



## EFFECT OF SALINITY STRESS ON MORPHOLOGICAL TRAITS AND FLORAL PERFORMANCE OF AFRICAN MARIGOLD (*TAGETES ERECTA* L.)

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### ABSTRACT

The present investigation was conducted to assess the effects of salinity stress on morphological traits and floral parameters of African marigold (*Tagetes erecta* L.) cultivars under pot conditions. The three cultivars were selected i.e Pusa Narangi, Pusa Bahar, and Double Orange. And the plants were treated with NaCl at seven different salinity levels. (0, 2, 4, 6, 8, 10 and 12 dS m<sup>-1</sup>) in a factorial completely randomized design. Increasing in salinity level significantly reduced the plant height, plant spread, number of leaves, primary branches, fresh flower weight and flower yield per plant, while it delayed flower bud initiation and first flowering was also recorded. Severe in reduction in growth was also identified beyond 6 dS m<sup>-1</sup> and the complete growth inhibition was occurred at 12 dS m<sup>-1</sup>. Among the three cultivars of African marigold the Pusa Narangi consistently exhibited superior performance and greater tolerance to salinity level, followed by Pusa Bahar, whereas the Double Orange was most sensitive to salinity stress. These results highlight the genotypic variation in salinity tolerance and also identified that Pusa Narangi is a suitable cultivar for cultivation under moderate saline conditions.

**Key words:** African marigold, NaCl, salinity stress, vegetative and floral traits and flower yield.

### Introduction

Flowers play a vital role in enhancing human well-being by fostering feelings of peace, pleasure, and harmony, alleviating stress and improving emotional health. Among ornamental plants marigold (*Tagetes* spp.) holds a prominent position in floriculture due to its wide adaptability, vibrant floral display and extended blooming period. Commonly known as *Gainda* and belongs to the family Asteraceae and native to Central and South America, particularly Mexico (Kumar *et al.*, 2016).

The genus *Tagetes* is of considerable aesthetic and economic importance widely utilized in marriages, religious rituals, garland making and for floral exhibitions. Marigold is predominantly cultivated as a loose flower and for the extraction of valuable pigments used in poultry feed and

other commercial applications. Among these, lutein-an oxycarotenoid xanthophyll pigment which is the principal bioactive compound in *Tagetes* species and has significant nutraceutical value (Kar and Patra, 2022). Like other crops, marigold is continuously exposed to environmental stresses throughout its growth cycle which adversely affect plant growth and development, productivity and flower quality (Bohnert *et al.*, 1995).

Among different abiotic stresses such as drought, flooding, soil salinity, sodicity and temperature etc. In which the soil salinity and high temperature are major constraints which affect the crop performance. The soil salinization is increasing rapidly and currently affecting the agricultural lands of more than 100 countries (Hammam and Mohamed, 2020). Globally, over 900

million hectares are salt-affected area (Rengasamy, 2006) with recent estimates suggesting this figure has exceeded one billion hectares (Hopmans *et al.*, 2021 and Tian *et al.*, 2020). Approximately 20% of irrigated land worldwide is affected by salinity and nearly 60% of these soils are sodic (Negacz *et al.*, 2022).

The highest proportions of salinized land are found in India, the United States, Sudan, Pakistan and Turkey (Seifi *et al.*, 2020). The saline soils are characterized by electrical conductivity of the saturation extract (EC<sub>e</sub>)  $\geq$  4 dS m<sup>-1</sup>, pH below 8.5 and exchangeable sodium percentage (ESP) is less than 15. Soil salinity reflects the concentration of soluble salts such as Na<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Cl<sup>-</sup>, and SO<sub>4</sub><sup>2-</sup> and it is most commonly quantified throughout the electrical conductivity measurements (Zaman *et al.*, 2018).

