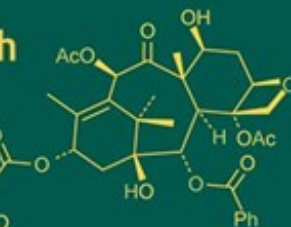
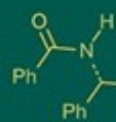
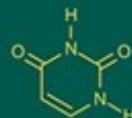
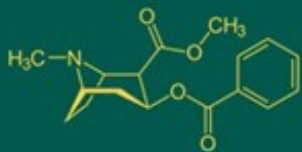


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Growth and water relations of African marigold under graded moisture regimes and foliar application of melatonin, salicylic acid and GABA

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ABSTRACT

Moisture deficit is an important constraint to ornamental crop production, affecting plant growth, pigment accumulation and tissue water status. A two-season factorial experiment (2024-25 and 2025-26) to evaluate the response of African marigold (*Tagetes erecta* L.) cv. *Pusa Bahar* to three moisture regimes and foliar application of GABA, salicylic acid and melatonin. Plants were maintained at three field capacity (FC) regimes (100%, 70% and 40% FC) and combined with seven foliar treatments (water-spray control, GABA at 200 and 400 ppm, salicylic acid (SA) at 100 and 150 ppm, and melatonin (MEL) at 10 and 20 ppm). Pooled means indicated progressive reductions in growth and pigment traits with decreasing soil moisture. Relative to 100% FC, 40% FC reduced leaf number, leaf area, chlorophyll b and root length by 49.6, 46.4, 44.9 and 39.3%, respectively, while water saturation deficit increased approximately 3.3-fold. Intrinsic water-use efficiency increased by 33.7% under 40% FC. Foliar application generally improved plant performance compared with the water-spray control. MEL at 20 ppm gave the highest chlorophyll a (8.94), chlorophyll b (5.44), leaf number (187.61), root length (26.53) and internal water content (7.66) and the lowest water saturation deficit (19.27), while SA at 100 ppm gave the largest leaf area (18.66) and IWUE (55.32). Correlation and multivariate analyses indicated strong associations among growth, pigment and water-status traits and ($r = -0.80$ to -0.94), and first two components explained 87.7% of the total variation, sprayed plants at 70% FC grouped with the well-watered treatments. Foliar GABA, SA and MEL partially alleviated the adverse effects of moisture deficit in African marigold.

Keywords: *Tagetes erecta*, Soil moisture regimes, GABA, Salicylic acid, Melatonin, Water saturation deficit, IWUE

Introduction

African marigold (*Tagetes erecta* L.) is a commercially important ornamental crop cultivated for loose-flower, garden display and pigment production or as coloring agent in poultry feed to obtain yellow egg yolks (Asrar *et al.*, 2011) [1]. Adequate soil moisture is essential for maintaining vegetative growth, leaf expansion, photosynthetic pigments and root development. Moisture deficit can restrict cell expansion and plant growth, disturb tissue water relations and ultimately reduce crop productivity (Kılıc *et al.*, 2024) [2]. Water-saving irrigation practices based on reduced soil moisture availability may help conserve water; however, prolonged moisture deficit can impose considerable physiological limitations on plants. Foliar application of plant growth regulators represents one possible approach for reducing the adverse effects of water deficit. Gamma-aminobutyric acid (GABA), salicylic acid (SA) and melatonin have been reported to participate in stress signalling, osmotic adjustment, antioxidant protection and maintenance of photosynthetic function under abiotic stress conditions (Yong *et al.*, 2017; Basit *et al.*, 2018; Zhang *et al.*, 2022) [4, 3, 5].

Although these compounds have individually been investigated in different crops, comparative information on their response under graded moisture regimes in African marigold remains limited. Therefore, the present study evaluated the effects of three soil moisture regimes and foliar application of GABA, SA and melatonin on selected growth, pigment, root and water-relation traits of African marigold cv. *Pusa Bahar*. Relationships among these traits were further examined using correlation and multivariate analyses.

