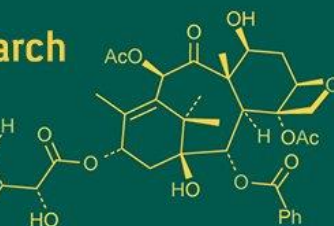
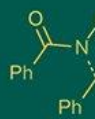
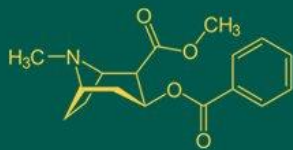


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Studies on the effect of bioinoculants and micronutrients on growth, flower yield, quality and shelf life of African marigold (*Tagetes erecta*) grown under walk-in tunnel

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Abstract

The present investigation entitled “Effect of bioinoculants and micronutrients on growth, flower yield, quality and shelf life of African marigold (*Tagetes erecta*) under walk-in tunnel conditions” was conducted at the Centre of Excellence, Protected Cultivation and Precision Farming, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.) during the *Rabi* season of 2024-25. The experiment was laid out in a Factorial Randomized Block Design comprising 12 treatment combinations with two factors, replicated three times. The treatments included four levels of soil drenching-no drenching (SD₀), PSB 10% (SD₁), KSB 10% (SD₂), and ZSB 10% (SD₃)-and three levels of foliar application-no spray (FS₀), ZnSO₄ 0.2% (FS₁), and FeSO₄ 0.2% (FS₂). The results revealed that the application of bioinoculants and micronutrients significantly influenced all growth, yield, and quality parameters. Among the treatments, soil drenching with PSB 10% and foliar spray of ZnSO₄ 0.2% individually showed notable improvement in plant growth and flowering traits. The combined treatment of PSB 10% × ZnSO₄ 0.2% (SD₁ × FS₁) performed superior for most vegetative and flowering parameters, while KSB 10% × ZnSO₄ 0.2% (SD₂ × FS₁) recorded the highest flower yield and shelf life. Overall, soil application of PSB and foliar application of ZnSO₄ were found to be most effective for enhancing growth, flower yield, quality, and shelf life of African marigold under protected cultivation.

Keywords: African marigold, biofertilizers, micronutrient, flower yield, shelf life

Introduction

Marigold (*Tagetes erecta* L.), belonging to the family Asteraceae (Compositae), holds a place of prime importance as a floricultural crop. It is an annual flowering plant extensively cultivated for loose flower production. Marigold flowers are used in garlands, decorations, religious ceremonies, and garden landscaping. Its high demand during festivals and its ability to thrive in a range of climatic conditions have earned it the reputation of being a “poor man’s flower.” The African marigold, with its bright yellow to orange blooms, is particularly valued for its aesthetic appeal, long flowering period, and good keeping quality. In India, marigold cultivation accounts for nearly two-thirds of the total area under loose flower production. According to Kaur *et al.* (2021), marigold is cultivated over approximately 255,000 hectares, producing about 1.754 million metric tonnes annually. In Chhattisgarh, marigold holds a dominant position in the flower market due to its year-round cultivation potential. The state’s favourable agro-climatic conditions and fertile soils have made it one of the key regions for marigold production.

In recent years, attention has increasingly turned toward sustainable methods of improving marigold yield and quality using bioinoculants and micronutrients. Biofertilizers, consisting of beneficial microorganisms, enhance soil fertility by mobilizing essential nutrients from unavailable to plant-available forms. They play a vital role in maintaining soil health, improving structure, and reducing dependency on chemical fertilizers, thereby mitigating soil and water pollution. Phosphate Solubilizing Bacteria (PSB), Potassium Solubilizing Bacteria (KSB), and Zinc Solubilizing Bacteria (ZSB) are particularly important, as they improve nutrient availability, promote root development, and enhance overall plant vigour. These bioinoculants not only improve nutrient uptake but also stimulate the production of plant

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growth-promoting substances such as hormones and vitamins, leading to better flowering and yield in floricultural crops.

Micronutrients, especially zinc (Zn) and iron (Fe), are essential for plant growth and physiological processes. Zinc is crucial in protein synthesis, auxin production, and regulation of enzyme systems, while iron plays an important role in chlorophyll formation, respiration, and photosynthesis. Deficiency of either element can lead to physiological disorders such as chlorosis, stunted growth, and reduced flower yield. Studies have demonstrated that foliar application of zinc and iron enhances vegetative growth, flower size, and color intensity in marigold, ultimately improving its aesthetic and commercial value. The combined use of biofertilizers and micronutrients represents an eco-friendly and cost-effective approach for optimizing marigold production.