The salinity imposes severe environmental and agricultural consequences, including it reduces the crop yields, loss of biodiversity, ecosystem degradation, soil erosion and land abandonment (Shahid, 2013). For enhancing productivity under saline conditions, it requires the adoption of salt-tolerant crops along with appropriate agronomic and soil management strategies such as marigold.

In India, marigold is an economically important floricultural crop cultivated over 0.26 million hectares and producing nearly 1.93 million tonnes of loose flowers. The Tamil Nadu alone accounts about 0.028 million hectares under marigold cultivation (Prabhakaran, 2025). The two major cultivated species of marigold are African marigold (*Tagetes erecta*) and French marigold (*Tagetes patula*). The *T. erecta* being preferred for large-scale cultivation due to its superior adaptability and stress tolerance activity. Because the *Tagetes erecta* possesses a robust root system that contributes significantly to its tolerance against adverse soil conditions which make it suitable for phytoremediation, biomass production and soil restoration (Farooq *et al.*, 2020; Biswal *et al.*, 2022; Khilji *et al.*, 2024). The marigold cultivation enhances soil moisture retention, enzymatic activity, and nitrogen availability, while intercropping with marigold improves soil physicochemical properties, metabolomic profiles and microbial diversity (Xue *et al.*, 2023). It has been observed that African marigold exhibits an efficient sodium exclusion mechanism that restricts Na<sup>+</sup> uptake and reduces ionic toxicity under saline stress. Although salinity may suppress growth and yield, it can simultaneously induce antioxidant synthesis, thereby enhancing the nutritional and functional value of marigold plants (Guzmán and Marques, 2023).

## Materials and Methods

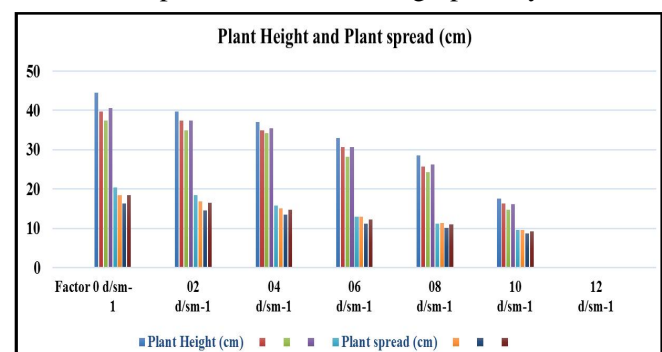
The present investigation entitled “Effect of salinity on morpho-physiological and biochemical characters of African marigold (*Tagetes erecta* L.) cultivars” was conducted during the academic year 2023–2024 at the Floriculture Nursery, Department of Floriculture and Landscape Architecture, College of Horticulture, Banda University of Agriculture and Technology (BUAT), Banda, Uttar Pradesh, India. The experimental site lies in the semi-arid agro-climatic zone of Bundelkhand at an altitude of approximately 128 m above mean sea level. The climate of the region is semi-arid, characterized by hot summers, a distinct monsoon season, and moderate winters. The average annual rainfall ranges between 800 and 900 mm, received mainly during the monsoon period from mid-June to September. Summer temperatures may reach up to 52°C, while winter temperatures may fall to around 8°C.

The experiment was laid out using a Factorial Completely Randomized Design (FCRD) to identify the response of African marigold to salinity stress condition. The three cultivars of African marigold (Pusa Narangi, Pusa Bahar, and Double Orange) were used as genotypes. And the salinity stress was imposed through NaCl concentration of seven levels viz., 0, 2, 4, 6, 8, 10, and 12 dS m<sup>-1</sup> and the factorial combination of these factors resulted in a total of 21 treatment combinations, each was replicated four times. Each replication consisted of one plant per pot, making a total of 84 pots for the entire experiment.