2. Materials and methods

The pot experiment was conducted during 2024-25 and 2025-26 in Mist chamber of dept. of Floriculture and Landscaping at Rani Lakshmi bai central agricultural university, with African marigold cv. *Pusa Bahar*. The experiment consisted of three moisture regimes, FC₁ (100% FC), FC₂ (70% FC) and FC₃ (40% FC), and seven foliar sprays: S₀ (water spray, control), S₁ (GABA 200 ppm), S₂ (GABA 400 ppm), S₃ (SA 100 ppm),

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S₄ (SA 150 ppm), S₅ (MEL 10 ppm) and S₆ (MEL 20 ppm), giving 21 treatment combinations in three replication. Observations were recorded on chlorophyll a (Cl_a , mg/g fresh weight) and b (Cl_b , mg/g fresh weight), leaf number (LN; plant⁻¹), leaf area (LA; cm²), stem diameter (SD; mm), water saturation deficit (WSD; %), water deficit ratio (WDR), root length (RL; cm), intrinsic water use efficiency (iWUE $\mu\text{mol CO}_2 \text{ mol}^{-1} \text{ H}_2\text{O}$) and internal water content (IWC, %), root to leaf area ratio (RtoLA). The effects of moisture regime and foliar treatment were evaluated using analysis of variance. Pooled means across the two experimental seasons were used for presentation of the principal treatment effects. Pearson correlation, path analysis, hierarchical clustering and principal component analysis were conducted using treatment means in R software.

3. Results

3.1 Effect of soil moisture regime

Graded Moisture regime significantly influenced the growth, pigment and water-status traits of African marigold (Table 1). Plants maintained at 100% FC recorded the highest chlorophyll a (9.24), chlorophyll b (6.17), leaf number (226.75), leaf area (23.66), stem diameter (8.04), root length (29.92) and internal water content (8.81).

Table 1. Effect of soil moisture regime on morpho-physiological traits

Treatment	Cl _a	Cl _b	LN	LA	SD	WSD	WDR	RL	iWUE	IWC
100% FC	9.24	6.17	226.75	23.66	8.04	11.67	1.36	29.92	45.47	8.81
70% FC	7.78	5.24	183.88	14.24	6.77	21.94	3.58	24.76	48.43	6.51
40% FC	6.55	3.40	114.28	12.68	6.06	38.13	8.43	18.16	60.78	4.85
S.Em±	0.11	0.07	1.07	0.47	0.08	0.54	0.22	0.33	1.43	0.15
CD(<i>p</i> = 0.05)	0.31	0.21	3.05	1.36	0.23	1.53	0.63	0.95	4.08	0.42

LN = leaf number; LA = leaf area; SD = stem diameter; WSD = water saturation deficit; WDR = water deficit ratio; RL = root length; IWUE = intrinsic water-use efficiency; IWC = internal water content.

Salicylic acid (SA) at 100 ppm produced the largest leaf area (18.66) and IWUE (55.32) while GABA at 200 ppm reported the highest stem diameter (7.35) and closely, followed mel 20 for chlorophyll a (8.63) and WSD (20.33). Increasing GABA concentration from 200 to

Progressive reduction in soil moisture resulted in a corresponding decline in these traits. At 40% FC, leaf number reduced by 49.6%, leaf area by 46.4%, chlorophyll b by 44.9%, IWC by 45.0%, root length by 39.3%, chlorophyll a by 29.1% and stem diameter by 24.6%. In contrast, WSD and WDR increased with increasing moisture deficit. WSD increased from 11.67 at 100% FC to 38.13 at 40% FC, while WDR increased from 1.36 to 8.43. iWUE increased from 45.47 at 100% FC to 60.78 at 40% FC. The difference in iWUE between 100 and 70% FC was comparatively small.

