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# Morphometric studies of marigold (*Tagetes erecta*) var. Pusa Narangi Gainda: Impact of cold stress and mitigation strategies

RAYAVARAPU TEJASWI[1], PRABHAT KUMAR[2]*, K P SINGH[1], M C SINGH[1], SAPNA PANWAR[1], RITU JAIN[1], TEJUKUMAR B K[1], POOJA A[3] and VARUN HIREMATH[3]

*ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India*

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ABSTRACT

The experiment was conducted during 2021 to 2023 at ICAR-Indian Agricultural Research Institute, New Delhi aimed to investigate the morphological changes of marigold (*Tagetes erecta* L.) var. Pusa Narangi Gainda under the influence of cold stress and mitigation techniques. The investigation included sowing the Pusa Narangi Gainda marigold variety on three distinct dates and subjecting the seedlings to two different growing environments [open field ($E_1$) and protected conditions ($E_2$)], each treated with various treatments and combinations included, $T_0$, Control; $T_1$, Salicylic acid (SA) @100 ppm; $T_2$, SA @200 ppm; $T_3$, SA @300 ppm; $T_4$, Chitooligosaccharide (COS) @100 ppm; $T_5$, COS @200 ppm; $T_6$, COS @300 ppm; $T_7$, Arbuscular mycorrhiza (AM) alone; $T_8$, SA @100 ppm + AM; $T_9$, SA @200 ppm + AM; $T_{10}$, SA @300 ppm + AM; $T_{11}$, COS @100 ppm + AM; $T_{12}$, COS @200 ppm + AM and $T_{13}$, COS @300 ppm + AM. The experiment was laid out in a factorial randomized block design (FRBD) with three replications. Parameters concerning plant growth, flowering, and yield were assessed and analysed. Findings indicated that plants cultivated within a low plastic tunnel, particularly those sown on October 15$^{th}$ exhibited superior growth and flowering characteristics compared to those grown in open field conditions. Upon examining different treatments, it was noted that combining COS at a concentration of 200 ppm with AM @10 g/plant yielded more favourable results compared to the control group and other treatments. This study underscores the advantageous effects of utilizing low plastic tunnels across different sowing dates and treatments on marigold plants' growth, flowering and yield attributes.

**Keywords**: Arbuscular mycorrhiza, Chitooligosaccharide, Low plastic tunnel, Marigold, Salicylic acid

Marigold (*Tagetes erecta* L.), a member of the Asteraceae family, holds significant commercial value in India. Widely sought after for its ornamental flowers, it is also cultivated for its use as a pigment source in poultry feed. Thriving in moderate climates, marigold can be grown year-round, in the rainy, winter, and summer seasons. However, the winter season in northern India poses challenges, as exceptionally low temperatures lead to reduced yields and prolonged vegetative phase, impacting profitability for farmers. Cold stress, a major environmental factor, adversely affects higher plants, manifesting in symptoms like stunted growth, wilting, yellowing, and tissue necrosis (Zhou *et al.* 2017). This stress disrupts crucial physiological processes, hampering plant reproductive growth and diminishing crop output and flower quality. Previous studies have demonstrated that marigold plants flower earlier at higher temperatures compared to lower temperatures (Blanchard and Runkle 2011). According to Van and Seymour (2002), plants grow slower under low temperatures due to inefficient carbon utilization than under higher temperatures. Given the complex nature of plant stress responses, novel strategies are needed to enhance stress tolerance. Utilizing bioagents and elicitors has emerged as a promising approach to bolster plant resilience against cold stress. Several studies revealed that inoculation of bioagents like arbuscular mycorrhizal fungi (AMF) enhance protein content and plant secondary metabolites, strengthening the plant's immune system to combat cold stress conditions (Abdel and Chaoxing 2011). It also enhances crop tolerance by balancing microbial community near rhizosphere and stimulating osmolytes in the host plants (Ci *et al.* 2021). Elicitors, are considered as defence molecules of plant immune system that can stimulate the signal cascade against abiotic stresses, eliciting a stress response alleviating stress condition (Lone *et al.* 2023). This study aims to explore various methods to mitigate yield losses caused by cold stress in marigold plants, considering their economic significance and commercial value.

[1]ICAR-Indian Agricultural Research Institute, New Delhi; [2]Krishi Bhavan, Ministry of Agriculture and Farmers Welfare, New Delhi; [3]Central Agriculture University, Imphal, Manipur. *Corresponding author email: prabhatflori@gmail.com

## MATERIALS AND METHODS

The experiment was conducted during 2021 to 2023 at ICAR-Indian Agricultural Research Institute, New Delhi.