## Results and Discussion

### Plant height (cm)

The data pertaining to plant height of marigold at full blooming in the years 2023–24 was significantly affected by salinity levels, varieties and their interaction. It has been observed that mean plant height decreased progressively with increasing salinity levels across all varieties are presented Table 1 and graphically illustrated



**Fig. 1:** Effect of salt stress on plant height (cm) & plant spread (cm).

**Table 1:** Effect of different concentration of NaCl on Plant Height (cm) & Plant spread (cm).

Factor	Plant Height (cm)				Plant spread (cm)			
	Pusa Narangi	Pusa Bahar	Double Orange	Mean A	Pusa Narangi	Pusa Bahar	Double Orange	Mean A
0 d/sm <sup>-1</sup> (Control)	44.5	39.75	37.5	40.58	20.375	18.5	16.25	18.375
02 d/sm <sup>-1</sup>	39.75	37.5	35	37.41	18.375	16.875	14.5	16.583
04 d/sm <sup>-1</sup>	37	35	34.25	35.41	15.75	15.05	13.55	14.783
06 d/sm <sup>-1</sup>	33	30.75	28.25	30.67	12.875	12.875	11.125	12.292
08 d/sm <sup>-1</sup>	28.5	25.75	24.25	26.17	11.25	11.375	10.125	10.917
10 d/sm <sup>-1</sup>	17.5	16.25	14.75	16.17	9.625	9.5	8.625	9.25
12 d/sm <sup>-1</sup>	0	0	0	0	0	0	0	0
Mean B	28.607	26.429	24.857		12.607	12.025	10.596	
	C.D.	SE(d)	SE(m)		C.D.	SE(d)	SE(m)	
Factor (A)	1.209	0.604	0.427		0.739	0.369	0.261	
Factor (B)	0.792	0.395	0.279		0.484	0.242	0.171	
Factor(A × B)	2.094	1.046	0.739		1.28	0.639	0.452	

in Fig. 1. Analysis of the data reveals that the maximum mean plant height (40.58 cm) was recorded under control conditions (0 dS m<sup>-1</sup>) which declined gradually at 2 and 4 dS m<sup>-1</sup> and sharply beyond 6 dS m<sup>-1</sup>. At 10 dS m<sup>-1</sup> mean plant height was reduced to 16.17 cm while at 12 dS m<sup>-1</sup> complete inhibition of plant growth was observed. The effect of salinity levels on plant height was statistically significant as the differences exceeded the critical difference value (CD<sub>0.05</sub> = 1.209). Among the different varieties, it has been observed that Pusa Narangi has significantly higher mean plant height (28.61 cm) followed by Pusa Bahar (26.43 cm) and Double Orange (24.86 cm). The varietal effect (Factor B) was significant (CD<sub>0.05</sub> = 0.792) indicating inherent differences in salinity tolerance and growth potential among the different varieties. Also, the interaction between salinity levels and varieties (Factor A × B) has also found significant (CD<sub>0.05</sub> = 2.094). The variety Pusa Narangi maintained comparatively higher plant height at all salinity levels whereas the Double Orange exhibited a sharper reduction in plant height with increasing salinity stress particularly beyond 6 dS m<sup>-1</sup>.

Plant growth is restricted by inhibiting photosynthesis mechanisms, taking excessive salt ions and producing metabolites Yasemin *et al.*, (2017). The relative growth rates decreases as increase in salinity level. Moreover, Cassaniti *et al.*, (2012). Similar results were also reported by Rodrigues *et al.*, (2019).

#### Plant spread (cm)

The data pertaining to plant spread of marigold at full blooming in the years 2023–24 was significantly affected by salinity levels, varieties and their interaction. It has been observed that mean plant spread decreased progressively with increasing salinity levels across all varieties are presented Table 1 and graphically illustrated

