	33.51	71.26	71.75	71.50
	82.02	81.58	81.80	12.26	12.53	12.40	31.35	30.12	30.73	14.79	16.00	14.41	37.37	38.06	37.71	69.91	70.25	70.08
S _{G1} S _{G2} S _{G3} S _{G4}	83.22	82.81	83.01	12.31	12.39	12.35	29.74	28.49	29.12	14.21	13.30	13.76	36.28	37.25	36.77	69.26	69.76	69.51
	87.32	86.87	87.10	12.16	12.23	12.20	27.21	25.98	26.59	13.22	14.41	12.94	40.15	40.61	40.38	68.81	68.93	68.87
	84.75	84.37	84.56	11.93	12.01	11.97	27.92	26.69	27.30	13.39	12.68	13.04	38.42	39.03	38.73	67.99	68.29	68.14
	0.56	0.53	0.38	0.49	0.42	0.31	0.38	0.42	0.38	0.44	0.45	0.44	1.17	0.93	0.79	1.66	1.65	1.65
	1.60	1.53	1.10	NS	NS	NS	1.09	1.20	1.10	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEm (±) CD (5 %)	95.69	95.87	95.78	11.40	11.43	11.42	21.67	20.44	21.06	10.98	10.72	10.84	24.34	24.73	24.53	63.28	63.20	63.24
	94.24	94.80	94.52	11.14	11.20	11.17	20.82	19.58	20.20	10.97	10.49	10.73	23.74	24.10	23.92	62.73	62.93	62.83
	78.99	77.90	78.44	12.56	12.61	12.59	33.01	31.78	32.39	15.32	14.17	14.74	36.01	36.27	36.14	69.90	70.02	69.96
	78.31	78.21	78.26	12.45	12.45	12.45	32.34	31.11	31.72	15.17	14.35	14.76	35.34	35.67	35.51	69.10	69.52	69.31
	66.15	65.60	65.87	13.81	13.94	13.85	40.83	39.59	40.21	18.82	18.00	18.40	44.73	45.09	44.91	79.69	80.12	79.91
S _{P2} SEm (±) CD (5 %)	66.75	65.71	66.23	13.74	13.86	13.84	41.18	40.11	40.64	18.45	17.44	17.94	44.93	45.28	45.10	78.92	79.57	79.24
	0.68	0.65	0.47	0.43	0.36	0.27	0.46	0.51	0.47	0.38	0.39	0.38	0.96	0.98	0.95	1.44	1.43	1.43
	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	91.96	92.34	92.15	11.42	11.40	11.41	23.17	21.94	22.55	11.80	11.41	11.61	21.14	20.43	20.79	64.84	64.65	64.75
	87.80	87.78	87.79	11.85	11.86	11.86	25.00	23.77	24.39	12.63	12.39	12.51	23.08	22.60	22.84	63.76	63.93	63.85
G _{2P0} G _{3P0} G _{4P0}	96.91	98.13	97.52	11.12	11.24	11.18	20.08	18.82	19.45	10.81	9.93	10.37	25.37	25.69	25.53	62.20	62.45	62.33
	103.18	103.10	103.14	10.70	10.75	10.73	16.75	15.52	16.14	8.68	8.69	8.68	28.77	28.36	28.57	61.23	61.24	61.23
	74.74	74.81	74.77	12.63	12.59	12.61	33.97	32.74	33.35	15.84	14.60	15.22	32.95	33.86	33.41	72.13	72.45	72.29
	72.97	72.31	72.64	12.97	13.00	12.98	35.34	34.11	34.72	16.65	15.70	16.18	34.91	35.98	35.45	70.61	71.42	71.02
	83.07	81.54	82.30	12.32	12.39	12.36	32.19	30.96	31.58	13.59	13.64	14.07	36.75	36.82	36.75	68.16	68.15	68.16
G _{1P1} G _{2P1} G _{3P1} G _{4P1}	83.82	83.57	83.70	12.10	12.15	12.12	29.20	27.97	28.58	13.99	13.11	13.55	38.82	39.17	37.45	67.09	67.05	67.07
	64.97	63.90	64.44	14.12	14.15	14.14	42.18	40.95	41.57	19.14	18.28	18.71	40.74	41.77	41.25	81.58	82.22	81.90
	61.83	61.64	61.73	14.21	14.26	14.23	45.71	44.81	45.26	19.95	19.46	19.46	43.93	44.74	44.34	80.35	80.22	80.28
	67.87	66.91	67.39	13.42	13.75	13.58	39.37	38.14	38.75	18.19	17.42	17.80	48.35	49.15	48.75	78.40	79.41	78.91
	71.11	70.19	70.65	13.34	13.46	13.40	36.75	35.52	36.13	17.25	16.23	16.74	50.27	51.14	50.70	76.89	77.54	77.21
SEm (±) CD (5 %)	0.56	0.53	0.54	0.61	0.51	0.38	0.38	0.42	0.38	0.54	0.55	0.54	2.03	1.14	0.97	2.03	2.02	2.02
	1.60	1.53	1.10	NS	NS	NS	1.09	1.20	1.10	NS	NS	NS	NS	NS	NS	NS	NS	NS

S₁: 25-day-old seedlings; S₂: 35-day-old seedlings; G₁: Cycocel 1500 ppm; G₂: Cycocel 2000 ppm; G₃: Cytokinin (BA) 200 ppm; G₄: Cytokinin (BA) 250 ppm; P₀: No pinching; P₁: Single pinching; P₂: Double pinching; SEm: Standard error of mean; CD (5 %): Critical difference at 5 % level; NS: Non-significant.