Seeds of the Pusa Narangi Gainda marigold variety were sourced from the ICAR-Indian Agricultural Research Institute, New Delhi. The seeds were sown on raised nursery beds inside polyhouse on three different dates, October 15$^{th}$ ($SD_1$); November 1$^{st}$ ($SD_2$) and November 15$^{th}$ ($SD_3$), with a spacing of 6–8 cm and a depth of 2 cm. Disease-free seedlings were carefully selected and transplanted to the main field, with a spacing of 45 cm × 35 cm. Chemical sprays of salicylic acid (SA) and chitooligosaccharide (COS) were applied at doses of 100, 200 and 300 parts per million (ppm) on 20, 30 and 40 days after sowing (DAS). Arbuscular mycorrhiza (AM) was applied at a rate of 10 g/plant during planting. The treatments included, $T_0$, Control; $T_1$, SA @100 ppm; $T_2$, SA @200 ppm; $T_3$, SA @300 ppm; $T_4$, COS @100 ppm; $T_5$, COS @200 ppm; $T_6$, COS @300 ppm; $T_7$, AM alone; $T_8$, SA @100 ppm + AM; $T_9$, SA @200 ppm + AM; $T_{10}$, SA @300 ppm + AM; $T_{11}$, COS @100 ppm + AM; $T_{12}$, COS @200 ppm + AM and $T_{13}$, COS @300 ppm + AM. Plants in the main field were cultivated under two different conditions, open field ($E_1$) and protected conditions ($E_2$). A low plastic tunnel was used to shield plants when temperatures dropped below the optimal threshold (<15) for 60 days, while the tunnel cover was removed when temperatures were conducive to growth. The experiment was laid out in a factorial randomized block design (FRBD) with three replications. Morphometric data was collected and aggregated over two years and subjected to statistical analysis using analysis of variance (ANOVA). The significance of the results was determined using the F test, and the critical difference (CD) was calculated with a significance level of $P$=0.05 using R software.

## RESULTS AND DISCUSSION

The pooled data of morphometric parameters presented in Table 1 and Table 2 illustrate the impact of elicitors [chitooligosaccharide (COS), salicylic acid (SA)], and bioagent [arbuscular mycorrhiza (AM)], sowing dates, and the utilization of low polytunnels on the growth and flowering characteristics of the Pusa Narangi Gainda marigold variety in mitigating cold stress. Significant variations in morphological traits were observed across the different factors under investigation. Plants cultivated under low plastic tunnel conditions ($E_2$) exhibited notable enhancements in growth parameters such as plant height (74.43 cm), stem diameter (0.66 cm), and number of primary branches (12.05), as well as in flowering and yield parameters like flower diameter (5.87 cm), individual flower weight (8.07 cm), number of flowers/plant (33.08) and yield/plant (313.67 g) compared to those grown in open field conditions ($E_1$). Similar results were reported by Amala *et al*. (2022) in marigold and Qayyum *et al*. (2020) in gladiolus. Conversely, plants grown within low plastic tunnels ($E_2$) exhibited an earlier onset of flowering (63.79 days) compared to those in open field conditions. Plastic tunnels not only elevate air temperatures but also moderate soil temperature extremes, fostering an environment conducive to plant growth (Lamont 2005). The rise in temperature within the plastic tunnel, attributed to the blocking of infrared radiation (Lim *et al*. 2017), significantly influences the timing of flowering. The plants sown on October 15$^{th}$ ($SD_1$) demonstrated notable superiority in growth parameters such as plant height (71.63 cm) and stem diameter (0.62 cm), as well as in flowering and yield parameters including flower diameter (5.52 cm), individual flower weight (7.14 g), number of flowers/plant (31.22) and yield/plant (293.00 g) compared to those from the other two sowing dates. However, the highest number of primary branches (10.96) was recorded from plants sown on November 1$^{st}$ ($SD_2$). Plants from November 15$^{th}$ ($SD_3$) exhibited a shorter duration for the first flowering (67.31 days). These variations in sowing times influence key environmental factors (especially temperatures) which significantly influence plant growth stages. It also impacts plant's ability to optimize resource use and adapt to environmental conditions, influencing overall performance of the plants. These findings are consistent with the results reported by Amala *et al*. (2022) in marigold. Among the various elicitors examined, treatment of COS @200 ppm along with 1 g/plant AM ($T_{12}$) demonstrated superior performance across several growth parameters. This treatment recorded the highest values for plant height (74.49 cm) and flowering and yield parameters such as flower diameter (5.99 cm), individual flower weight (7.64 g), number of flowers/plant (35.45), and yield/plant (292.42 g) compared to the control and other treatments. The treatment of SA @300 ppm in combination with AM ($T_{10}$) and treatment of COS @200 ppm in combination with AM ($T_{12}$) showed best results recording on par with respect to stem diameter (0.64 cm and 0.64 cm, respectively) and the number of primary branches (12.05 and 11.98, respectively). Moreover, applying COS @200 ppm with AM ($T_{12}$) resulted in the shortest time for first flowering (66.71 days) compared to other treatments. COS enhances plant growth and development by promoting the production of specific phytohormones. Numerous studies have documented the beneficial effects of natural polysaccharides like chitosan and chitooligosaccharide on various aspects of plant growth, suggesting that using chitosan improves water and nutrient uptake efficiency, leading to enhanced plant growth. These findings are supported by research reported by Zhang *et al.* (2019) in rice, Wang *et al*. (2021) in banana, and Tan *et al*. (2023) in cucumber. Furthermore, AM forms symbiotic relationships with plant roots, enhancing nutrient uptake (particularly phosphorus), water absorption, and the production of stress-related hormones like abscisic acid. Additionally, AM can stimulate the production of antioxidants and osmolytes, which help to mitigate oxidative damage caused by cold stress. This symbiosis likely enhances the marigold plants' physiological and biochemical resilience, enabling them to better withstand and recover from cold stress conditions. These findings are consistent with research reported by Abdel and Chaoxing (2011) and Liu *et al*. (2015) in tomato, and Martin and Stutz (2004) in capsicum.