3.2 Effect of foliar treatments

Foliar application generally improved measured growth, pigment concentration and water-status traits relative to the untreated control (Table 2). Among the treatments, melatonin at 20 ppm was the found to be most consistent across several traits. It recorded the highest Chl a (8.94), Chl b (5.44), leaf number (187.61), root length (26.53 cm) and IWC (7.66), while WSD (19.27) and WDR (2.84) were the lowest among the foliar treatments. Compared with the water-spray control, melatonin at 20 ppm increased Chl a, Chl b, leaf number, root length and IWC by approximately 49.5, 30.8, 25.5, 37.2 and 33.2%, respectively, while reducing WSD and WDR by approximately 40.4 and 62.9%.

Table 2. Effect of foliar treatments on morpho-physiological traits

Treatment	Cl _a	Cl _b	LN	LA	SD	WSD	WDR	RL	iWUE	IWC
Control (S ₀)	5.98	4.16	149.50	12.06	5.99	32.33	7.65	19.34	40.93	5.75
GABA 200 (S ₁)	8.63	5.26	179.46	17.09	7.35	20.33	3.13	23.18	53.67	7.12
GABA 400 (S ₂)	7.77	4.87	183.99	17.04	6.96	22.46	4.08	23.91	53.35	6.70
SA 100 (S ₃)	8.12	5.05	171.86	18.66	7.11	22.55	4.44	25.67	55.32	6.43
SA 150 (S ₄)	7.61	4.81	168.21	17.69	6.98	24.81	4.82	25.51	52.47	6.31
MEL 10 (S ₅)	7.94	4.95	184.15	18.43	7.18	25.63	4.22	25.81	53.83	7.07
MEL 20 (S ₆)	8.94	5.44	187.61	17.04	7.13	19.27	2.84	26.53	51.34	7.66
S.Em. ±	0.16	0.11	1.63	0.73	0.12	0.82	0.33	0.51	2.18	0.23
CD (<i>P</i> = 0.05)	0.47	0.32	4.66	2.07	0.34	2.33	0.95	1.46	6.23	0.64

3.3 Interaction effect of moisture regime and foliar treatments

Interaction effect of morpho-physiological traits under 100%, 70% and 40% FC in African marigold (*Tagetes erecta*) cv Pusa Bahar. The interaction between moisture regime and foliar treatment was significant for the measured traits except root-to-leaf-area ratio (Fig. 1).

Under well-watered conditions, several foliar treatments produced the highest values for individual traits. Leaf Number was highest in FC₁S₄ (235.6) and FC₁S₁ (234.3), leaf area in FC₁S₃ (27.0), Cl_a and Cl_b in FC₁S₆ (10.4 and 6.7), RL in FC₁S₃ (33.6), IWC in FC₁S₆ (9.6) and SD in FC₁S₁ and FC₁S₅ (8.4), with the lowest WSD (10.4) and WDR (1.1) were recorded in FC₁S₆. The untreated severe-stress treatment (FC₃S₀) showed the poorest