Materials and Methods

The experiment was conducted at the Centre of Excellence for Protected Cultivation and Precision Farming, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.), during the *Rabi* season of 2024-25 under open field conditions. The experiment was laid out in a Factorial Randomized Block Design (FRBD) with three replications and twelve treatments. The crop selected for the study was African marigold (*Tagetes erecta* L.) cv. 'Calcuttia'. Each plot measured 2 m × 0.6 m, accommodating 12 plants per plot with a spacing of 30 cm × 30 cm. The treatments comprised four levels of soil drenching and three levels of foliar spray, making a total of twelve treatment combinations viz., T₁ (SD₀ × FS₀): No soil drenching + No foliar spray, T₂ (SD₀ × FS₁): No soil drenching + Foliar spray of ZnSO₄ (0.2%), T₃ (SD₀ × FS₂): No soil drenching + Foliar spray of FeSO₄ (0.2%), T₄ (SD₁ × FS₀): Soil drenching of PSB (10%) + No foliar spray, T₅ (SD₁ × FS₁): Soil drenching of PSB (10%) + Foliar spray of ZnSO₄ (0.2%), T₆ (SD₁ × FS₂): Soil drenching of PSB (10%) + Foliar spray of FeSO₄ (0.2%), T₇ (SD₂ × FS₀): Soil drenching of KSB (10%) + No foliar spray, T₈ (SD₂ × FS₁): Soil drenching of KSB (10%) + Foliar spray of ZnSO₄ (0.2%), T₉ (SD₂ × FS₂): Soil drenching of KSB (10%) + Foliar spray of FeSO₄ (0.2%), T₁₀ (SD₃ × FS₀): Soil drenching of ZSB (10%) + No foliar spray, T₁₁ (SD₃ × FS₁): Soil drenching of ZSB (10%) + Foliar spray of ZnSO₄ (0.2%), T₁₂ (SD₃ × FS₂): Soil drenching of ZSB (10%) + Foliar spray of FeSO₄ (0.2%).

Results and Discussion

Number of days to 50% flowering

Among soil applied bioinoculants, the earliest 50% bud initiation was recorded under SD₁ (PSB 10%) at 37.92 days, followed by SD₂ (KSB 10%) at 44.32 days. The control treatment (SD₀, no soil drenching) showed the maximum duration of 55.15 days. The earliness in flowering with PSB may be attributed to enhanced phosphorus availability, which supports floral primordia formation. Among the foliar application of micronutrients, the earliest 50% flowering occurred under FS₁ (ZnSO₄ 0.2%) at 42.58 days, followed by FS₂ (FeSO₄ 0.2%) at 49.21 days, while the control (FS₀, no spray) was delayed at 57.78 days. In the interaction of bioinoculants and micronutrients, the earliest 50% flowering was observed under T₅ (PSB 10% × ZnSO₄ 0.2%) at 35.58 days, followed by T₈ (KSB 10% × ZnSO₄ 0.2%) at 37.59

days and T₄ (PSB 10% × No foliar spray) at 39.50 days. Treatments without soil drenching and foliar spray (T₁) showed the maximum delay at 58.43 days.

Number of days to full bloom

Among the soil-applied bioinoculants, the earliest full bloom (49.63 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 56.764 days to full bloom. The maximum number of days to full bloom (68.56 days) was observed under the control treatment SD₀ (No soil drenching). Plants treated with ZnSO₄ (0.2%) (FS₁) reached full bloom the earliest at 54.58 days, followed by FeSO₄ (0.2%) (FS₂) at 61.75 days. The control plants without foliar spray (FS₀) required the longest duration, 69.78 days, to reach full bloom. The earliest full bloom was recorded under T₅ (Soil Drenching of PSB 10% × Foliar Spray of ZnSO₄ 0.2%) at 47.26 days, followed closely by T₈ (KSB 10% × ZnSO₄ 0.2%) at 48.47 days and T₄ (PSB 10% × No Foliar Spray) at 51.24 days. T₆ (PSB 10% × FeSO₄ 0.2%) also promoted early full bloom at 52.96 days. In contrast, the maximum duration to attain full bloom was observed under the control T₁ (No Soil Drenching × No Foliar Spray) at 70.06 days, followed by T₁₂ (ZSB 10% × FeSO₄ 0.2%) at 67.48 days and T₃ (No Soil Drenching × FeSO₄ 0.2%) at 66.78 days. Intermediate values were recorded under T₂ (No Soil Drenching × ZnSO₄ 0.2%) at 58.64 days and T₇ (KSB 10% × No Foliar Spray) at 58.74 days.