In the current study, the interaction effect of three

Table 1 Vegetative parameters of marigold under different cold mitigation strategies (Pooled data of 2021–22 and 2022–23)

| Factors | Plant height (cm) | Stem diameter (cm) | Number of primary branches | Number of days to first flowering |
|---|---|---|---|---|
| Growing condition | | | | |
| Open, $E_1$ | 66.83 | 0.58 | 9.64 | 77.92 |
| Low plastic tunnel, $E_2$ | 74.43 | 0.66 | 12.05 | 63.79 |
| SEM(±) | 0.11 | 0.00 | 0.02 | 0.11 |
| CD (*P*=0.05) | 0.29 | 0.00 | 0.05 | 0.30 |
| Sowing date | | | | |
| October 15th, $SD_1$ | 71.63 | 0.62 | 10.84 | 73.09 |
| November 1st, $SD_2$ | 70.85 | 0.62 | 10.96 | 72.16 |
| November 15th, $SD_3$ | 69.40 | 0.61 | 10.73 | 67.31 |
| SEM(±) | 0.13 | 0.00 | 0.02 | 0.13 |
| CD (*P*=0.05) | 0.36 | 0.00 | 0.06 | 0.37 |
| Treatment | | | | |
| Control, $T_0$ | 67.21 | 0.59 | 9.35 | 75.64 |
| SA @100 ppm, $T_1$ | 68.88 | 0.59 | 9.61 | 73.50 |
| SA @200 ppm, $T_2$ | 69.51 | 0.60 | 10.23 | 72.34 |
| SA @300 ppm, $T_3$ | 69.38 | 0.61 | 10.81 | 72.51 |
| COS @100 ppm, $T_4$ | 69.31 | 0.60 | 9.73 | 72.58 |
| COS @200 ppm, $T_5$ | 70.36 | 0.62 | 10.87 | 70.05 |
| COS @300 ppm, $T_6$ | 69.83 | 0.61 | 10.30 | 72.02 |
| AM, $T_7$ | 70.83 | 0.62 | 11.10 | 70.51 |
| SA @100 ppm + AM, $T_8$ | 69.99 | 0.63 | 11.17 | 71.32 |
| SA @200 ppm + AM, $T_9$ | 70.99 | 0.63 | 11.48 | 68.91 |
| SA @300 ppm + AM, $T_{10}$ | 73.40 | 0.64 | 12.05 | 67.60 |
| COS @100 ppm + AM, $T_{11}$ | 71.51 | 0.63 | 11.53 | 70.20 |
| COS @200 ppm + AM, $T_{12}$ | 74.49 | 0.64 | 11.98 | 66.71 |
| COS @300 ppm + AM, $T_{13}$ | 73.08 | 0.63 | 11.59 | 68.09 |
| SEM(±) | 0.28 | 0.00 | 0.05 | 0.28 |
| CD (*P*=0.05) | 0.78 | 0.01 | 0.13 | 0.79 |

SA, Salicylic acid; COS, Chitooligosaccharide; AM, Arbuscular mycorrhiza.