Table 2. Interaction effect of seedling age, plant growth regulators and pinching on plant height (cm), number of primary branches, number of secondary branches, stem diameter (mm), chlorophyll content (SPAD meter) and 50 % flowering in African marigold cv. Pusa Bahar

Treatment	Plant height (cm)				Number of primary branches				Number of secondary branches				Stem diameter (mm)				Chlorophyll content (SPAD meter)				50 % flowering			
	2023-24		2024-25		2023-24		2024-25		2023-24		2024-25		2023-24		2024-25		2023-24		2024-25		2023-24		2024-25	
	Pooled mean		Pooled mean		Pooled mean		Pooled mean		Pooled mean		Pooled mean		Pooled mean		Pooled mean		Pooled mean		Pooled mean		Pooled mean		Pooled mean	
T ₁	S ₁ G ₁ P ₀	91.08	91.65	91.36	11.60	11.52	11.56	23.97	22.74	23.36	12.00	11.70	11.85	20.67	19.88	20.27	65.10	64.89	65.00					
T ₂	S ₂ G ₁ P ₀	92.83	93.03	92.93	11.23	11.28	11.26	22.37	21.13	21.75	11.60	11.12	11.36	21.62	20.97	21.30	64.57	64.41	64.49					
T ₃	S ₁ G ₂ P ₀	89.39	87.90	88.64	11.87	11.94	11.91	25.54	24.31	24.93	12.43	12.27	12.36	23.53	23.10	23.32	63.87	63.99	63.93					
T ₄	S ₂ G ₂ P ₀	86.21	87.66	86.94	11.83	11.77	11.80	24.46	23.23	23.85	12.80	12.52	12.66	22.63	22.10	22.36	63.65	63.87	63.76					
T ₅	S ₁ G ₃ P ₀	96.45	97.56	97.01	11.20	11.29	11.25	21.55	20.32	20.94	11.30	10.53	10.92	25.99	26.24	26.11	62.41	62.44	62.43					
T ₆	S ₂ G ₃ P ₀	97.37	98.70	98.04	11.04	11.19	11.12	18.60	17.31	17.96	10.32	9.33	9.83	24.75	25.14	24.95	61.98	62.47	62.23					
T ₇	S ₁ G ₄ P ₀	105.83	106.38	106.11	10.93	10.96	10.95	15.63	14.40	15.02	8.16	8.37	8.26	29.61	28.83	29.22	61.73	61.50	61.62					
T ₈	S ₂ G ₄ P ₀	100.53	99.81	100.17	10.47	10.54	10.50	17.87	16.64	17.25	9.20	9.00	9.10	27.92	27.89	27.91	60.72	60.97	60.85					
T ₉	S ₁ G ₁ P ₁	75.47	74.90	75.19	12.72	12.68	12.70	34.34	33.11	33.73	15.66	14.04	14.85	32.00	33.57	32.79	72.69	72.54	72.62					
T ₁₀	S ₂ G ₁ P ₁	74.01	74.71	74.36	12.55	12.49	12.52	33.59	32.36	32.98	16.01	15.16	15.59	33.91	34.15	34.03	71.57	72.35	71.96					
T ₁₁	S ₁ G ₂ P ₁	73.25	72.25	72.75	13.01	13.10	13.06	35.47	34.24	34.86	16.80	15.72	16.26	35.50	36.47	35.99	70.98	71.57	71.28					
T ₁₂	S ₂ G ₂ P ₁	72.68	72.37	72.53	12.92	12.89	12.91	35.20	33.97	34.59	16.50	15.68	16.09	34.33	35.49	34.91	70.24	71.27	70.75					
T ₁₃	S ₁ G ₃ P ₁	82.59	80.92	81.75	12.37	12.46	12.42	32.44	31.21	31.83	14.70	13.71	14.20	37.33	38.37	37.85	68.83	68.64	68.74					
T ₁₄	S ₂ G ₃ P ₁	83.56	82.15	82.86	12.27	12.32	12.30	31.94	30.71	31.33	14.30	13.57	13.93	36.17	37.90	37.04	67.49	67.66	67.58					
T ₁₅	S ₁ G ₄ P ₁	84.65	83.52	84.09	12.16	12.19	12.17	29.78	28.55	29.17	14.10	13.22	13.66	39.51	40.84	40.17	67.10	67.31	67.21					
T ₁₆	S ₂ G ₄ P ₁	82.99	83.62	83.31	12.04	12.11	12.07	28.61	27.38	28.00	13.88	13.00	13.44	38.13	39.10	38.62	67.08	66.79	66.94					
T ₁₇	S ₁ G ₁ P ₂	65.52	64.26	64.89	14.15	14.18	14.16	42.47	41.24	41.86	19.40	18.50	18.95	41.00	41.86	41.43	81.86	82.50	82.18					
T ₁₈	S ₂ G ₁ P ₂	64.43	63.53	63.98	14.10	14.12	14.11	41.89	40.66	41.28	18.88	18.05	18.47	40.47	41.67	41.07	81.30	81.94	81.62					
T ₁₉	S ₁ G ₂ P ₂	60.54	61.21	60.88	14.19	14.22	14.20	44.56	43.33	43.95	20.10	19.26	19.68	44.95	45.87	45.41	80.79	80.34	80.57					
T ₂₀	S ₂ G ₂ P ₂	63.12	62.06	62.59	14.23	14.29	14.26	46.85	46.29	46.57	19.80	18.68	19.24	42.91	43.61	43.26	79.90	80.10	80.00					
T ₂₁	S ₁ G ₃ P ₂	67.02	66.25	66.63	13.22	13.83	13.53	40.05	38.82	39.44	18.36	17.84	18.10	48.78	49.57	49.18	78.50	79.67	79.09					
T ₂₂	S ₂ G ₃ P ₂	68.73	67.57	68.15	13.62	13.66	13.64	38.68	37.45	38.07	18.01	17.00	17.51	47.92	48.72	48.32	78.30	79.15	78.73					
T ₂₃	S ₁ G ₄ P ₂	71.50	70.69	71.10	13.40	13.53	13.47	36.22	34.98	35.60	17.40	16.41	16.91	51.33	52.17	51.75	77.61	77.97	77.79					
T ₂₄	S ₂ G ₄ P ₂	70.72	69.69	70.21	13.29	13.38	13.33	37.28	36.05	36.67	17.10	16.04	16.57	49.21	50.10	49.65	76.16	77.10	76.63					
SEM (±)		0.96	0.92	0.66	0.86	0.72	0.53	0.66	0.72	0.66	0.76	0.77	0.76	2.03	1.62	1.37	2.88	2.86	2.86					
CD(5 %)		2.78	2.66	1.90	NS	NS	NS	1.89	2.08	1.90	NS	NS	NS	NS	NS	NS	NS	NS	NS					

