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Naveena R
Student, Department of Floriculture and Landscape Architecture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India

Vijay Kumar
Professor, Department of Floriculture and Landscape Architecture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India

Pooja Gupta
Professor, Department of Floriculture and Landscape Architecture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India

Kotha Likhitha
Department of Floriculture and Landscape Architecture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India

Venkatesh
Student, Department of Floriculture and Landscape Architecture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India

Corresponding Author:
Naveena R
Student, Department of Floriculture and Landscape Architecture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India

Studies on the effect of bioinoculants, plant growth regulators and humic acid on growth and flower yield of African marigold (*Tagetes erecta*) under walk-in tunnel

Naveena R, Vijay Kumar, Pooja Gupta, Kotha Likhitha and Venkatesh

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Abstract
The present study, entitled "Studies on the effect of bioinoculants, plant growth regulators and humic acid on growth and flower yield of African marigold (*Tagetes erecta*) under walk-in tunnel", was carried out at the Centre of Excellence, Protected Cultivation and Precision Farming, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.) during 2024-25 *Rabi* season. The experiment was laid out in a Factorial Randomized Block Design with 12 treatments of two factors and replicated three times. The treatments consisted of three levels of soil drenching: no drenching (SD_0), PSB 10% (SD_1), and KSB 10% (SD_2), and four levels of foliar application: no spray (FS_0), humic acid 0.2% (FS_1), GA_3 200 ppm (FS_2), and NAA 50 ppm (FS_3). The study found that applying Phosphorous Solubilizing Bacteria (PSB) through soil drenching at 10%, GA3 200ppm as a foliar spray and especially their combined treatment (T_7: PSB @ 10% + GA3 200 ppm) performed best with regards to early 50% flowering, minimum number of days to full bloom, flower yield per hectare, flower diameter, fresh weight of flowers per plant, dry weight of flowers per plant, flowering span and shelf life in African marigold.

Keywords: African marigold, phosphorous solubilizing bacteria, GA3, early 50% flowering and flower yield per hectare

Introduction
Marigold (*Tagetes spp.*) is gaining prominence as a commercially valuable floricultural crop in India, primarily due to its ease of cultivation, adaptability, and increasing market demand. This genus, belonging to the Asteraceae (or Composite) family, encompasses approximately 33 species. Commercially, marigolds are integral to the pigment extraction industry and dried flower production, serving as a natural source of carotenoids such as xanthophyll and lutein (C40H56O2), oleoresins, and natural dyes. The aromatic oil derived from marigold flowers, known as "tagetes oil," finds application in the creation of high-quality perfumes and in pharmaceutical formulations. Furthermore, dried marigold petals are incorporated into poultry feed as natural food additives to enhance the pigmentation of egg yolks and broiler skin, while simultaneously boosting their vitamin A content.

Biofertilizers have proven to be an excellent source of essential nutrients for plants, while also enhancing soil fertility and improving soil structure. They offer a sustainable and practical solution for producing high-quality flowers and achieving greater yields on a commercial scale. Moreover, biofertilizers are environmentally friendly, readily accessible, and economically viable, making them an ideal choice for profitable floriculture.

External application of growth regulators significantly boosts flower production by directing a greater allocation of nutrients towards the reproductive organs of the plant. Among the most critical growth regulators for African marigold are Gibberellic Acid (GA3) and Naphthalene acetic Acid (NAA). These compounds are known to promote vigorous growth, enhance flower yield, and precisely control plant development and flowering. Additionally, Humic acid facilitates ion uptake and encourages the growth of lateral roots.

Methods and Materials

The experiment was conducted at the Centre of Excellence for Protected Cultivation and Precision Farming, located at the College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.), during the *Rabi* season of 2024-25. The experiment was laid out in factorial randomized block design with 3 replications and 15 treatments viz T_1 (SD0×FS0) No soil drenching + No foliar application, T_2 (SD0 ×FS1 (HA 0.2%)) No soil drenching + Foliar spray 0.2% Humic acid, T_3 (SD0× FS2 (GA3 200ppm)) No soil drenching + Foliar spray of GA3 200ppm, T_4 (SD0× FS3 (NAA 50ppm))No Soil drenching + Foliar spray of NAA 50ppm, T_5 (SD1(PSB10%)×FS0)Soil drenching of PSB10%+No foliar Application, T_6 (SD1(PSB10%)×FS1 (HA 0.2%)) Soil drenching of PSB 10%+ Foliar spray of 0.2% Humic acid, T_7 (SD1(PSB10%)×FS2 (GA3)) Soil drenching of PSB 10%+ Foliar spray of GA3 200ppm, T_8 (SD1(PSB10%)×FS3(NAA)) Soil drenching of PSB 10%+ Foliar spray of NAA 50ppm, T_9 (SD2(KSB10%)×FS0) Soil drenching of KSB 10%+No foliar Application, T_{10} (SD2(KSB10%)×FS1(HA0.2%)) Soil drenching of KSB10% + Foliar spray of 0.2% Humic acid, T_{11} (SD2 (KSB10%)× FS2 (GA3)) Soil drenching of KSB 10%+Foliar spray of GA3 200ppm and T_{12} (SD2(KSB) ×FS3 (NAA)) Soil drenching of KSB 10%+ Foliar spray of NAA 50ppm. were treated.