Table 2 Flowering and yield parameters of marigold under different cold mitigation strategies (Pooled data of 2021–22 and 2022–23)

| Factors | Flower diameter (cm) | Individual flower weight (g) | Number of flowers/ plant | Yield/plant (g) |
|---|---|---|---|---|
| Growing condition | | | | |
| Open, $E_1$ | 4.60 | 5.64 | 28.84 | 237.49 |
| Low plastic tunnel, $E_2$ | 5.87 | 8.07 | 33.08 | 313.67 |
| SEM (±) | 0.01 | 0.01 | 0.05 | 0.40 |
| CD (*P*=0.05) | 0.02 | 0.03 | 0.14 | 1.11 |
| Sowing Date | | | | |
| October 15th, $SD_1$ | 5.52 | 7.14 | 31.22 | 293.00 |

*Contd.*

Table 2 (*Concluded*)

| Factors | Flower diameter (cm) | Individual flower weight (g) | Number of flowers/ plant | Yield/plant (g) |
|---|---|---|---|---|
| November 1st, $SD_2$ | 5.23 | 6.83 | 31.00 | 274.86 |
| November 15th, $SD_3$ | 4.95 | 6.60 | 30.67 | 258.89 |
| SEM(±) | 0.01 | 0.01 | 0.06 | 0.49 |
| CD (*P*=0.05) | 0.03 | 0.03 | 0.18 | 1.36 |
| Treatment | | | | |
| Control, $T_0$ | 4.45 | 6.18 | 26.74 | 263.47 |
| SA @100 ppm, $T_1$ | 4.63 | 6.36 | 28.13 | 269.77 |
| SA @200 ppm, $T_2$ | 4.80 | 6.43 | 28.79 | 272.41 |
| SA @300 ppm, $T_3$ | 5.03 | 6.59 | 29.91 | 272.36 |
| COS @100 ppm, $T_4$ | 4.77 | 6.30 | 28.41 | 266.85 |
| COS @200 ppm, $T_5$ | 5.23 | 6.74 | 30.04 | 271.07 |
| COS @300 ppm, $T_6$ | 4.93 | 6.57 | 29.58 | 268.02 |
| AM, $T_7$ | 5.39 | 6.88 | 31.01 | 274.48 |
| SA @100 ppm + AM, $T_8$ | 5.49 | 7.03 | 31.44 | 276.15 |
| SA @200 ppm + AM, $T_9$ | 5.63 | 7.24 | 33.58 | 279.52 |
| SA @300 ppm + AM, $T_{10}$ | 5.83 | 7.49 | 34.37 | 286.89 |
| COS @100 ppm + AM, $T_{11}$ | 5.47 | 7.12 | 32.09 | 281.57 |
| COS @200 ppm + AM, $T_{12}$ | 5.99 | 7.64 | 35.45 | 292.42 |
| COS @300 ppm + AM, $T_{13}$ | 5.61 | 7.43 | 33.94 | 283.19 |
| SEM(±) | 0.02 | 0.03 | 0.14 | 1.05 |
| CD (*P*=0.05) | 0.06 | 0.07 | 0.38 | 2.93 |

SA, Salicylic acid; COS, Chitooligosaccharide; AM, Arbuscular mycorrhiza.

sowing dates and fourteen treatments under varied growing conditions was investigated. The findings revealed (Table 3) that the combination of plants sown on November 1st, treated with COS at 200 ppm in conjunction with AM under low plastic tunnel conditions ($E_2$ $SD_2$ $T_{12}$), displayed the greatest plant height (78.78 cm) which was on par with $E_2$ $SD_1$ $T_{12}$, $E_2$ $SD_1$ $T_{13}$, $E_2$ $SD_2$ $T_2$ and $E_2$ $SD_3$ $T_{12}$. Similarly, with respect to number of flowers/plant, the treatment $E_2$ $SD_2$ $T_{12}$ (38.54) recorded highest which was on par with $E_2$ $SD_1$ $T_{12}$. Additionally, the greatest number of primary branches (13.62, 13.57 and 13.31, respectively) was observed in the interaction of plants sown on November 1st, treated with COS @ 200 ppm in conjunction with AM under low plastic tunnel conditions ($E_2$ $SD_2$ $T_{12}$), and with treatments $E_2$ $SD_3$ $T_{12}$; $E_2$ $SD_3$ $T_{10}$. Conversely, the interaction of plants sown on October 15th and treated with COS at 200 ppm in conjunction with AM under low plastic tunnel conditions ($E_2$ $SD_1$ $T_{12}$) recorded the greater values for stem diameter at 0.70 cm, flower diameter at 6.90 cm (which was on par with $E_2$ $SD_2$ $T_{12}$), individual flower weight at 9.12 g (which was on par with $E_2$ $SD_1$ $T_{10}$, $E_2$ $SD_2$ $T_{12}$, $E_2$ $SD_2$ $T_{13}$), and yield per plant at 360.10 g. Furthermore, the interaction of plants sown on November 15th, treated with SA at 300 ppm + AM under low plastic tunnel conditions ($E_2$ $SD_3$ $T_{10}$), exhibited the shortest duration (57.30 days) for first flowering.