Flower diameter (cm)

Among the soil-applied bioinoculants, the maximum flower diameter (4.96 cm) was recorded under the treatment SD₂ (KSB), followed by SD₁ (PSB), which recorded a flower diameter of 4.90 cm and was statistically *at par* with SD₂ but significantly higher than the control (SD₀: no soil drenching), which recorded the minimum flower diameter (4.25 cm). Plants treated with ZnSO₄ (0.2%) (FS₁) recorded the highest flower diameter (4.863 cm), followed by FeSO₄ (0.2%) (FS₂) with 4.43 cm. The treatment with no foliar spray (FS₀), recorded the smallest flower diameter (4.087 cm). The largest flower diameter was recorded under T₈ (Soil Drenching of KSB 10% × Foliar Spray of ZnSO₄ 0.2%) at 4.99 cm, followed closely by T₅ (PSB 10% × ZnSO₄ 0.2%) at 4.89 cm and T₄ (PSB 10% × No Foliar Spray) at 4.72 cm. Other treatments producing relatively wider flowers included T₂ (No Soil Drenching × ZnSO₄ 0.2%) at 4.69 cm, T₁₁ (ZSB 10% × ZnSO₄ 0.2%) at 4.71 cm, and T₆ (PSB 10% × FeSO₄ 0.2%) at 4.52 cm. In contrast, the smallest flower diameters were observed under the control T₁ (No Soil Drenching × No Foliar Spray) at 3.45 cm, followed by T₁₀ (ZSB 10% × No Foliar Spray) at 4.24 cm and T₁₂ (ZSB 10% × FeSO₄ 0.2%) at 4.25 cm. Treatments with intermediate flower diameters included T₃ (No Soil Drenching × FeSO₄ 0.2%) at 4.29 cm, T₇ (KSB 10% × No Foliar Spray) at 4.46 cm, and T₉ (KSB 10% × FeSO₄ 0.2%) at 4.48 cm.

Flower yield per hectare (q/ha)

The maximum flower yield (117.32 q/ha) was recorded under the treatment SD₂ (KSB) and was statistically *at par* with SD₁ (PSB) (114.65 q/ha). The minimum flower yield (105.35 q/ha) was observed in the control treatment (SD₀: no soil drenching). The highest yield (113.74 q/ha) was

recorded in plants treated with ZnSO_4 (0.2%) (FS_1), followed closely by FeSO_4 (0.2%) (FS_2) with 111.42 q/ha. The control plants (FS_0), which received no foliar spray, recorded the lowest yield (108.63 q/ha). Among the interaction treatments, T_8 (Soil Drenching of KSB 10% $\times$ Foliar Spray of ZnSO_4 0.2%) recorded the highest flower yield at 117.54 q/ha, representing a 15.00% increase over the untreated control T_1 (102.54 q/ha). This was statistically at par with T_5 (PSB 10% $\times$ ZnSO_4 0.2%) at 116.47 q/ha and T_6 (PSB 10% $\times$ FeSO_4 0.2%) at 114.62 q/ha. Other notable treatments that significantly enhanced yield included T_4 (PSB 10% $\times$ No Foliar Spray) at 114.52 q/ha, T_7 (KSB 10% $\times$ No Foliar Spray) at 115.02 q/ha, and T_{10} (ZSB 10% $\times$ No Foliar Spray) at 114.03 q/ha. The lowest yield was observed under T_1 (No Soil Drenching $\times$ No Foliar Spray) at 102.54 q/ha, followed by T_3 (No Soil Drenching $\times$ FeSO_4 0.2%) at 103.65 q/ha and T_{12} (ZSB 10% $\times$ FeSO_4 0.2%) at 106.54 q/ha, indicating that absence of soil inoculants or sole foliar application of FeSO_4 without microbial inoculation was less effective in boosting yield.