in Fig. 1. Analysis of the data reveals that the maximum mean plant spread (18.37 cm) was recorded under control conditions (0 dS m<sup>-1</sup>) which declined gradually at 2 and 4 dS m<sup>-1</sup> and sharply beyond 6 dS m<sup>-1</sup>. At 10 dS m<sup>-1</sup> mean plant spread was reduced to 9.25 cm while at 12 dS m<sup>-1</sup> complete inhibition of plant growth was observed. The effect of salinity levels on plant spread was statistically significant as the differences exceeded the critical difference value (CD<sub>0.05</sub> = 0.739). Among the different varieties, it has been observed that Pusa Narangi has significantly higher mean plant spread (12.60cm) followed by Pusa Bahar (12.02 cm) and Double Orange (10.59 cm). The varietal effect (Factor B) was significant (CD<sub>0.05</sub> = 0.484) indicating inherent differences in salinity tolerance and growth potential among the different varieties. Also, the interaction between salinity levels and varieties (Factor A × B) has also found significant (CD<sub>0.05</sub> = 1.28). The variety Pusa Narangi maintained comparatively higher plant spread at all salinity levels whereas the Double Orange exhibited a sharper reduction in plant spread with increasing salinity stress particularly beyond 6 dS m<sup>-1</sup>.

Salinity significantly reduced plant spread, their size in all cultivars studied likely due to the stress triggered by salinity (García and Lao, 2012). This oxidative, osmotic, and toxic stress affects the direction of cell division, the formation of phragmoplasts, and the structural organization of cells, often leading to significant damage in the cytoskeleton (Baranova *et al.*, 2021 and Zagoskina *et al.*, 2023). Consequently, these processes may lead to the death of cells and/or changes in plant morphology and growth (Baranova *et al.*, 2021 and Bano *et al.*, 2019) as reported here.

#### Number of leaf

The number of leaves per plant of marigold at full

**Table 2:** Effect of different concentration of NaCl on primary branches per plant & Number of leaves.

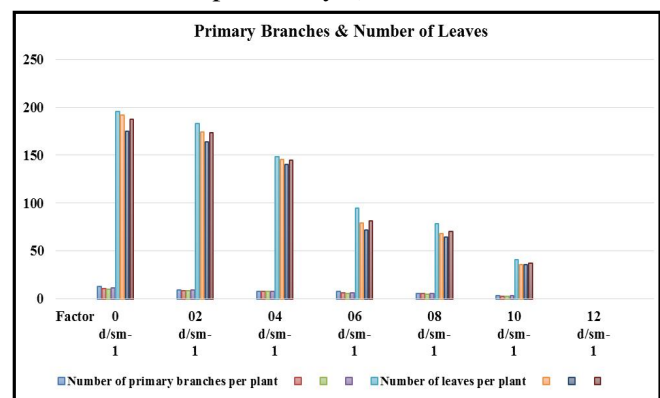
Factor	Number of primary branches per plant				Number of leaves per plant			
	Pusa Narangi	Pusa Bahar	Double Orange	Mean A	Pusa Narangi	Pusa Bahar	Double Orange	Mean A
0 d/sm <sup>-1</sup> (Control)	13	11	10	11.33	195.75	192.25	174.75	187.583
02 d/sm <sup>-1</sup>	9.5	9	8.75	9.08	183	174.25	164.25	173.833
04 d/sm <sup>-1</sup>	8.25	8.25	7.75	8.08	148.5	146	140.25	144.917
06 d/sm <sup>-1</sup>	7.75	6.25	5.75	6.58	94.5	79.25	71.75	81.833
08 d/sm <sup>-1</sup>	6	5.75	4.75	5.5	78.5	68	64.75	70.417
10 d/sm <sup>-1</sup>	3.5	3	3	3.167	41.25	35.75	35.75	37.583
12 d/sm <sup>-1</sup>	0	0	0	0	0	0	0	0
Mean B	6.86	6.18	5.71		105.92	99.36	93.07	
	C.D.	SE(d)	SE(m)		C.D.	SE(d)	SE(m)	
Factor (A)	0.641	0.32	0.226		5.69	2.841	2.009	
Factor (B)	0.42	0.21	0.148		3.725	1.86	1.315	
Factor(A × B)	1.111	0.555	0.392		9.855	4.92	3.479	