S₁: 25-day-old seedlings; S₂: 35-day-old seedlings; G₁: Cycocel 1500 ppm; G₂: Cycocel 1000 ppm; G₃: Cytokinin (BA) 200 ppm; G₄: Cytokinin (BA) 250 ppm; P₀: No pinching; P₁: Single pinching; P₂: Double pinching; SEM: Standard error of mean; CD (5 %): Critical difference at 5 % level; NS: Non-significant.

improvement in stem diameter due to with the use of CCC at 2000 ppm, this effect may attribute the growth-retardant action of CCC, which inhibits gibberellin biosynthesis. As a result, apical elongation is restricted and assimilates are redirected towards radial thickening of stem tissues, leading to enhanced stem diameter. The CCC application effectively promoted stem thickening by restricting excessive apical growth (15). It is evident from the data, indicated that P_2 recorded the maximum stem thickness (18.18 mm), whereas P_0 produced the comparatively thinnest stems (10.79 mm).

Chlorophyll content measured using a SPAD meter. Seedling age had a non-significant effect on chlorophyll content (SPAD values). Chlorophyll content was significantly increased by plant growth regulators. As regards the plant growth regulator treatments G_4 (39.55) showed the highest SPAD readings and G_1 (31.82) the lowest. The probable reason for this trend could be attributed to the improvement in chlorophyll content under BA treatments, which might be due to its role in facilitating greater accumulation of chlorophyll a and b by increasing the number and functionality of chloroplasts, thereby enhancing the overall photosynthetic capacity of plants (13). Data showed that P_2 recorded the maximum chlorophyll content (46.26), whereas P_0 had the lowest chlorophyll values (24.43). This may be due to the removal of apical dominance, which promotes lateral bud growth and increases leaf area, ultimately leading to greater photosynthate accumulation (16–18).

Flower quality characters

The data on flower yield characters, viz. flower diameter (cm), number of flowers per plant, flower yield per plant (g), flower yield per plot (kg) and flower yield per hectare (t), are presented in Table 3 and 4. All data were recorded and analysed.

The 50 % flowering significantly influenced by different levels of plant growth regulators, the minimum days for 50 % flowering (68.50 days) was recorded under 250 ppm of BA (G_4), which was statically similar to BA at 200 ppm (G_3 ; 69.80 days). On the other hand, maximum days were recorded under CCC at 1500 ppm (G_1 ; 72.98 days). Based on experimentation, it was found that BA induced early 50 % flowering. Such effects might be explained by stimulating meristem activity, improving assimilate partitioning to the growing apex and promoting floral organ initiation, whereas CCC delayed flowering by restricting cell elongation and suppressing the vegetative-to-reproductive phase transition (19). The 50 % flowering was significantly influenced by all the levels pinching. However, P_0 recorded minimum days (63.04 days) for 50 % flowering, whereas P_2 recorded maximum days (79.58 days) to 50 % flowering. The interaction effects on 50 % flowering were found to be statistically non-significant.

The effect of seedling age on flower diameter was found to be non-significant. Based on data, the maximum flower diameter (6.36 cm) was recorded in G_4 (BA at 250 ppm) which was statistically at par with G_3 (BA at 200 ppm; 6.11 cm), whereas the minimum flower diameter (5.35 cm) was observed in G_1 (CCC at 1500 ppm). The increase in flower diameter under BA application may attributed to its cytokinin effect, which promotes enhanced cell division and expansion in floral tissues, thereby resulting in larger flowers (20). It is evident from the data that maximum flower size was observed in treatment P_0 (P_0 : 7.22 cm) and minimum flower diameter was recorded in treatment P_2 (P_2 : 4.74 cm). The increase in flower diameter under P_0 conditions may be attributed to the

availability of more assimilates and better allocation of energy towards fewer flowers (21). The interaction effects of seedling age $\times$ PGR ($S \times G$), seedling age $\times$ pinching ($S \times P$), PGR $\times$ pinching ($G \times P$) and ($S \times G \times P$) on flower diameter were statistically non-significant.