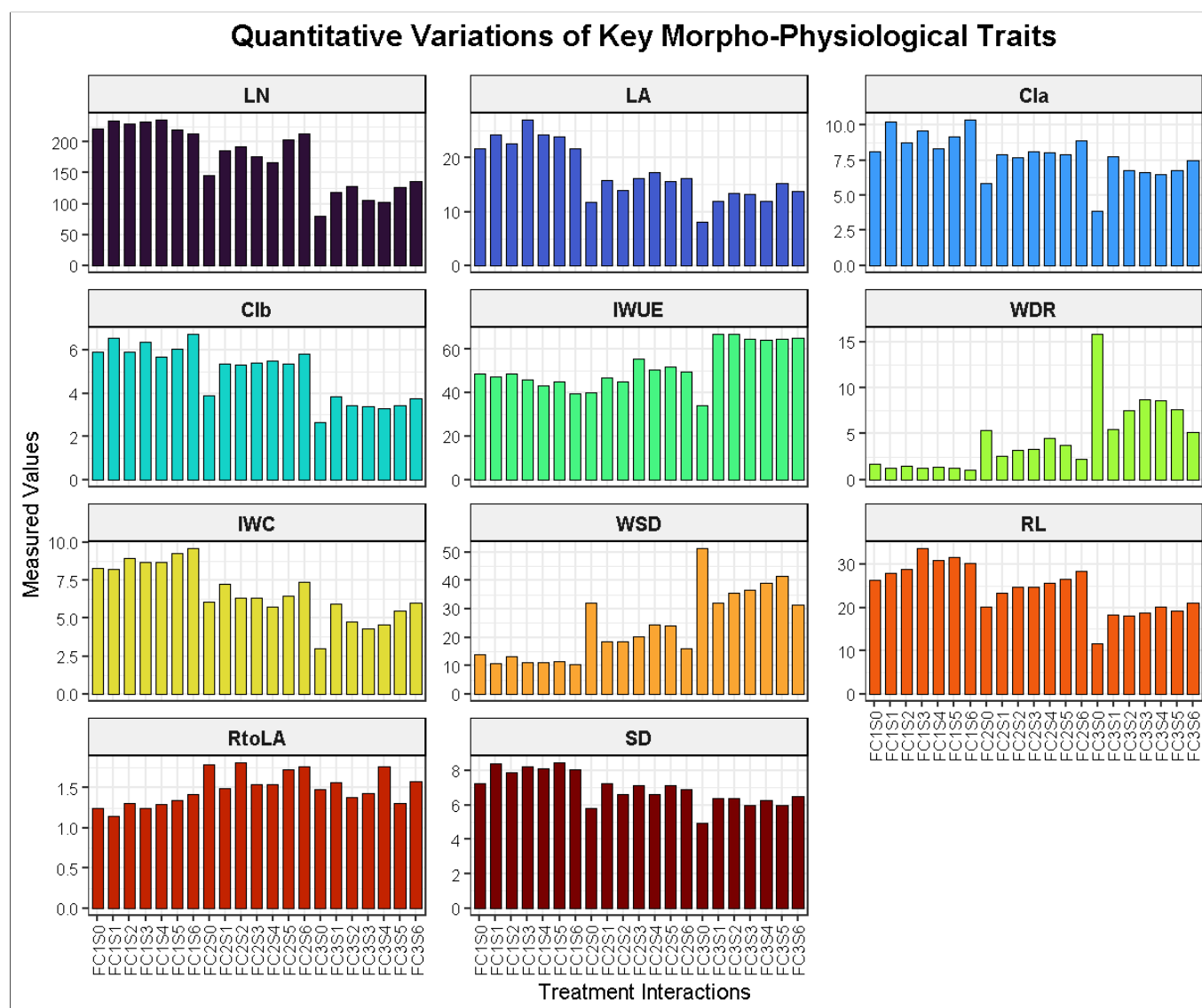
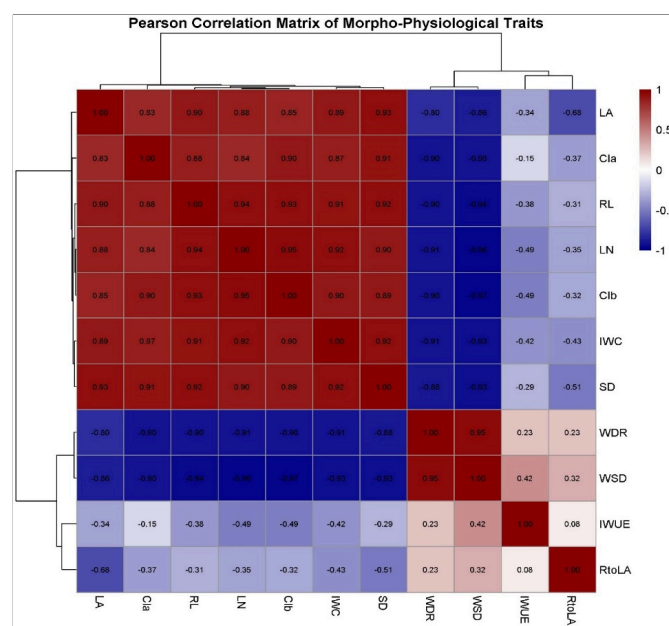