bloom during 2023–24 was significantly influenced by salinity levels, varieties and their interaction. The mean number of leaves per plant decreased progressively with increasing salinity across all varieties are presented Table 02 and graphically illustrated in Fig. 02. The highest mean value (187.58) was recorded under control conditions (0 dS m<sup>-1</sup>) which declined gradually at lower salinity levels and sharply beyond 6 dS m<sup>-1</sup>. A severe reduction was observed at 10 dS m<sup>-1</sup> (37.58) while complete growth inhibition occurred at 12 dS m<sup>-1</sup>. The effect of salinity levels was statistically significant ( $CD_{0.05} = 5.69$ ). Among the varieties Pusa Narangi recorded a significantly higher mean number of leaves per plant (105.92) followed by Pusa Bahar (99.35) and Double Orange (93.07). The varietal effect was significant ( $CD_{0.05} = 3.72$ ). The interaction between salinity levels and varieties was also significant ( $CD_{0.05} = 9.85$ ) indicating differential varietal responses to salinity stress with Pusa Narangi showing greater tolerance and Double Orange exhibiting a sharper decline particularly beyond 6 dS m<sup>-1</sup>. The salt stress environment also induced decrease vegetative part of the plants. This response may be attributed to the adverse effects of salinity on enzymatic activities in plants, which consequently disrupt normal metabolic processes. In addition, the high osmotic pressure induced by salt stress restricts the ability of plant cells to effectively absorb water and essential mineral nutrients (Cicek and Cakirlar, 2002). Similarly, Kaouther *et al.*, (2012) reported a significant reduction in fresh biomass with increasing salinity levels.

### Primary branches

The data pertaining to number of primary branches per plant of marigold at full bloom during 2023–24 was significantly influenced by salinity levels, varieties and their interaction. The mean Number of primary branches

per plant decreased progressively with increasing salinity across all varieties are presented table 02 and graphically illustrated in Fig. 2. The highest mean value (11.33) was recorded under control conditions (0 dS m<sup>-1</sup>) which declined gradually at lower salinity levels and sharply beyond 6 dS m<sup>-1</sup>. A severe reduction was observed at 10 dS m<sup>-1</sup> (3.16) while complete growth inhibition occurred at 12 dS m<sup>-1</sup>. The effect of salinity levels was statistically significant ( $CD_{0.05} = 0.641$ ). Among the varieties Pusa Narangi recorded a significantly higher mean Number of primary branches per plant (6.85) followed by Pusa Bahar (6.17) and Double Orange (5.71). The varietal effect was significant ( $CD_{0.05} = 0.42$ ). The interaction between salinity levels and varieties was also significant ( $CD_{0.05} = 1.11$ ) indicating differential varietal responses to salinity stress with Pusa Narangi showing greater tolerance and Double Orange exhibiting a sharper decline particularly beyond 6 dS m<sup>-1</sup>. The obtained data showed that all salt treatments caused a significant reduction in all vegetative parameters. The high salt concentration produced the highest reduction of number of primary branches. Similar studies were reported by (Nofal *et al.*, 2015 and