Flower yield parameters

The effect of seedling age on the number of flowers plant⁻¹ was non-significant. The PGRs application significantly affected the number of flowers plant⁻¹. Based on data, it was observed that treatment G_2 (CCC at 2000 ppm) recorded maximum number of flowers plant⁻¹ (56.13) and minimum number of flowers plant⁻¹ (45.32) was recorded in treatment G_4 (BA at 250 ppm). Pinching exhibited a significant effect on flower number. Among the different levels of pinching, the maximum number of flowers plant⁻¹ (70.91) were noted in treatment P_2 . On the other hand, treatment P_0 recorded the minimum number of flowers plant⁻¹ (27.99).

The interaction between seedling age and PGRs ($S \times G$) was found significant for number of flowers plant⁻¹. The S_1G_2 (25-day seedlings $\times$ CCC at 2000 ppm) produced the highest number of flowers plant⁻¹ (57.59), whereas the lowest number of flowers plant⁻¹ (44.76) was observed in S_1G_4 ($S_1 \times$ BA at 250 ppm). Data revealed that S_1P_2 produced the maximum number of flowers (71.53), which was statistically at par with S_2P_2 (70.28) and minimum number of flowers plant⁻¹ (27.90) was observed under S_1P_0 .

Interaction between plant growth regulators and pinching ($G \times P$) exhibited significant differences in number of flowers plant⁻¹, maximum number of flowers plant⁻¹ (76.59), followed by G_1P_2 (CCC at 1500 ppm $\times$ P_2 ; 71.01), whereas G_4P_0 (CCC at 250 ppm $\times$ P_0) produced the minimum number of flowers plant⁻¹ (22.14). The interaction between plant growth regulators and pinching ($G \times P$) exerted a significant influence on the number of flowers plant⁻¹. The combined interaction of seedling age, PGRs and pinching ($S \times G \times P$) had a significant effect on number of flowers plant⁻¹, where $S_1G_2P_2$ (S_1 treated with CCC at 2000 ppm combined with S_2) produced the maximum number of flowers plant⁻¹ (79.13), followed by $S_2G_2P_2$ (S_2 treated with CCC at 2000 ppm combined with P_2 ; 74.05), while the minimum number of flowers plant⁻¹ (19.74) was recorded under $S_1G_4P_0$ (BA at 250 ppm). These findings clearly indicate that the combination of younger seedlings (25 days after seedling (DAS)), CCC at 2000 ppm and double pinching synergistically enhanced flowering potential.

The probable reason for this trend could be younger seedlings (25 DAS) possess higher physiological activity, better establishment potential and a well-balanced root-shoot system that ensures efficient nutrient absorption and assimilate translocation, supporting vigorous vegetative and reproductive growth. The application of CCC (CCC at 2000 ppm), a growth retardant, inhibits gibberellin biosynthesis, thereby reducing apical dominance and promoting the initiation of lateral branches and flower buds (22–24) and furthermore, double pinching physically removes apical meristems, which not only suppresses apical dominance but also enhances the outgrowth of secondary branches, providing more sites for flower initiation and development. The combined physiological and hormonal responses thus resulted in a marked increase in the total number of flowers per plant under this treatment (25).

Data revealed that flower yield plant⁻¹ was significantly influenced by seedling age in the pooled mean. It is evident from the results that the maximum flower yield plant⁻¹ (462.04 g) was

Table 3. Effect of seedling age, plant growth regulators and pinching on flower diameter (cm), number of flowers per plant, flower yield per plant (g), flower yield per plot (kg), flower yield per hectare (t) in African marigold cv. Pusa Bahar