Fresh weight of flowers per plant (g)

In the soil applied bioinoculants, the highest fresh weight (304.50 g) was recorded under SD_2 (KSB @ 10%), which was statistically at par with SD_1 (PSB @ 10%) at 302.54 g. Both treatments were significantly superior to the control (SD_0 , no soil drenching), which recorded the lowest fresh weight (218.90 g). The highest fresh weight (263.41 g) was observed in plants treated with ZnSO_4 (0.2%) (FS_1), followed by FeSO_4 (0.2%) (FS_2) with 245.26 g. The control treatment (FS_0), which did not receive any foliar application, recorded the lowest fresh weight (233.6 g). For the interaction effects, highest fresh flower weight was observed under T_8 (Soil Drenching of KSB 10% $\times$ Foliar Spray of ZnSO_4 0.2%), which recorded 312.64 g per plant. This was statistically at par with T_5 (PSB 10% $\times$ ZnSO_4 0.2%) at 305.68 g per plant and T_7 (KSB 10% $\times$ No Foliar Spray) at 286.21 g per plant. Other treatments such as T_4 (PSB 10% $\times$ No Foliar Spray) at 276.25 g and T_6 (PSB 10% $\times$ FeSO_4 0.2%) at 253.14 g per plant also showed considerable improvements in flower weight compared to the untreated control T_1 (No Soil Drenching $\times$ No Foliar Spray) at 136.71 g per plant. Among the lower-performing treatments, T_{12} (ZSB 10% $\times$ FeSO_4 0.2%) recorded 199.85 g per plant, followed by T_3 (No Soil Drenching $\times$ FeSO_4 0.2%) at 192.47 g, and T_2 (No Soil Drenching $\times$ ZnSO_4 0.2%) at 206.32 g per plant, reflecting that absence of microbial inoculation or the sole application of micronutrients was less effective in increasing flower biomass.

Dry weight of flowers per plant (g)

The effect of soil drenching treatments on dry weight of flowers per plant was found to be significant. The highest dry weight (86.59 g) was recorded with SD_2 (KSB10%), which was statistically at par with SD_1 (PSB10%) (84.97 g). Both treatments were significantly superior to the control (SD_0 : no soil drenching), which recorded the lowest dry weight (50.09 g). The highest dry weight (75.25 g) was recorded in plants treated with ZnSO_4 (0.2%) (FS_1), followed by FeSO_4 (0.2%) (FS_2) with 69.52 g. The control plants (FS_0), which received no foliar spray, recorded the lowest dry weight (54.52 g). Among the interaction treatments, T_8 (Soil Drenching of KSB 10% $\times$ Foliar Spray of ZnSO_4 0.2%) produced the highest dry flower weight,

recording 97.63 g per plant. This treatment was statistically at par with T_5 (PSB 10% $\times$ ZnSO_4 0.2%) at 89.74 g, indicating that both KSB and PSB in combination with zinc significantly enhanced floral dry biomass. Other effective treatments included T_4 (PSB 10% $\times$ No Foliar Spray) at 85.17 g, T_6 (PSB 10% $\times$ FeSO_4 0.2%) at 80.25 g, and T_9 (KSB 10% $\times$ FeSO_4 0.2%) at 78.52 g per plant, which were also significantly superior to the untreated control T_1 (No Soil Drenching $\times$ No Foliar Spray) at 43.52 g per plant. Treatments T_7 (KSB 10% $\times$ No Foliar Spray) at 76.79 g, T_{10} (ZSB 10% $\times$ No Foliar Spray) at 83.41 g, and T_{11} (ZSB 10% $\times$ ZnSO_4 0.2%) at 82.14 g recorded moderate dry flower weights, while T_2 (No Soil Drenching $\times$ ZnSO_4 0.2%) at 73.54 g and T_{12} (ZSB 10% $\times$ FeSO_4 0.2%) at 74.63 g were comparatively lower but still higher than the control.

Flowering span (days)