**Fig. 2:** Effect of salt stress on primary branches per plant & Number of leaves.

**Table 3:** Effect of different concentration of NaCl on first flower bud initiation plant & first flowering.

Factor	Days to first flower but initiation				Days to first flowering			
	Pusa Narangi	Pusa Bahar	Double Orange	Mean A	Pusa Narangi	Pusa Bahar	Double Orange	Mean A
0 d/sm <sup>-1</sup> (Control)	37.5	38.75	39.25	38.5	44.5	46.75	47.5	46.25
02 d/sm <sup>-1</sup>	38.25	39.5	40.5	39.41	46.25	47.5	48.5	47.417
04 d/sm <sup>-1</sup>	39.75	41	42.25	41	48	49	50.25	49.083
06 d/sm <sup>-1</sup>	41.25	42.75	43.5	42.5	49.25	51	52.5	50.917
08 d/sm <sup>-1</sup>	42.25	42.75	44.75	43.25	51.75	52.75	54.75	53.083
10 d/sm <sup>-1</sup>	45.5	47.5	48.75	47.25	55.75	57.75	59.25	57.583
12 d/sm <sup>-1</sup>	0	0	0	0	0	0	0	0
Mean B	34.92	36.036	37		42.214	43.536	44.679	
	C.D.	SE(d)	SE(m)		C.D.	SE(d)	SE(m)	
Factor (A)	0.44	0.22	0.155		0.419	0.209	0.148	
Factor (B)	0.288	0.144	0.102		0.274	0.137	0.097	
Factor(A × B)	0.762	0.381	0.269		0.725	0.362	0.256	

Kozminska *et al.*, 2017) found the reduction in the vegetative growth of plants as a result of the high salt application. The inhibitory effect on plant growth might be caused by morphological and physiological effects (Kozminska *et al.*, 2017). The increasing of soil salinity decreased plant growth because of the effect of salt on plant roots (Lambers *et al.*, 2008).

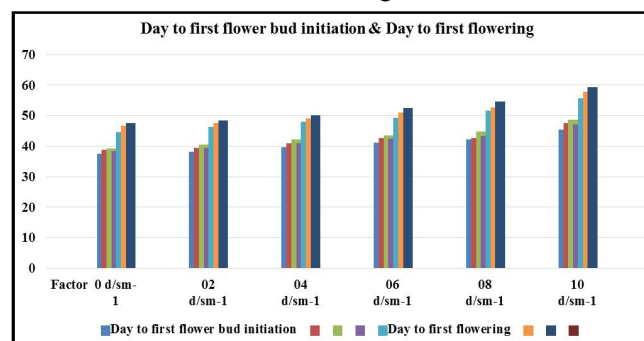
#### Day to first flower bud initiation

The data pertaining to day to first flower bud initiation of marigold at full blooming in the years 2023–24 was significantly affected by salinity levels, varieties and their interaction. It has been observed that mean plant height decreased progressively with increasing salinity levels across all varieties are presented Table 3 and graphically illustrated in Fig. 3. Analysis of the data reveals that the minimum mean day to flower bud initiation (38.5) was recorded under control conditions (0 dS m<sup>-1</sup>) which declined gradually at 2 and 4 dS m<sup>-1</sup> and sharply beyond 6 dS m<sup>-1</sup>. At 10 dS m<sup>-1</sup> maximum mean day to flower bud initiation was increased to 47.25 days while at 12 dS m<sup>-1</sup> complete inhibition of plant growth was observed. The effect of salinity levels on first flower bud initiation was statistically significant as the differences exceeded the critical difference value (CD<sub>0.05</sub> = 0.44). Among the different varieties, it has been observed that Pusa Narangi has significantly minimum mean flower bud initiation (34.92 days) followed by Pusa Bahar (36.03 days) and Double Orange (37). The varietal effect (Factor B) was significant (CD<sub>0.05</sub> = 0.288) indicating inherent differences in salinity tolerance and growth potential among the different varieties. Also, the interaction between salinity levels and varieties (Factor A × B) has also found significant (CD<sub>0.05</sub> = 0.762). The variety Pusa Narangi maintained comparatively day to flower bud initiation at all salinity levels whereas the Double Orange exhibited a

sharper increased in day to flower bud initiation with increasing salinity stress particularly beyond 6 dS m<sup>-1</sup>. Similar inhibitory effects of high salinity on flowering Salinity stress has a profound negative impact on bud initiation, development and subsequent reproductive growth in plants primarily through osmotic stress, ionic toxicity (Na<sup>+</sup> and Cl<sup>-</sup> accumulation) and oxidative stress have been reported in ornamental crops by Munns and Tester (2008) and Taiz *et al.*, (2015).