Results and Discussion

Number of days to 50% flowering

Among soil applied bioinoculants, the minimum number of days to 50% bud initiation (37.81 days) was recorded under the treatment (SD1) PSB @10%, which was significantly earlier than all other treatments. This was followed by (SD2) KSB @10% (45.22 days) and among foliar applied bioinoculants (36.52 days) was recorded under the treatment (FS2) GA_3 @200 ppm, which was significantly earlier than all other treatments. This was followed by (FS3) NAA @50 ppm (45.44 days) and (FS1) 0.2% Humic acid (45.96 days). Among different treatment combinations minimum number of days to 50% bud initiation (33.69 days) was recorded under the treatment T_7 (SD2 - PSB @10% + FS2 - GA_3 @200 ppm), which was significantly earlier than all other treatments. This was followed by T_6 (SD1 - PSB @10% + FS1 - 0.2% Humic acid) with 36.89 days and T_{11} (SD2 - KSB @10% + FS2 - GA_3 @200 ppm) with 37.46 days. Similar findings were also reported by Yadav *et al.* (2013) [1], Kumar *et al.* (2022) [2], and Megha *et al.* (2022) [3].

Number of days to full bloom

Among soil applied bioinoculants, the minimum number of days to 100% flowering (49.67 days) was recorded under the treatment (SD1) PSB @10%, which was significantly earlier than all other treatments. This was followed by (SD2) KSB @10%, which recorded 59.64 days to full bloom and among foliar applied bioinoculants (49.28 days) was recorded under the treatment (FS2) GA_3 @200 ppm, which was significantly earlier than all other treatments. This was followed by (FS3) NAA @50 ppm, which recorded 57.63 days to full bloom. Among different treatment combinations, minimum number of days to 50% flowering (45.90 days) was recorded under treatment T_7 (SD1 - PSB @10% + FS2 - GA_3 @200 ppm), which was significantly earlier than all other treatments. This was followed by T_6 (SD1 - PSB @10% + FS1 - 0.2% Humic acid) with 48.28 days. Similar findings were reported by Himabindu (2010) [4], Shaikh *et al.* (2018) [5].

Flower diameter (cm)

Among soil applied bioinoculants, the maximum flower diameter (4.79 cm) was recorded under the treatment SD_2 (KSB), which was significantly superior to all other treatments. and among foliar applied bioinoculants (4.75 cm) was recorded under FS2 (GA_3 200 ppm). Among different treatment combinations, the maximum flower diameter bioinoculants (4.98 cm) was recorded under T_{11} (SD2 (KSB) @10% +FS2 (GA3 200ppm)), which was statistically superior to all other treatments. This was followed by T_{10} (SD2 (KSB) @10% +FS1 (0.2% Humic acid)) (4.89 cm). Similar findings were reported by Yadav *et al.* (2018) [15] and Kumar & Kumar (2017) [6] in marigold.

Flower yield per hectare (q/ha)

Among soil applied bioinoculants, the maximum flower yield per hectare (117.32 q/ha) was recorded under the treatment SD_2 (KSB) and (116.42 q/ha) was recorded under the treatment FS_2 (GA_3 @ 200 ppm). Among different treatment combinations, the maximum flower yield per hectare (119.90 q/ha) was recorded under the treatment T_7 (SD1 + FS2: PSB @10% + GA_3 200 ppm). Similar findings have been reported by Verma and Arha (2004) [9] and Palagani *et al.* (2013) [10] in chrysanthemum, Singh and Kumar (2016) [11] and Kumar & Kumar (2017) [6] in marigold, and Jogi *et al.* (2022) [12] in China aster.