Among the soil-applied bioinoculants, the maximum flowering span (75.71 days) was observed in plants treated with SD_1 (PSB @ 10%), which was statistically at par with SD_2 (KSB @ 10%) (74.97 days). The minimum flowering span (68.17 days) was recorded in the control (SD_0 : no soil drenching), which was significantly lower than both PSB and KSB treatments. The longest flowering duration (71.52 days) was observed in plants treated with ZnSO_4 (0.2%) (FS_1), followed by FeSO_4 (0.2%) (FS_2) with 68.54 days. The control plants (FS_0), which did not receive any foliar spray, exhibited the shortest flowering span (62.12 days). The flowering span of marigold plants was markedly influenced by the combined application of soil bioinoculants and foliar micronutrients. Maximum flowering duration was observed in T_5 (Soil Drenching of PSB 10% $\times$ Foliar Spray of ZnSO_4 0.2%) at 80.35 days, which was statistically at par with T_8 (KSB 10% $\times$ ZnSO_4 0.2%) at 79.85 days. These treatments were followed by T_4 (PSB 10% $\times$ No Foliar Spray) and T_7 (KSB 10% $\times$ No Foliar Spray) recording 75.36 and 76.58 days, respectively, and were also statistically at par. Moderate flowering spans were recorded in T_{10} (ZSB 10% $\times$ No Foliar Spray) at 70.21 days and T_{11} (ZSB 10% $\times$ ZnSO_4 0.2%) at 72.54 days. The shortest flowering period was observed in the untreated control, T_1 (No Soil Drenching $\times$ No Foliar Spray), at 61.29 days, followed by treatments receiving only foliar sprays or ZSB drenching, including T_2 (No Soil Drenching $\times$ ZnSO_4 0.2%) at 65.52 days, T_6 (PSB 10% $\times$ FeSO_4 0.2%) at 62.65 days, T_3 (No Soil Drenching $\times$ FeSO_4 0.2%) at 58.63 days, T_9 (KSB 10% $\times$ FeSO_4 0.2%) at 59.45 days, and T_{12} (ZSB 10% $\times$ FeSO_4 0.2%) at 60.52 days.

Shelf life (days)

Among the soil-applied bioinoculants, the longest shelf life of flowers (3.60 days) was recorded under SD_1 (PSB10%). This was followed by SD_2 (KSB @ 10%), which showed a shelf life of 3.06 days. The shortest shelf life (2.42 days) was observed under SD_0 i.e. no soil drenching. The maximum shelf life (3.21 days) was observed in plants treated with ZnSO_4 (0.2%) (FS_1), while FeSO_4 (0.2%) (FS_2) recorded a moderate shelf life (2.45 days). The control treatment (FS_0), without any foliar spray, exhibited the shortest shelf life (2.13 days). The longest shelf life was recorded in T_8 (Soil Drenching of KSB 10% $\times$ Foliar Spray of ZnSO_4 0.2%) at 3.84 days, which was statistically at par with T_5 (PSB 10% $\times$ ZnSO_4 0.2%) at 3.62 days. Treatments T_4 (PSB 10% $\times$ No Foliar Spray), T_6 (PSB 10% $\times$ FeSO_4

0.2%), T₉ (KSB 10% × FeSO₄ 0.2%), and T₁₁ (ZSB 10% × ZnSO₄ 0.2%) exhibited moderate shelf life ranging from 2.76 to 3.15 days and were statistically at par. Shorter shelf life was observed in untreated control and single-factor treatments, including T₁ (No Soil Drenching × No Foliar

Spray) at 2.06 days, T₂ (No Soil Drenching × ZnSO₄ 0.2%) at 2.18 days, T₃ (No Soil Drenching × FeSO₄ 0.2%) at 2.36 days, T₇ (KSB 10% × No Foliar Spray) at 2.11 days, and T₁₂ (ZSB 10% × FeSO₄ 0.2%) at 2.15 days.

Table 1: Individual effect of soil applied bioinoculants on flowering behaviour, yield, quality and shelf life of 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 (days)	Shelf life (days)
Soil drenching (Factor A)								
(SD ₀) No soil drenching	55.15 ^a	68.56 ^a	4.25 ^a	105.35 ^d	218.9 ^c	50.09 ^d	68.17 ^d	2.42 ^d
(SD ₁) PSB10%	37.92 ^d	49.63 ^d	4.9 ^a	114.65 ^b	302.54 ^a	84.97 ^b	75.71 ^a	3.6 ^a
(SD ₂) KSB10%	44.32 ^c	56.74 ^c	4.96 ^a	117.32 ^a	304.5 ^a	86.59 ^a	74.97 ^b	3.06 ^b
(SD ₃) ZSB 10%	49.14 ^b	61.23 ^b	4.42 ^a	110.68 ^c	289.63 ^b	78.25 ^c	70.12 ^c	2.75 ^c
SE (m)	0.28	0.29	0.13	1.12	1.47	0.53	0.1	0.02
CD (5%)	0.83	0.86	0.44	3.32	4.31	1.55	0.93	0.06