Treatment	Flower diameter (cm)			Number of flowers per plant			Flower yield per plant (g)			Flower yield per plot (kg)			Flower yield per hectare (t)		
	2023-24	2024-25	Pooled mean	2023-24	2024-25	Pooled mean	2023-24	2024-25	Pooled mean	2023-24	2024-25	Pooled mean	2023-24	2024-25	Pooled mean
S ₁	5.88	5.95	5.91	51.98	50.01	51.00	475.24	448.83	462.04	7.70	7.28	7.49	19.71	18.62	19.16
S ₂	5.85	5.81	5.83	50.86	49.01	49.93	458.67	428.21	443.44	7.33	6.88	7.11	18.77	17.60	18.19
SEm (±)	0.08	0.07	0.08	0.44	0.35	0.35	3.12	3.12	3.11	0.07	0.08	0.07	0.19	0.21	0.18
CD (5 %)	NS	NS	NS	1.25	1.00	1.02	9.84	8.98	8.95	0.21	0.23	0.20	0.55	0.60	0.52
G ₁	5.35	5.35	5.35	52.93	50.80	51.87	501.89	471.83	486.86	8.03	7.55	7.79	20.55	19.32	19.93
G ₂	5.64	5.69	5.66	56.84	55.43	56.13	563.38	531.73	547.55	9.23	8.83	9.03	23.61	22.59	23.10
G ₃	6.11	6.10	6.11	49.60	47.47	48.53	403.30	380.25	391.77	6.45	6.08	6.27	16.51	15.57	16.04
G ₄	6.34	6.37	6.36	46.31	44.34	45.32	399.26	370.29	384.77	6.36	5.85	6.11	16.28	14.97	15.62
SEm (±)	0.11	0.10	0.11	0.36	0.28	0.29	2.79	2.55	2.54	0.06	0.07	0.06	0.16	0.17	0.15
CD (5 %)	0.30	0.30	0.30	1.02	0.82	0.83	8.04	7.34	7.31	0.17	0.19	0.17	0.45	0.49	0.42
P ₀	7.17	7.27	7.22	28.99	26.98	27.99	384.16	355.86	370.01	6.13	5.64	5.88	15.68	14.43	15.05
P ₁	5.64	5.67	5.66	53.57	51.44	52.50	515.21	487.74	501.47	8.40	8.01	8.21	21.50	20.49	21.00
P ₂	4.78	4.69	4.74	71.70	70.11	70.91	501.50	471.97	486.74	8.02	7.59	7.81	20.53	19.41	19.97
SEm (±)	0.09	0.09	0.09	0.44	0.35	0.35	3.42	3.12	3.11	0.07	0.08	0.07	0.19	0.21	0.18
CD (5 %)	0.26	0.26	0.26	1.25	1.00	1.02	9.84	8.98	8.95	0.21	0.23	0.20	0.55	0.60	0.52
S ₂ G ₁	5.34	5.45	5.40	53.59	51.46	52.52	512.40	482.12	497.26	8.20	7.71	7.96	20.98	19.74	20.36
S ₂ G ₂	5.37	5.25	5.31	52.28	50.15	51.21	491.37	461.54	476.45	7.86	7.38	7.62	20.12	18.90	19.51
S ₂ G ₃	5.62	5.77	5.70	58.49	56.69	57.59	572.06	550.47	561.27	9.60	9.34	9.47	24.55	23.89	24.22
S ₂ G ₄	5.66	5.60	5.63	55.18	54.16	54.67	554.71	512.98	533.84	8.86	8.32	8.59	22.67	21.29	21.98
S ₂ G ₃	6.13	6.17	6.15	50.17	48.04	49.10	414.13	389.14	401.64	6.63	6.23	6.43	16.96	15.93	16.44
S ₂ G ₄	6.10	6.03	6.07	49.03	46.90	47.97	392.47	371.35	381.91	6.28	5.94	6.11	16.07	15.20	15.64
S ₂ G ₃	6.41	6.39	6.40	45.66	43.86	44.76	402.37	373.60	387.98	6.39	5.83	6.10	16.34	14.91	15.63
S ₂ G ₄	6.28	6.34	6.31	46.95	44.82	45.89	396.15	366.98	381.57	6.34	5.87	6.11	16.22	15.03	15.62
SEm (±)	0.15	0.15	0.15	0.62	0.49	0.50	4.83	4.41	4.39	0.11	0.12	0.10	0.27	0.29	0.25
CD (5 %)	NS	NS	NS	1.77	1.42	1.44	NS	12.71	NS	0.30	0.33	0.29	0.78	0.85	0.73
S ₁ P ₀	7.16	7.36	7.26	28.84	26.96	27.90	386.58	359.28	372.93	6.15	5.64	5.89	15.73	14.42	15.07
S ₁ P ₁	7.18	7.18	7.18	29.13	27.00	28.07	381.75	352.45	367.10	6.11	5.64	5.87	15.63	14.43	15.03
S ₁ P ₂	5.65	5.77	5.71	54.62	52.49	53.55	528.46	504.65	516.56	8.79	8.40	8.59	22.49	21.50	21.99
S ₁ P ₃	5.64	5.57	5.61	52.52	50.39	51.46	501.95	470.82	486.39	8.02	7.62	7.82	20.52	19.49	20.01
S ₁ P ₄	4.82	4.72	4.77	72.47	70.59	71.53	510.68	482.57	496.63	8.17	7.79	7.98	20.91	19.94	20.42
S ₂ P ₂	4.74	4.67	4.70	70.93	69.63	70.28	492.32	461.37	476.85	7.88	7.38	7.63	20.16	18.89	19.52
SEm (±)	0.13	0.13	0.13	0.75	0.60	0.61	5.92	5.40	5.38	0.13	0.14	0.12	0.33	0.36	0.31
CD (5 %)	NS	NS	NS	NS	NS	1.77	17.05	15.56	15.50	0.37	0.41	0.35	0.95	1.04	0.90
G ₁ P ₀	6.34	6.55	6.45	31.19	29.06	30.13	419.45	389.31	404.38	6.71	6.23	6.47	17.17	15.94	16.56
G ₂ P ₀	6.84	7.03	6.93	34.17	32.04	33.10	462.39	431.83	447.11	7.40	6.91	7.15	18.93	17.68	18.31
G ₃ P ₀	7.58	7.63	7.60	27.64	25.51	26.58	352.69	326.48	339.58	5.64	5.22	5.43	14.44	13.37	13.90
G ₄ P ₀	7.91	7.87	7.89	22.96	21.33	22.14	302.12	275.83	288.98	4.76	4.19	4.47	12.17	10.71	11.44
G ₁ P ₁	5.24	5.20	5.22	55.53	53.40	54.47	545.95	514.57	530.26	8.74	8.23	8.48	22.35	21.07	21.71
G ₂ P ₁	5.44	5.45	5.44	59.78	57.65	58.71	621.21	597.54	609.38	10.58	10.38	10.48	27.07	26.56	26.82
G ₃ P ₁	5.84	5.87	5.85	51.48	49.35	50.42	442.78	415.16	428.97	7.08	6.64	6.86	18.13	17.00	17.56
G ₄ P ₁	6.06	6.16	6.11	47.49	45.36	46.43	450.88	423.69	437.28	7.21	6.78	7.00	18.46	17.35	17.90
G ₁ P ₂	4.48	4.30	4.39	72.08	69.95	71.01	540.26	511.61	525.93	8.64	8.19	8.41	22.12	20.95	21.53
G ₂ P ₂	4.65	4.59	4.62	76.57	76.61	76.59	606.55	565.81	586.18	9.70	9.19	9.45	24.83	23.52	24.18
G ₃ P ₂	4.93	4.82	4.87	69.68	67.55	68.61	414.43	399.10	406.77	6.63	6.39	6.51	16.97	16.34	16.65
G ₄ P ₂	5.06	5.08	5.07	68.47	66.34	67.41	444.77	411.36	428.06	7.12	6.58	6.85	18.21	16.84	17.53
SEm (±)	0.19	0.18	0.18	0.62	0.49	0.50	4.83	4.41	4.39	0.11	0.12	0.10	0.27	0.29	0.25
CD (5 %)	NS	NS	NS	1.77	1.42	1.44	13.92	12.71	12.66	0.30	0.33	0.29	0.78	0.85	0.73