Table 3 Interaction effect on vegetative, flowering, and yield parameters of marigold under different cold mitigation strategies (Pooled data of 2021–22 and 2022–23)

| Interactions | PH | SD | PB | DFF | FD | FW | FPP | YP |
|---|---|---|---|---|---|---|---|---|
| $E_1$ $SD_1$ $T_0$ | 65.57 | 0.57 | 7.91 | 83.73 | 4.08 | 5.52 | 26.58 | 236.86 |
| $E_1$ $SD_1$ $T_1$ | 68.06 | 0.57 | 8.22 | 81.27 | 4.15 | 5.69 | 26.71 | 247.23 |
| $E_1$ $SD_1$ $T_2$ | 67.54 | 0.58 | 9.02 | 82.97 | 4.56 | 5.72 | 27.20 | 248.75 |
| $E_1$ $SD_1$ $T_3$ | 65.17 | 0.58 | 9.95 | 83.75 | 4.75 | 5.92 | 28.34 | 244.85 |
| $E_1$ $SD_1$ $T_4$ | 67.95 | 0.58 | 8.73 | 80.30 | 4.35 | 5.64 | 25.48 | 240.83 |
| $E_1$ $SD_1$ $T_5$ | 68.56 | 0.60 | 9.69 | 80.53 | 5.00 | 6.02 | 28.34 | 244.15 |

*Contd.*

Table 3 (*Contd.*)