Fresh weight of flowers per plant (g)

Among soil applied bioinoculants, the maximum average fresh weight of flowers per plant (304.50 g) was recorded with SD2 (KSB @10%) and among foliar applied bioinoculant (324.84 g) was recorded with FS2 (GA_3 200 ppm), which was significantly higher than all other treatments. Among different treatment combinations, the maximum average fresh weight of flowers per plant (368.20 g) was recorded under the treatment combination T_{11} (SD2 [KSB @10%] + FS2 [GA_3 200 ppm]), which was significantly superior to all other treatments. It was followed by T_7 (SD1 [PSB @10%] + FS2 [GA_3 200 ppm]) (323.88 g). Similar findings were reported by Kumar *et al.* (2022) [2] in China aster, Singh and Kumar (2016) [11] in marigold, Jogi *et al.* (2022) in China aster, and Kumar and Kumar (2017) [6] in marigold.

Dry weight of flowers per plant (g)

Among soil applied bioinoculants, the maximum average dry weight of flowers per plant SD2 (KSB10%) (86.59 g), which was statistically at par with SD1 (PSB10%) (84.97 g) and among foliar applied bioinoculants (91.96 g) was recorded under FS2 (GA_3 200 ppm), which was significantly superior to all other treatments. This was followed by FS1 (0.2% humic acid) with 71.67 g and FS3 (NAA 50 ppm) with 68.41 g. Among different treatment combinations, the maximum average dry weight of flowers per plant (103.03 g) was recorded under the treatment combination SD2 (KSB @10%) + FS2 (GA_3 200 ppm) (T_{11}), which was statistically at par with SD1 (PSB @10%) + FS2 (GA_3 200 ppm) (T_7, 99.97 g). Similar findings were reported by Likhitha *et al.* (2024) [13], Kumar and Kumar (2017) [6] in marigold, Pansuriya *et al.* (2018) [7] in gladiolus, and Patil and Agasmani (2013) [8] in China aster.

Flowering span

Among soil applied bio inoculant, maximum flowering duration was observed under

(75.71 days) in plants treated with SD1 (PSB @10%) and among foliar applied bioinoculants (81.37 days) was recorded in plants treated with FS2 (GA_3 200 ppm). Among treatment combinations Maximum flowering duration (82.29 days) was recorded under treatment T_7 [SD1 (PSB @10%) + FS2 (GA_3 200 ppm)], which was statistically at par with T_{11} [SD2 (KSB @10%) + FS2 (GA_3 200 ppm)] (82.11 days).

Shelf life (days)

Among soil applied bioinoculants, maximum shelf life was observed in the application of soil drenching of (3.50 days) SD0 (No soil drenching), which was significantly higher than all other treatments and (3.75 days) was observed with the foliar application of FS1 (0.2% Humic acid), which was significantly superior to the rest of the treatments. Maximum shelf life was observed in treatment combination of (5.42 days) T_2: SD0 + FS1 (0.2% Humic acid), significantly superior to all other treatments. Next best was T_7: SD1 + FS2 (GA_3) (3.64 days), T_3: SD0 + FS2 (GA_3) (3.62 days) as also reported by Goyal and Singh (2023) [14] in petunia.

Conclusion

The results indicating the effect of soil applied bio-inoculants and foliar applied plant growth regulators and humic acid on flower yield, quality and shelf life in African marigold revealed that soil drenching of PSB@10% alone and foliar application GA3 200ppm. Treatment combination T_7 (SD1(PSB) @10% +FS2 (GA3 200ppm)) and T_{11}(SD2(KSB) @10% +FS2(GA3200ppm)) performed best with regards to early 50% flowering, minimum number of days to full bloom, flower yield per hectare, flower diameter, fresh weight of flowers per plant, dry weight of flowers per plant, flowering span and shelf life in African marigold.

Table 1: Individual effect of soil applied bioinoculants on flowering behaviour, yield and quality in African marigold

Treatments	Number of days to 50% flowering	Number of days to full bloom	Flower diameter (cm)	Flower yield per hectare (q/ha)	Fresh weight of flowers per plant (g)	Dry weight of flowers per plant (g)	Flowering span	Shelf life (days)
Soil drenching (Factor A)								
(SD0) No soil drenching	49.1a	61.76a	4.32c	105.33b	218.9b	50.09b	68.17b	3.5a
(SD1) PSB10%	37.81c	49.67c	4.56b	114.63a	302.54a	84.97a	75.71a	2.75c
(SD2) KSB10%	45.22b	59.64b	4.79a	117.32a	304.5a	86.59a	74.97a	3.06b
SE(m)	0.28	0.29	0.03	1.13	1.47	0.53	0.28	0.02
CD (5%)	0.83	0.86	0.09	3.33	4.31	1.55	0.83	0.05

Table 2: Individual effect of foliar applied plant growth regulators and humic acid on flowering behaviour, yield and quality in African marigold