S₁: 25-day-old seedlings; S₂: 35-day-old seedlings; G₁: Cycocel 1500 ppm; G₂: Cycocel 2000 ppm; G₃: Cytokinin (BA) 200 ppm; G₄: Cytokinin (BA) 250 ppm; P₀: No pinching; P₁: Single pinching; P₂: Double pinching; SEm: Standard error of mean; CD (5 %): Critical difference at 5 % level; NS: Non-significant.

Table 4. Interaction effect of seedling age, plant growth regulators and pinching on flower diameter (cm), number of flowers per plant, flower yield per plant (g), flower yield per plot (kg), flower yield per hectare (t) in African marigold cv. Pusa Bahar

Treatment	Flower diameter (cm)				Number of flowers per plant				Flower yield per plant (g),				Flower yield per plot (kg)				Flower yield per hectare (t)			
	2023-24		2024-25		Pooled mean		2023-24		2024-25		Pooled mean		2023-24		2024-25		Pooled mean		2023-24	
T ₁	6.23	6.76	6.50	31.72	29.59	30.66	426.25	393.89	410.07	6.82	6.30	6.56	17.45	16.13	16.79					
T ₂	6.45	6.34	6.40	30.66	28.53	29.60	412.65	384.73	398.69	6.60	6.16	6.38	16.90	15.75	16.32					
T ₃	6.87	7.10	6.99	34.74	32.61	33.68	470.81	440.81	455.81	7.53	7.05	7.29	19.28	18.05	18.66					
T ₄	6.81	6.95	6.88	33.59	31.46	32.53	453.98	422.84	438.41	7.26	6.77	7.01	18.59	17.31	17.95					
T ₅	7.52	7.67	7.60	28.61	26.48	27.55	363.96	340.68	352.32	5.82	5.45	5.64	14.90	13.95	14.43					
T ₆	7.63	7.58	7.61	26.67	24.54	25.61	341.41	312.28	326.85	5.46	5.00	5.23	13.98	12.79	13.38					
T ₇	8.01	7.89	7.95	20.31	19.18	19.74	285.30	261.72	273.51	4.41	3.73	4.07	11.29	9.56	10.42					
T ₈	7.81	7.84	7.83	25.61	23.48	24.55	318.94	289.94	304.44	5.10	4.64	4.87	13.06	11.87	12.46					
T ₉	5.27	5.28	5.28	56.78	54.65	55.72	558.94	529.38	544.16	8.94	8.47	8.71	22.89	21.67	22.28					
T ₁₀	5.21	5.12	5.17	54.28	52.15	53.22	532.96	499.75	516.36	8.53	8.00	8.26	21.82	20.46	21.14					
T ₁₁	5.32	5.58	5.45	61.04	58.91	59.98	634.39	623.45	628.92	11.48	11.28	11.38	29.37	28.86	29.12					
T ₁₂	5.56	5.31	5.44	58.51	56.38	57.45	608.03	571.64	589.83	9.68	9.48	9.58	24.77	24.26	24.52					
T ₁₃	5.89	5.98	5.94	51.98	49.85	50.92	450.38	423.72	437.05	7.21	6.78	6.99	18.44	17.35	17.89					
T ₁₄	5.78	5.76	5.77	50.98	48.85	49.92	435.18	406.59	420.88	6.96	6.51	6.73	17.82	16.65	17.23					
T ₁₅	6.11	6.22	6.17	48.66	46.53	47.60	470.12	442.06	456.09	7.52	7.07	7.30	19.25	18.10	18.67					
T ₁₆	6.01	6.10	6.06	46.32	44.19	45.26	431.64	405.31	418.48	6.91	6.49	6.70	17.67	16.60	17.13					
T ₁₇	4.51	4.31	4.41	72.27	70.14	71.20	552.02	523.08	537.55	8.83	8.37	8.60	22.60	21.42	22.01					
T ₁₈	4.44	4.28	4.36	71.89	69.76	70.82	528.49	500.14	514.31	8.46	8.00	8.23	21.64	20.48	21.06					
T ₁₉	4.68	4.62	4.65	79.69	78.56	79.13	610.98	587.15	599.07	9.78	9.67	9.73	25.02	24.76	24.89					
T ₂₀	4.61	4.55	4.58	73.45	74.65	74.05	602.12	544.46	573.29	9.63	8.71	9.17	24.65	22.29	23.47					
T ₂₁	4.98	4.87	4.93	69.91	67.78	68.85	428.05	403.03	415.54	6.85	6.45	6.65	17.53	16.50	17.01					
T ₂₂	4.88	4.76	4.82	69.44	67.31	68.38	400.82	395.18	398.00	6.41	6.32	6.37	16.41	16.18	16.30					
T ₂₃	5.11	5.07	5.09	68.02	65.89	66.95	451.68	417.01	434.34	7.23	6.67	6.95	18.49	17.07	17.78					
T ₂₄	5.01	5.08	5.05	68.92	66.79	67.86	437.87	405.70	421.79	7.01	6.49	6.75	17.93	16.61	17.27					
SEm (±)	0.26	0.26	0.26	1.07	0.85	0.87	8.37	7.64	7.61	0.18	0.20	0.17	0.47	0.51	0.44					
CD (5 %)	NS	NS	NS	3.70	2.45	2.50	24.11	22.01	21.93	0.52	0.57	0.50	1.34	1.47	1.27					