Table 2: Individual effect of foliar applied micronutrients on flowering behaviour, yield, quality and shelf life 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 (days)	Shelf life (days)
Foliar Spray (Factor B)								
(FS ₀) No foliar spray	57.78 ^a	69.78 ^a	4.087 ^a	108.63 ^b	233.6 ^c	54.52 ^c	62.12 ^c	2.13 ^b
(FS ₁) ZnSO ₄ (0.2%)	42.58 ^c	54.58 ^c	4.863 ^a	113.74 ^a	263.41 ^a	75.25 ^a	71.52 ^a	3.21 ^a
(FS ₂) FeSO ₄ (0.2%)	49.21 ^b	61.75 ^b	4.43 ^a	111.42 ^a	245.26 ^b	69.52 ^b	68.54 ^b	2.45 ^b
SE (m)	0.32	0.34	0.26	1.31	1.70	0.52	0.35	0.02
CD (5%)	0.95	0.99	0.07	3.84	4.95	1.79	0.96	0.05

Table 3: Interaction effect of soil applied bioinoculants and foliar applied micronutrients on flowering behaviour, yield, quality and shelf life of 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 (days)	Shelf life (days)
T ₁	58.43 ^a	70.06 ^a	3.45 ^c	102.54 ^f	136.71 ⁱ	43.52 ⁱ	61.29 ^g	2.06 ^c
T ₂	46.14 ^e	58.64 ^e	4.69 ^{ab}	105.25 ^{ef}	206.32 ⁱ	73.54 ^g	65.52 ^e	2.18 ^c
T ₃	53.23 ^{bc}	66.78 ^b	4.29 ^{ab}	103.65 ^f	192.47 ^k	65.12 ^h	58.63 ⁱ	2.36 ^c
T ₄	39.5 ^g	51.24 ^h	4.72 ^{ab}	114.52 ^{bc}	276.25 ^d	85.17 ^c	75.36 ^b	3.12 ^{abc}
T ₅	35.58 ⁱ	47.26 ⁱ	4.89 ^{ab}	116.47 ^{ab}	305.68 ^b	89.74 ^b	80.35 ^a	3.62 ^{ab}
T ₆	40.25 ^g	52.96 ^g	4.52 ^{ab}	114.62 ^{bc}	253.14 ^f	80.25 ^e	62.65 ^f	2.76 ^{abc}
T ₇	46.57 ^e	58.74 ^e	4.46 ^{ab}	115.02 ^{bc}	286.21 ^c	76.79 ^f	76.58 ^b	2.11 ^c
T ₈	37.59 ^h	48.47 ⁱ	4.99 ^a	117.54 ^a	312.64 ^a	97.63 ^a	79.85 ^a	3.84 ^a
T ₉	49.78 ^d	61.52 ^d	4.48 ^{ab}	110.47 ^d	267.12 ^e	78.52 ^{ef}	59.45 ^{hi}	2.82 ^{abc}
T ₁₀	52.12 ^c	64.74 ^c	4.24 ^b	114.03 ^{bc}	241.32 ^g	83.41 ^d	70.21 ^d	2.56 ^{bc}
T ₁₁	43.96 ^f	55.84 ^f	4.71 ^{ab}	113.54 ^c	231.74 ^h	82.14 ^d	72.54 ^c	3.15 ^{abc}
T ₁₂	54.28 ^b	67.48 ^b	4.25 ^b	106.54 ^e	199.85 ^j	74.63 ^g	60.52 ^{gh}	2.15 ^c
SE (m)	0.56	0.59	0.14	1.98	1.94	1.05	0.58	0.4
CD (5%)	1.65	1.72	0.41	5.95	5.82	3.09	1.74	0.11

Conclusion

The results indicated that both soil-applied bioinoculants and foliar-applied micronutrients significantly influenced vegetative, flowering, yield, and quality parameters of African marigold under protected conditions. The combined application of PSB or KSB with ZnSO₄ foliar spray (T₅ and T₈) consistently recorded the highest performance across all growth stages. The flowering parameters also revealed significant differences among treatments. The earliest 50% flowering (35.58 days) was achieved under T₅ (PSB + ZnSO₄), followed by T₈ (37.59 days), compared to 58.43 days in the control. The yield attributes exhibited a similar trend. The maximum flower yield per plant (313 g fresh weight and 98 g dry weight) and per hectare (117.5 q/ha) were recorded under T₈ (KSB 10% + ZnSO₄ 0.2%), followed by T₅ (PSB 10% + ZnSO₄ 0.2%) with

approximately 504 g total plant fresh weight and 187 g dry weight. Therefore, the integrated nutrient management involving bioinoculants (PSB or KSB) and micronutrients (ZnSO₄) can be recommended as an effective, eco-friendly, and sustainable practice for achieving higher productivity and improved flower quality of African marigold under protected cultivation systems.

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