Treatments	Number of days to 50% flowering	Number of days to full bloom	Flower diameter (cm)	Flower yield per hectare (q/ha)	Fresh weight of flowers per plant (g)	Dry weight of flowers per plant (g)	Flowering span	Shelf life (days)
Foliar spray (Factor B)								
(FS0) No foliar spray	48.26a	60.25a	4.26b	110.56a	233.6d	63.5d	72.33b	2.59c
(FS1) 0.2%Humic acid	45.96b	60.93a	4.62a	111.49a	260c	71.67b	69.22c	3.75a
(FS2) GA3 200ppm	36.52c	49.28c	4.75a	116.42a	324.84a	91.96a	81.37a	3.49b
(FS3) NAA 50ppm	45.44b	57.63b	4.61a	111.23a	282.81b	68.41c	68.88c	2.59c
SE(m)	0.32	0.34	0.04	1.31	1.70	0.61	0.33	0.02
CD (5%)	0.95	0.99	0.11	3.84	4.98	1.79	0.96	0.06

Table 3: Interaction effect of soil applied bioinoculants and Foliar Applied Plant Growth Regulators and Humic acid on flowering behaviour, yield and quality in African marigold

Treatments	Number of days to 50% flowering	Number of days to full bloom	Flower diameter (cm)	Flower yield per hectare (q/ha)	Fresh weight of flowers per plant (g)	Dry weight of flowers per plant (g)	Flowering span	Shelf life (Days)
SD_0 (No soil drenching) +FS_0 (No foliar spray)	57.43^{a}	69.9^{a}	3.45^{f}	100.53^{d}	136.71^{i}	28.52^{i}	61.29^{h}	2.36^{h}
SD_0 (No soil drenching) +FS_1 (0.2% Humic acid)	55.87^{a}	68.67^{a}	4.51^{de}	103.22^{cd}	205.25^{h}	45.65^{h}	62.59^{h}	5.42^{a}
SD_0(No soil drenching) + FS_2 (GA3 200 ppm)	38.42^{fg}	51.35^{fg}	4.67^{cd}	109.83^{bc}	282.45^{e}	72.87^{e}	79.7^{b}	3.62^{b}
SD_0(No soil drenching) + FS_3 (NAA 50 ppm)	44.7^{d}	57.12^{e}	4.66^{cd}	107.73^{cd}	251.19^{g}	53.3^{g}	69.11^{f}	2.6^{g}
SD_1(PSB) @ 10% +FS_0 (No foliar spray)	39.5^{f}	51.36^{fg}	4.56^{de}	114.87^{ab}	279.7^{e}	85.18^{b}	78.78^{b}	2.79^{f}
SD_1(PSB) @ 10% +FS_1 (0.2% Humic acid)	36.89^{g}	48.28^{h}	4.46^{e}	116.23^{ab}	307.14^{c}	87.61^{b}	71.41^{e}	2.38^{h}
SD_1(PSB) @ 10% +FS_2 (GA3 200 ppm)	33.69^{h}	45.9^{i}	4.6^{cde}	119.9^{a}	323.88^{b}	99.97^{a}	82.29^{a}	3.64^{b}
SD_1(PSB) @ 10% +FS_3 (NAA 50 ppm)	41.17^{e}	53.15^{f}	4.61^{cde}	107.5^{cd}	299.46^{cd}	67.14^{f}	70.34^{ef}	2.18^{i}
SD_2(KSB) @1 0% +FS_0 (No foliar spray)	47.84^{c}	59.5^{d}	4.77^{bc}	116.28^{ab}	284.38^{e}	76.79^{d}	76.92^{c}	2.62^{g}
SD_2(KSB) @ 10% +FS_1 (0.2% Humic acid)	45.13^{d}	65.85^{b}	4.89^{ab}	115.02^{ab}	267.62^{f}	81.74^{c}	73.65^{d}	3.44^{c}
SD_2(KSB) @ 10% +FS_2 (GA3 200 ppm)	37.46^{g}	50.59^{g}	4.98^{a}	119.52^{a}	368.2^{a}	103.03^{a}	82.11^{a}	3.2^{d}
SD_2(KSB) @ 10% +FS_3 (NAA 50 ppm)	50.46^{b}	62.64^{c}	4.54^{de}	118.46^{a}	297.79^{d}	84.78^{bc}	67.2^{g}	2.98^{e}
SE (m)	0.56	0.59	0.06	2.27	2.94	1.05	0.57	0.04
CD (5%)	1.65	1.72	0.18	6.66	8.62	3.09	1.67	0.11

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