| Interactions | PH | SD | PB | DFF | FD | FW | FPP | YP |
|---|---|---|---|---|---|---|---|---|
| $E_1$ $SD_1$ $T_6$ | 66.92 | 0.58 | 9.04 | 82.20 | 4.65 | 5.68 | 29.39 | 248.55 |
| $E_1$ $SD_1$ $T_7$ | 68.24 | 0.59 | 9.87 | 80.61 | 5.22 | 6.15 | 29.96 | 255.33 |
| $E_1$ $SD_1$ $T_8$ | 68.33 | 0.59 | 10.13 | 84.51 | 5.53 | 6.22 | 31.07 | 253.19 |
| $E_1$ $SD_1$ $T_9$ | 68.65 | 0.59 | 10.40 | 80.49 | 5.48 | 6.63 | 32.91 | 252.77 |
| $E_1$ $SD_1$ $T_{10}$ | 72.34 | 0.62 | 10.81 | 75.98 | 5.79 | 6.76 | 33.82 | 256.96 |
| $E_1$ $SD_1$ $T_{11}$ | 69.31 | 0.60 | 10.63 | 78.58 | 5.35 | 6.60 | 32.11 | 244.36 |
| $E_1$ $SD_1$ $T_{12}$ | 72.94 | 0.61 | 10.90 | 76.49 | 6.03 | 6.74 | 34.97 | 266.97 |
| $E_1$ $SD_1$ $T_{13}$ | 71.30 | 0.62 | 10.39 | 76.69 | 5.61 | 6.61 | 34.39 | 255.18 |
| $E_1$ $SD_2$ $T_0$ | 63.14 | 0.58 | 7.85 | 84.90 | 4.04 | 5.15 | 24.52 | 216.59 |
| $E_1$ $SD_2$ $T_1$ | 63.25 | 0.56 | 8.14 | 84.41 | 4.18 | 5.32 | 25.39 | 226.47 |
| $E_1$ $SD_2$ $T_2$ | 62.78 | 0.57 | 9.18 | 84.59 | 4.23 | 5.32 | 25.29 | 221.38 |
| $E_1$ $SD_2$ $T_3$ | 66.10 | 0.58 | 9.82 | 80.26 | 4.37 | 5.58 | 26.03 | 227.75 |
| $E_1$ $SD_2$ $T_4$ | 62.91 | 0.58 | 8.21 | 83.77 | 4.26 | 5.28 | 26.42 | 214.56 |
| $E_1$ $SD_2$ $T_5$ | 67.11 | 0.61 | 10.33 | 78.61 | 4.39 | 5.48 | 28.02 | 227.36 |
| $E_1$ $SD_2$ $T_6$ | 66.27 | 0.57 | 9.32 | 79.54 | 4.46 | 5.40 | 26.02 | 215.60 |
| $E_1$ $SD_2$ $T_7$ | 67.63 | 0.60 | 10.16 | 79.44 | 4.72 | 5.50 | 29.01 | 230.83 |
| $E_1$ $SD_2$ $T_8$ | 68.71 | 0.59 | 10.65 | 80.38 | 4.61 | 5.52 | 29.20 | 232.89 |
| $E_1$ $SD_2$ $T_9$ | 67.62 | 0.59 | 10.26 | 76.66 | 4.79 | 5.58 | 31.86 | 226.67 |
| $E_1$ $SD_2$ $T_{10}$ | 71.57 | 0.60 | 11.13 | 74.49 | 4.95 | 5.78 | 33.31 | 244.59 |
| $E_1$ $SD_2$ $T_{11}$ | 67.28 | 0.58 | 10.80 | 81.14 | 4.70 | 5.50 | 29.65 | 242.04 |
| $E_1$ $SD_2$ $T_{12}$ | 71.65 | 0.59 | 10.57 | 76.59 | 4.86 | 6.21 | 33.43 | 256.51 |
| $E_1$ $SD_2$ $T_{13}$ | 71.15 | 0.61 | 10.94 | 75.92 | 4.73 | 5.86 | 33.04 | 243.68 |
| $E_1$ $SD_3$ $T_0$ | 61.02 | 0.54 | 8.35 | 80.73 | 3.50 | 4.76 | 25.18 | 222.94 |
| $E_1$ $SD_3$ $T_1$ | 63.53 | 0.56 | 8.45 | 77.53 | 3.62 | 4.66 | 25.74 | 227.03 |
| $E_1$ $SD_3$ $T_2$ | 62.39 | 0.57 | 8.70 | 72.41 | 3.90 | 4.94 | 28.10 | 225.04 |
| $E_1$ $SD_3$ $T_3$ | 62.14 | 0.55 | 9.03 | 76.45 | 4.07 | 5.14 | 27.44 | 233.37 |
| $E_1$ $SD_3$ $T_4$ | 62.53 | 0.59 | 8.40 | 77.20 | 3.70 | 4.63 | 26.84 | 228.58 |
| $E_1$ $SD_3$ $T_5$ | 62.33 | 0.54 | 9.15 | 70.25 | 4.24 | 5.08 | 27.14 | 226.90 |
| $E_1$ $SD_3$ $T_6$ | 64.58 | 0.57 | 8.99 | 74.71 | 4.07 | 5.17 | 27.16 | 219.15 |
| $E_1$ $SD_3$ $T_7$ | 65.60 | 0.55 | 9.44 | 71.58 | 4.48 | 5.34 | 27.36 | 234.69 |
| $E_1$ $SD_3$ $T_8$ | 66.37 | 0.56 | 9.43 | 73.02 | 4.52 | 5.39 | 28.32 | 234.86 |
| $E_1$ $SD_3$ $T_9$ | 65.73 | 0.57 | 10.39 | 70.33 | 4.54 | 5.54 | 29.23 | 237.62 |
| $E_1$ $SD_3$ $T_{10}$ | 67.93 | 0.58 | 10.93 | 71.29 | 4.66 | 5.78 | 29.22 | 242.77 |
| $E_1$ $SD_3$ $T_{11}$ | 67.72 | 0.57 | 9.73 | 71.97 | 4.51 | 5.66 | 27.14 | 242.31 |
| $E_1$ $SD_3$ $T_{12}$ | 69.18 | 0.58 | 10.48 | 65.31 | 4.74 | 5.86 | 30.55 | 239.81 |
| $E_1$ $SD_3$ $T_{13}$ | 67.62 | 0.56 | 10.17 | 71.00 | 4.63 | 5.60 | 29.39 | 236.79 |
| $E_2$ $SD_1$ $T_0$ | 71.89 | 0.60 | 10.33 | 69.24 | 5.14 | 7.03 | 28.34 | 320.92 |
| $E_2$ $SD_1$ $T_1$ | 73.68 | 0.60 | 11.30 | 67.33 | 5.38 | 7.48 | 30.37 | 326.41 |
| $E_2$ $SD_1$ $T_2$ | 72.08 | 0.63 | 11.95 | 67.90 | 5.55 | 7.61 | 29.93 | 327.49 |
| $E_2$ $SD_1$ $T_3$ | 75.00 | 0.64 | 11.94 | 68.45 | 5.77 | 7.76 | 31.48 | 326.91 |
| $E_2$ $SD_1$ $T_4$ | 71.59 | 0.65 | 10.92 | 65.59 | 5.58 | 7.28 | 30.55 | 324.97 |
| $E_2$ $SD_1$ $T_5$ | 75.72 | 0.65 | 12.09 | 64.63 | 5.90 | 8.32 | 30.81 | 334.94 |
| $E_2$ $SD_1$ $T_6$ | 75.83 | 0.63 | 11.79 | 65.19 | 5.58 | 7.66 | 30.38 | 326.91 |
| $E_2$ $SD_1$ $T_7$ | 74.14 | 0.65 | 12.09 | 65.30 | 6.10 | 8.45 | 31.83 | 334.36 |
| $E_2$ $SD_1$ $T_8$ | 72.56 | 0.67 | 12.11 | 65.83 | 6.27 | 8.45 | 32.47 | 340.64 |