S_i: 25-day-old seedlings; S₂: 35-day-old seedlings; G_i: Cycocel 1500 ppm; G₂: Cycocel 2000 ppm; G₃: Cytokinin (BA) 200 ppm; G₄: Cytokinin (BA) 250 ppm; P_i: No pinching; P₂: Single pinching; P₃: Double pinching; SEm: Standard error of mean; CD (5 %): Critical difference at 5 % level; NS: Non-significant.

recorded with S_1 , while S_2 produced lower flower yield plant⁻¹ (443.44 g). Application of plant growth regulators exerted significant effect on flower yield plant⁻¹. Amongst the different levels of plant growth regulators, significantly maximum flower yield plant⁻¹ (g) was observed under CCC at 2000 ppm (G_2 : 547.55 g), whereas minimum flower yield plant⁻¹ (g) was recorded under BA at 250 ppm (G_4 : 384.77 g). The data revealed that treatment single pinching (P_1) produced maximum flower yield plant⁻¹ (501.47 g), whereas treatment non-pinched plants (P_0 : 370.01 g) showed minimum flower yield plant⁻¹ (g).

The interaction between seedling age and pinching was found to be significant, S_1P_1 produced maximum flower yield plant⁻¹ (516.56 g), while the lowest flower yield plant⁻¹ (367.10 g) was obtained under S_2P_0 . From the observations the results indicated that G_2P_1 (CCC at 2000 ppm $\times$ single pinching) produced the highest flower yield plant⁻¹ (609.38 g), while lowest pooled flower yield plant⁻¹ (288.98 g) was recorded under G_4P_0 (BA at 250 ppm $\times P_0$).

The data indicate that the combined interaction of seedling age, plant growth regulators and pinching ($S \times G \times P$) significantly influenced flower yield plant⁻¹. Findings based on pooled mean data, the highest flower yield plant⁻¹ (628.92 g) was recorded under $S_1G_2P_1$ ($S_1 \times$ CCC at 2000 ppm $\times P_1$), followed by $S_1G_2P_2$ (25-day-old seedlings $\times$ CCC at 2000 ppm $\times P_2$ produced 599.07 g flower yield plant⁻¹. However, the lowest flower yield plant⁻¹ (273.51 g) was observed in $S_1G_4P_0$ ($S_1 \times$ BA at 250 ppm $\times P_0$). These results clearly demonstrate that younger seedlings (25 DAS) when treated with CCC (2000 ppm) with pinching produced higher flower yield plant⁻¹ compared to older seedlings or treatments with BA.

A perusal of data revealed that flower yield plot⁻¹ was significantly influenced by seedling age. The results pertaining to the maximum flower yield plot⁻¹ (7.49 kg) was recorded with S_1 , while the minimum flower yield plot⁻¹ (7.11 kg) was observed with S_2 . In the present study showed that S_1 produced higher flower yield plot⁻¹ than S_2 . Significant differences were observed among the different levels of plant growth regulators for flower yield plot⁻¹ (kg). Among the PGRs, G_2 (CCC at 2000 ppm) recorded the highest flower yield plot⁻¹, (9.03 kg) whereas the lowest flower yield plot⁻¹ (6.11 kg) was recorded under G_4 (BA at 200 ppm). The data with respect to flower yield plot⁻¹ that treatment P_1 produced the highest yield (8.21 kg), while P_0 resulted in the lowest flower yield plot⁻¹ (5.95 kg in). In the present study, it was observed that P_1 produced the highest flower yield compared to P_0 during the experimentation.

The interaction effects of seedling age $\times$ PGR ($S \times G$), seedling age $\times$ pinching ($S \times P$), PGR $\times$ pinching ($G \times P$) and $S \times G \times P$ on flower yield plot⁻¹ were statistically significant. The interaction between seedling age and plant growth regulators was found significant. the treatment S_1G_2 recorded the highest yield (9.47 kg plot⁻¹). However, lowest flower yield plot⁻¹ (6.10 kg) was observed under both S_1G_4 (25-day-old seedlings $\times$ BA at 250 ppm). The interaction between seedling age and pinching exhibited a significant influence on flower yield plot⁻¹. The results of this investigation the treatment S_1P_1 noted the maximum flower yield (8.59 kg plot⁻¹) and the lowest flower yield plot⁻¹ (5.87 kg) was recorded under S_2P_0 . The interaction between PGRs and pinching showed a significant effect on flower yield plot⁻¹. The combination G_2P_1 (CCC at 2000 ppm $\times P_1$) recorded the maximum flower yield (10.48 kg plot⁻¹) and the lowest pooled yield (4.47 kg plot⁻¹) was observed under G_4P_0 (BA at 250 ppm $\times P_0$).