#### Day to first flowering

During 2023–24, days to first flowering in marigold were significantly influenced by salinity levels, varieties and their interaction. Increasing salinity caused a progressive delay in flowering across all varieties are presented Table 3 and graphically illustrated in Fig. 4. The earliest flowering (46.25 days) occurred under control conditions (0 dS m<sup>-1</sup>) followed by a gradual delay at 2–4 dS m<sup>-1</sup> and a sharp increase beyond 6 dS m<sup>-1</sup>. Flowering was delayed to 57.58 days at 10 dS m<sup>-1</sup> while complete inhibition occurred at 12 dS m<sup>-1</sup>. Salinity effects were statistically significant (CD<sub>0.05</sub> = 0.419). Among varieties Pusa Narangi flowered earliest (42.21 days) followed by Pusa Bahar and Double Orange. Varietal differences

**Fig. 3:** Effect of salt stress on first flower bud initiation plant & first flowering.

**Table 4:** Effect of different concentration of NaCl on Fresh flower weight (g) & Flower yield per plant (g).

Factor	Fresh flower weight (g)				Flower yield per plant (g)			
	Pusa Narangi	Pusa Bahar	Double Orange	Mean A	Pusa Narangi	Pusa Bahar	Double Orange	Mean A
0 d/sm <sup>-1</sup> (Control)	7.025	7.65	5.615	6.763	137.45	131.85	85.19	118.163
02 d/sm <sup>-1</sup>	5.813	6.525	4.613	5.65	97.65	96	60.438	84.696
04 d/sm <sup>-1</sup>	5	5.875	4.425	5.1	70.25	76.15	52.35	66.25
06 d/sm <sup>-1</sup>	4.425	5.075	3.675	4.392	53.9	53.35	37.85	48.367
08 d/sm <sup>-1</sup>	3.625	4.125	2.875	3.542	44.4	36	24.875	35.092
10 d/sm <sup>-1</sup>	2.05	2.7	1.95	2.233	11.275	14.5	10.75	12.175
12 d/sm <sup>-1</sup>	0	0	0	0	0	0	0	0
Mean B	3.991	4.564	3.308		59.275	58.264	38.779	
	C.D.	SE(d)	SE(m)		C.D.	SE(d)	SE(m)	
Factor (A)	0.464	0.232	0.164		8.055	4.021	2.843	
Factor (B)	0.304	0.152	0.107		5.273	2.632	1.861	
Factor(A × B)	N/A	0.402	0.284		13.951	6.965	4.925	

were significant ( $CD_{0.05} = 0.274$ ) reflecting genotypic variation in salinity tolerance. The salinity × variety interaction was also significant ( $CD_{0.05} = 0.725$ ) with Pusa Narangi showing greater stability in flowering whereas Double Orange exhibited a pronounced delay beyond 6 dS m<sup>-1</sup>. Salt stress interferes enzymatic activities and several physiological processes that lead to adverse effect first flowering, crop yield and quality (Carter and Grieve, 2008; Friedman *et al.*, 2010; Grieve *et al.*, 2005; Shillo *et al.*, 2002).

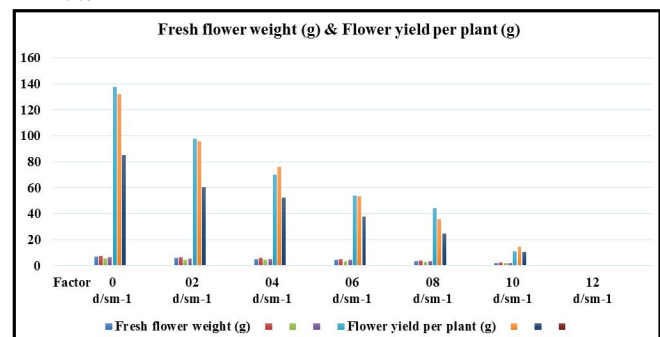
#### Fresh flower weight (g)