*Contd.*

Table 3 (*Concluded*)

| Interactions | PH | SD | PB | DFF | FD | FW | FPP | YP |
|---|---|---|---|---|---|---|---|---|
| $E_2$ $SD_1$ $T_9$ | 75.82 | 0.68 | 12.52 | 63.74 | 6.48 | 8.58 | 34.67 | 345.57 |
| $E_2$ $SD_1$ $T_{10}$ | 76.55 | 0.67 | 12.97 | 63.91 | 6.75 | 9.08 | 36.98 | 348.65 |
| $E_2$ $SD_1$ $T_{11}$ | 75.34 | 0.68 | 12.67 | 65.61 | 6.31 | 8.37 | 33.02 | 347.45 |
| $E_2$ $SD_1$ $T_{12}$ | 77.34 | 0.70 | 12.73 | 62.50 | 6.90 | 9.12 | 37.65 | 360.10 |
| $E_2$ $SD_1$ $T_{13}$ | 77.12 | 0.67 | 12.47 | 63.15 | 6.34 | 8.88 | 34.36 | 342.69 |
| $E_2$ $SD_2$ $T_0$ | 71.65 | 0.60 | 10.76 | 68.37 | 5.09 | 7.28 | 27.46 | 304.39 |
| $E_2$ $SD_2$ $T_1$ | 72.59 | 0.64 | 10.44 | 66.34 | 5.22 | 7.48 | 29.16 | 305.63 |
| $E_2$ $SD_2$ $T_2$ | 77.63 | 0.63 | 10.95 | 65.40 | 5.54 | 7.62 | 31.52 | 313.27 |
| $E_2$ $SD_2$ $T_3$ | 74.90 | 0.68 | 11.99 | 64.48 | 5.80 | 7.76 | 32.79 | 317.73 |
| $E_2$ $SD_2$ $T_4$ | 74.87 | 0.62 | 10.95 | 66.71 | 5.32 | 7.52 | 30.89 | 314.39 |
| $E_2$ $SD_2$ $T_5$ | 75.19 | 0.67 | 12.02 | 63.42 | 5.92 | 8.08 | 31.51 | 309.83 |
| $E_2$ $SD_2$ $T_6$ | 74.71 | 0.65 | 11.42 | 66.76 | 5.52 | 7.83 | 33.18 | 317.88 |
| $E_2$ $SD_2$ $T_7$ | 75.12 | 0.68 | 12.79 | 63.03 | 6.05 | 7.84 | 33.32 | 305.13 |
| $E_2$ $SD_2$ $T_8$ | 72.23 | 0.68 | 12.58 | 65.02 | 6.23 | 8.42 | 33.77 | 316.39 |
| $E_2$ $SD_2$ $T_9$ | 73.52 | 0.69 | 12.81 | 61.32 | 6.38 | 8.60 | 35.96 | 327.31 |
| $E_2$ $SD_2$ $T_{10}$ | 76.29 | 0.69 | 13.13 | 62.60 | 6.65 | 8.82 | 36.53 | 340.75 |
| $E_2$ $SD_2$ $T_{11}$ | 74.02 | 0.68 | 13.14 | 64.14 | 6.01 | 8.37 | 35.65 | 320.73 |
| $E_2$ $SD_2$ $T_{12}$ | 78.78 | 0.69 | 13.57 | 59.79 | 6.89 | 9.04 | 38.54 | 343.00 |
| $E_2$ $SD_2$ $T_{13}$ | 75.17 | 0.68 | 12.99 | 62.51 | 6.42 | 9.05 | 36.41 | 332.67 |
| $E_2$ $SD_3$ $T_0$ | 70.01 | 0.62 | 10.91 | 66.85 | 4.84 | 7.33 | 28.35 | 279.13 |
| $E_2$ $SD_3$ $T_1$ | 72.18 | 0.63 | 11.12 | 64.09 | 5.21 | 7.49 | 31.38 | 285.83 |
| $E_2$ $SD_3$ $T_2$ | 74.63 | 0.63 | 11.55 | 60.79 | 5.04 | 7.35 | 30.70 | 298.54 |
| $E_2$ $SD_3$ $T_3$ | 72.95 | 0.63 | 12.12 | 61.69 | 5.41 | 7.36 | 33.38 | 283.54 |
| $E_2$ $SD_3$ $T_4$ | 76.02 | 0.59 | 11.21 | 61.90 | 5.40 | 7.47 | 30.28 | 277.79 |
| $E_2$ $SD_3$ $T_5$ | 73.26 | 0.67 | 11.94 | 62.88 | 5.89 | 7.47 | 34.41 | 283.23 |
| $E_2$ $SD_3$ $T_6$ | 70.70 | 0.65 | 11.21 | 63.72 | 5.29 | 7.70 | 31.34 | 280.02 |
| $E_2$ $SD_3$ $T_7$ | 74.26 | 0.67 | 12.28 | 63.07 | 5.78 | 7.98 | 34.60 | 286.55 |
| $E_2$ $SD_3$ $T_8$ | 71.76 | 0.67 | 12.13 | 59.15 | 5.77 | 8.19 | 33.83 | 278.93 |
| $E_2$ $SD_3$ $T_9$ | 74.58 | 0.64 | 12.49 | 60.92 | 6.09 | 8.50 | 36.83 | 287.15 |
| $E_2$ $SD_3$ $T_{10}$ | 75.72 | 0.69 | 13.31 | 57.30 | 6.17 | 8.73 | 36.35 | 287.61 |
| $E_2$ $SD_3$ $T_{11}$ | 75.37 | 0.69 | 12.19 | 59.76 | 5.95 | 8.19 | 35.00 | 292.51 |
| $E_2$ $SD_3$ $T_{12}$ | 77.02 | 0.68 | 13.62 | 59.56 | 6.54 | 8.89 | 37.53 | 288.14 |
| $E_2$ $SD_3$ $T_{13}$ | 76.15 | 0.67 | 12.58 | 59.27 | 5.93 | 8.58 | 36.03 | 288.12 |
| SEM± | 0.68 | 0.01 | 0.11 | 0.70 | 0.05 | 0.06 | 0.34 | 2.57 |
| CD ($P$=0.05) | 1.90 | 0.02 | 0.31 | 1.94 | 0.14 | 0.17 | 0.94 | 7.19 |