Figure 1. Interaction effect of morpho-physiological traits under 100%, 70% and 40% FC in African marigold (*Tagetes erecta*) cv Pusa Bahar.

performance for major growth trait (LN 80.8, LA 8.1, Cl_a 3.9, Cl_b 2.6, RL 11.7, SD 4.9, IWC 3.0) and recorded the highest WSD (51.1) and WDR (15.8). Foliar application substantially reduced the severity of these responses at 40% FC. MEL 20 ppm (FC_3S_6) increased leaf number by 68.6% and lowered WSD by 38.7% and WDR by 67.1%, MEL 10 ppm (FC_3S_5) raised leaf area to 15.2 (+87.7%), and GABA 200 ppm doubled Cl_a (7.8). At 70% FC, MEL 20 ppm (FC_2S_6) produced values comparable with the well-watered control for several traits and was at par with the well-watered control (FC_1S_0) for LN (213.4), Cl_a (8.9), Cl_b (5.8), WSD (16.1), IWC (7.4) and RL (28.3), but not for LA (16.2). IWUE was lowest in FC_3S_0 (34.1) and increased markedly with foliar application under 40% FC. These results indicate that foliar treatments reduced, but did not completely eliminate, the adverse effects associated with severe moisture deficit.

3.4 Correlations and multivariate analysis

Pearson correlation analysis revealed two broad groups of associated traits. Growth and pigment traits, including leaf area, Chl a, Chl b, leaf number, root length, stem diameter and IWC, showed strong positive associations with one another ($r = 0.83$ – 0.95). In contrast, these traits showed strong negative associations with WSD and WDR ($r = -0.80$ to -0.94). WSD and WDR were themselves strongly positively associated ($r = 0.95$). IWUE showed relatively weak associations with most of the measured traits ($r = -0.15$ to 0.42), indicating that its response to moisture deficit was not directly aligned with the major growth variables. Root-to-leaf-area ratio showed negative associations with leaf area and stem diameter.



Principal component analysis showed that PC1 and PC2 explained 77.9 and 9.8% of the total variation, respectively, accounting for 87.7% of the overall variation. PC1 primarily separated well-watered treatments from the 40% FC treatments based on the contrasting distribution of growth/pigment traits and water-deficit indicators. IWUE and root-to-leaf-area ratio contributed more strongly to PC2.

Hierarchical clustering produced a similar pattern. Most well-watered treatments and sprayed 70% FC treatments were grouped together, whereas the 40% FC treatments formed a separate group. The un-

treated severe-stress treatment, FC₃S0, was the most distinct treatment in the multivariate analysis.