It was observed that $S_1G_2P_1$ recorded the highest flower yield plot⁻¹ (11.38 kg) followed by $S_1G_2P_2$ ($S_1 \times$ CCC at 2000 ppm $\times P_2$; 9.73 kg), while data showed that the lowest pooled flower yield plot⁻¹ (4.07 kg) was noted under $S_1G_4P_0$ ($S_1 \times$ BA at 250 ppm $\times P_0$). The effect of seedling age on flower yield hectare⁻¹ was found to be statistically significant. Data revealed that S_1 produced higher flower yield (19.16 t ha⁻¹) whereas S_2 recorded flower lower yield (18.19 t ha⁻¹). In the present investigation, it was found that S_1 produced significantly higher flower yield hectare⁻¹ as compared to S_2 . The result obtained in this investigation G_2 (CCC at 2000 ppm) recorded the highest yield (23.10 t ha⁻¹) whereas lowest flower yield hectare⁻¹ was recorded under G_4 (BA at 200 ppm) (15.62 t ha⁻¹). From the above results, it was shown that CCC-treated plants produced higher flower yield compared to other treatments.

It is crystal clear from the data on treatment P_1 produced the highest flower yield hectare⁻¹ (21.00 t), while no P_0 resulted in the lowest yield (15.05 t ha⁻¹). In the present study, the data clearly showed that P_1 produced the highest flower yield per plant and per hectare. The interaction effects of seedling age $\times$ PGR ($S \times G$), seedling age $\times$ pinching ($S \times P$), PGR $\times$ pinching ($G \times P$) and $S \times G \times P$ on flower yield plot⁻¹ were statistically significant.

The interaction between seedling age and plant growth regulators was found significant. It is evident from the data, S_1G_2 ($S_2 \times$ CCC at 2000 ppm) recorded highest flower yield (24.22 t ha⁻¹), whereas the lowest flower yield (15.62 t ha⁻¹) was recorded under S_2G_4 . The interaction between seedling age and pinching ($S \times P$) was significant, S_1P_1 produced the highest flower yield (21.99 t ha⁻¹), while S_2P_0 recorded the lowest flower yield (15.03 t ha⁻¹). A significant interaction between PGRs and pinching. It is evident from the data that G_2P_1 (CCC at 2000 ppm $\times$ single pinching) noted highest flower yield (26.82 t ha⁻¹), followed by G_2P_2 (CCC at 2000 ppm $\times$ double pinching; 24.18 t ha⁻¹), whereas G_4P_0 (BA at 250 ppm $\times P_0$) recorded the lowest flower yield (11.44 t ha⁻¹).

The three-way interaction among seedling age, PGRs and pinching was found significant. Data revealed that the combination $S_1G_2P_1$ ($S_1 \times$ CCC at 2000 ppm $\times P_1$ recorded the maximum flower yield (29.12 t ha⁻¹), followed by $S_1G_2P_2$ ($S_1 \times$ CCC at 2000 ppm $\times P_2$; 24.89 t ha⁻¹), while the lowest flower yield (10.42 t ha⁻¹) was obtained under $S_1G_4P_0$ ($S_1 \times$ BA at 250 ppm $\times P_0$). The improved flower yield observed in the experiment can be explained through the coordinated influence of seedling physiology, hormonal regulation and mechanical canopy manipulation. Younger seedlings (25 DAS) generally possess a more active meristematic system, higher root proliferation and superior transplant recovery, which together enable rapid canopy development and timely transition to the reproductive phase. Their efficient resource acquisition and early establishment create a favourable internal environment for initiating more floral meristems. In contrast, older seedlings experience greater transplant shock, slower root regeneration and reduced physiological activity, which limit branch formation and ultimately restrict flower production.

The application of CCC further enhanced yield by altering endogenous hormonal balance. By suppressing gibberellin synthesis, CCC reduces cell elongation and restricts apical dominance, encouraging the activation of axillary buds and promoting a compact but highly branched plant structure. This shift in growth pattern channels assimilates toward developing reproductive organs instead of excessive vegetative expansion. Several earlier studies have also noted that CCC-mediated

modification of hormonal pathways increases branching intensity and supports higher flower production in ornamental crops (26, 27). Pinching complemented these effects by mechanically removing the apical meristem, which eliminates the dominance of the main shoot and facilitates the emergence of numerous lateral branches. This structural modification increases the number of potential flowering sites and enhances the distribution of photosynthates across developing buds. Plants that remain unpinched retain strong apical control, produce fewer branches and consequently bear fewer flowers (28, 29). These findings agree with previous studies, which reported that the integration of growth retardants like CCC with pinching enhances branching and flower yield in marigold (30–32). When these three factors operate together, they create a highly efficient and well-coordinated growth system. Vigorous young seedlings provide a strong physiological foundation, CCC regulates hormonal pathways to favour branching and reproductive growth and pinching amplifies lateral shoot proliferation through the removal of apical dominance. The synergy of these mechanisms results in a larger number of floral buds, improved assimilate allocation and ultimately, the highest flower yield per plant. This integrated approach harmonises plant architecture, hormonal balance and resource distribution, resulting in superior reproductive performance.

Conclusion

The findings of the present investigation clearly revealed that among the individual treatments, the combination of 25-day-old seedlings, cycocel at 2000 ppm and single pinching consistently enhanced vegetative growth, improved flowering traits and flower Yield. The combined interaction $S \times G \times P$ indicated that $S_1G_2P_1$ (25-day seedlings $\times$ cycocel at 2000 ppm $\times$ single pinching) was the best overall treatment, producing the highest flower yield of African marigold (*Tagetes erecta*) cv. Pusa Bahar.

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Authors' contributions

TK conducted data collection, recording and statistical analysis. SKT performed the data analysis. VK verified the data and statistical analysis and coordinated the study. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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