$E_1$, Open field; $E_2$, Protected condition; $SD_1$, October $15^{th}$; $SD_2$, November $1^{st}$; $SD_3$, November $15^{th}$; $T_0$, Control; $T_1$, Salicylic acid (SA) @100 ppm; $T_2$, SA @200 ppm; $T_3$, SA @300 ppm; $T_4$, Chitooligosaccharide (COS) @100 ppm; $T_5$, COS @200 ppm; $T_6$, COS @300 ppm; $T_7$, Arbuscular mycorrhiza (AM) alone; $T_8$, SA @100 ppm + AM; $T_9$, SA @200 ppm + AM; $T_{10}$, SA @300 ppm + AM; $T_{11}$, COS @100 ppm + AM; $T_{12}$, COS @200 ppm + AM and $T_{13}$, COS @300 ppm + AM; PH, Plant height (cm); D, Stem diameter (cm); PB, Primary branches; DFF, Number of days to first flowering (days); FD, Flower diameter (cm); FW, Individual flower weight (g); FPP, Flowers/plant; YP, Yield/plant (g).

Significant influence of growing conditions, sowing dates and other treatments were observed in growth, flowering, and yield characteristics of marigold variety Pusa Narangi Gainda. Results indicated that plants sown on October $15^{th}$ and cultivated within low plastic tunnels and treated with AM @10 g/plant and three times sprayed with COS @200 ppm displayed better growth and yield. Additionally, the use of low plastic tunnels to alleviate cold stress yielded positive results across various sowing dates and treatments, surpassing open field conditions. This study underscores the potential benefits of low plastic tunnels as a mitigation strategy against cold stress impacts in marigold.

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