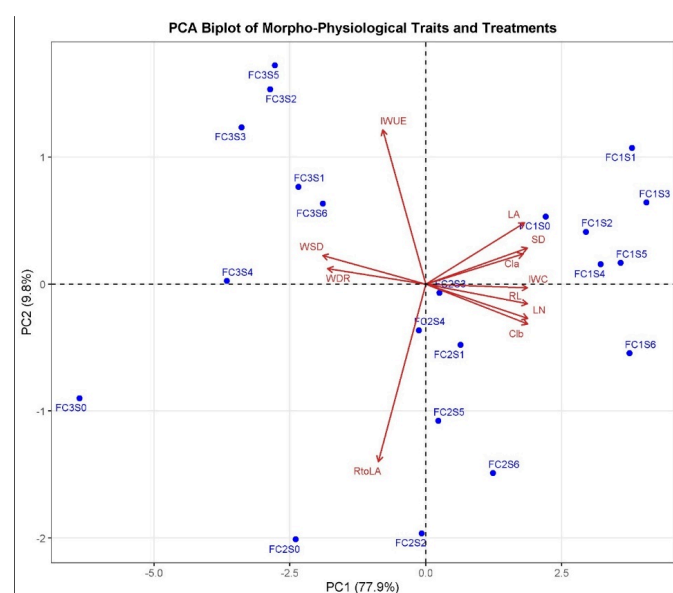
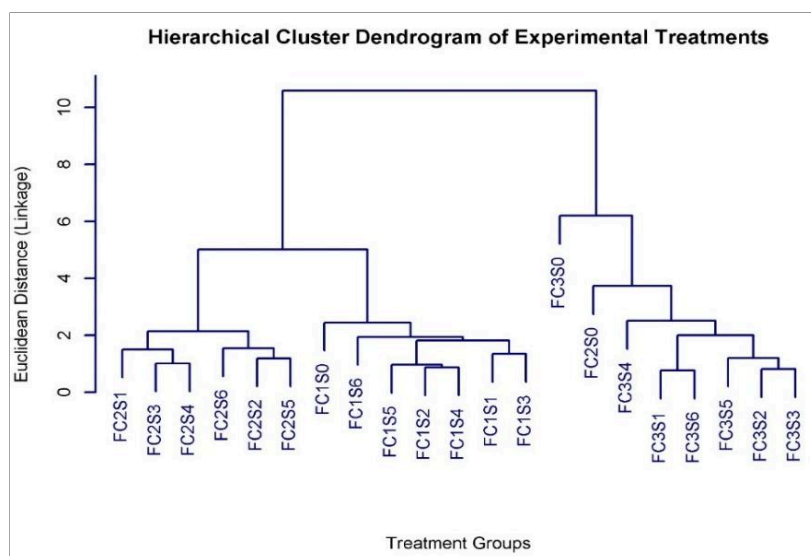


Figure 2. A: Correlations analyses, **B:** Hierarchical clustering **C:** Biplot showing the relationship of morpho-physiological traits under 100%, 70% and 40% FC in African marigold (*Tagetes erecta*) cv Pusa Bahar.

4. Discussion

The steady decline in leaf number, leaf area, chlorophyll and root length with decreasing moisture reflects the well-known suppression of cell expansion, pigment synthesis and root proliferation under water deficit (Abd El-Gawad *et al.*, 2021; Kılıc *et al.*, 2024) [6, 2]. The decline in chlorophyll concentration further indicates impairment of pigment maintenance under severe moisture deficit (Tavassoli *et al.*, 2025) [7]. The increase in WSD and WDR together with the decline in IWC at 40% FC indicate unstable tissue hydration, and the strong negative correlations of these traits with growth traits further indicates that deterioration in plant water status was closely associated with reductions in vegetative growth. A increase in WSD could lead may be due severity of drought which can lead to a decrease in leaf water content, cell turgor pressure, potentially impacting the plant's strength and structural integrity (Liu *et al.*, 2022; Kumar *et al.*, 2018) [9, 8]. The interaction data show that iWUE was lowest in unsprayed severely stressed plants (34.1) and nearly doubled with sprays (64.0-66.7), suggesting that the bioregulators helped plants retain intrinsic water-use efficiency under severe stress. This agrees with the weak

correlation of IWUE with the other traits and its separate loading on PC2.

The positive response to foliar application is consistent with the known stress-related functions of GABA, SA and melatonin. GABA accumulates under stress and contributes to osmotic adjustment, membrane stabilisation and antioxidant defence (Yong *et al.*, 2017; Abd El-Gawad *et al.*, 2021) [4, 6]. SA acts as a signalling molecule under stress and can influence growth and physiological processes under adverse environmental conditions (Basit *et al.*, 2018) [3], which may explain the higher leaf area and IWUE at 100 ppm. Melatonin reduces oxidative damage and helps retain chlorophyll and tissue water under drought (Silalert *et al.*, 2021; Zhang *et al.*, 2022) [10, 5]. The absence of a benefit from higher GABA and SA doses suggests that the response saturates at moderate concentrations, a common pattern with growth regulators. The clustering of the sprayed 70% FC plants with the well-watered group, and of the unsprayed 70% FC plants with the 40% FC group, indicates that foliar treatment can compensate for a 30% reduction in available moisture. At 40% FC, however, sprays reduced but did not completely remove the effects of severe moisture deficit. The present findings therefore suggest that foliar bioregulators can moderate the adverse effects of reduced soil moisture in African marigold, with the magnitude of response depending on both the moisture regime and the compound applied.

5. Conclusion

Reducing soil moisture from 100 to 40% FC substantially affected growth, pigment accumulation, root development and tissue water status of African marigold cv. Pusa Bahar. Leaf number, leaf area, chlorophyll concentration, root length and internal water content declined progressively with increasing moisture deficit, whereas water saturation deficit and water deficit ratio increased. Foliar application of GABA, SA and melatonin partially alleviated these effects. Among the tested treatments, melatonin at 20 ppm showed the most consistent improvement across several growth, pigment and water-status traits, while SA at 100 ppm produced the highest leaf area and IWUE and GABA at 200 ppm produced the highest stem diameter. Under 70% FC, several sprayed treatments showed responses comparable with well-watered plants for selected traits, whereas severe moisture deficit at 40% FC continued to impose a substantial growth penalty even after foliar treatment. Overall, the findings indicate that foliar application of GABA, SA and melatonin can contribute to maintaining growth and water status of African marigold under reduced soil moisture, with melatonin at 20 ppm showing particularly consistent effects across the traits evaluated in the present study.

References

- Asrar AW A, Elhindi KM. Alleviation of drought stress of marigold (*Tagetes erecta*) plants by using arbuscular mycorrhizal fungi. Saudi journal of biological sciences. 2011;18(1):93-98.
- Kılıc T, Dogan Meral E, Kirbay E, Dursun H, Kazaz S. Oxalic Acid's Impact on the Morphological, Physiological and Biochemical Characteristics of Marigolds under Drought Stress. 2024.
- Basit A, Shah K, Rahman MU, Xing L, Zuo X, Han M, Khalid MA. 15. Salicylic acid an emerging growth and flower inducing hormone in marigold (*Tagetes* sp. L.). Pure and Applied Biology (PAB). 2018;7(4):1301-1308.
- Yong B, Xie H, Li Z, Li YP, Zhang Y, Nie G, Peng Y. Exogenous application of GABA improves PEG-induced drought tolerance positively associated with GABA-shunt, polyamines, and proline metabolism in white clover. Frontiers in physiology. 2017;8:1107.
- Zhang P, Hu Y, Zhou R, Zhang X, Hu H, Lang D. The antioxidant system response to drought-stressed *Diospyros lotus* treated with exogenous melatonin. PeerJ. 2022;10:e13936.
- Abd El-Gawad HG, Mukherjee S, Farag R, Abd Elbar OH, Hikal M, Abou El-Yazied A, et al. Exogenous γ -aminobutyric acid (GABA)-induced signaling events and field performance associated with mitigation of drought stress in *Phaseolus vulgaris* L. Plant Signaling & Behavior. 2021;16:1853384.
- Tavassoli A, Tavakol E, Heidari B, et al. Drought stress effects on pot marigold (*Calendula officinalis* L.) revealed by REML and BLUES analysis. Sci Rep. 2025;15:30613.
- Kumar S, Sachdeva S, Bhat KV, Vats S. Plant responses to drought stress: physiological, biochemical and molecular basis. In: Vats S, editor. Biotic Abiotic Stress Tolerance in Plants. Springer; 2018:1–25.
- Liu J, et al. GRACE combined with WSD to assess the change in drought severity in arid Asia. Remote Sens. 2022;14(14):3454–3454.
- Silalert P, Pattanagul W. Foliar application of melatonin alleviates the effects of drought stress in rice (*Oryza sativa* L.) seedlings. Notulae Botanicae Horti Agrobotanici Cluj-Napoca. 2021;49(3):12417-12417.
- Ahmad P, Jamsheed S, Hameed A, Rasool S, Sharma I, Azooz M, Hasanuzzaman M. Drought stress induced oxidative damage and antioxidants in plants. Oxidative damage to plants. Academic Press: Elsevier; 2014:345–367.

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