The data pertaining to fresh flower weight (g) with different treatments are presented in table and graphically illustrated in fig. Fresh flower weight of marigold was significantly influenced by salinity levels and varieties, whereas their interaction was nonsignificant. Increasing salinity caused a progressive reduction in fresh flower weight across all varieties are presented Table 4 and graphically illustrated in Fig. 4. The maximum fresh flower weight (6.76 g) was recorded under control conditions (0 dS m<sup>-1</sup>) followed by a gradual decline at 2–4 dS m<sup>-1</sup> and a sharp reduction beyond 6 dS m<sup>-1</sup>. At 10 dS m<sup>-1</sup> fresh flower weight decreased to (2.23 g) while complete inhibition of flower quality occurred at 12 dS m<sup>-1</sup>. The effect of salinity was statistically significant ( $CD_{0.05} = 0.464$ ). Among varieties Pusa Bahar produced the highest mean fresh flower weight (4.56 g) followed by Pusa Narangi and Double Orange. Varietal differences were significant ( $CD_{0.05} = 0.304$ ) indicating genotypic variation in salinity tolerance with Pusa Bahar showing superior performance under saline conditions. Oxidative, osmotic and ionic toxicity induced by salinity disrupt normal cell division, phragmoplast formation and cytoskeletal organization resulting in pronounced cellular damage (Baranova *et al.*, 2021; Zagorskina *et al.*, 2023). Such

structural and physiological impairments lead to reduced cell expansion, premature cell death, and altered assimilate partitioning, ultimately limiting floral development and fresh flower weight, as also reported by Baranova *et al.*, (2021) and Bano *et al.*, (2019).

#### Flower yield per plant (g)

The data pertaining to flower yield per plant (g) of marigold at full bloom during 2023–24 was significantly influenced by salinity levels, varieties and their interaction. The mean flower yield per plant (g) decreased progressively with increasing salinity across all varieties are presented Table 4 and graphically illustrated in Fig. 4. The highest mean value (118.16 g) was recorded under control conditions (0 dS m<sup>-1</sup>) which declined gradually at lower salinity levels and sharply beyond 6 dS m<sup>-1</sup>. A severe reduction was observed at 10 dS m<sup>-1</sup> (10.75 g) while complete plant growth inhibition occurred at 12 dS m<sup>-1</sup>. The effect of salinity levels was statistically significant ( $CD_{0.05} = 8.05$ ). Among the varieties Pusa Narangi recorded a significantly higher mean flower yield per plant (g) (59.27 g) followed by Pusa Bahar (58.26 g) and Double Orange (38.77 g). The varietal effect was significant ( $CD_{0.05} = 5.27$ ). The interaction between salinity levels

**Fig. 4:** Effect of salt stress on Fresh flower weight (g) & Flower yield per plant (g).

and varieties was also significant ( $CD_{0.05} = 13.95$ ) indicating differential varietal responses to salinity stress with Pusa Narangi showing greater tolerance and Double Orange exhibiting a sharper decline particularly beyond 6 dS m<sup>-1</sup>. Effects of salt stress restricts the ability of plant cells to effectively absorb water and essential mineral nutrients and reducing flower quality and growth of different ornamental plants have also been reported in gladiolus (Ahir and Singh 2017), in marigold (ValdezAguilar *et al.*, 2009), in zinnia (Zivder *et al.*, 2011) and in rosemary (Kiarostami *et al.*, 2010).

### Conclusion

Salinity stress effectively influenced the plant growth and their development and also influence the flowering behaviour, and their yield of marigold cultivars, with detrimental effects when the salinity level has increased. The moderate salinity level (2 to 4 dS m<sup>-1</sup>) influences the limited reductions in the plant growth, development and their flowering. whereas salinity beyond 6 dS m<sup>-1</sup> severely restricted vegetative growth, delayed flowering occurs and drastically reduced the flower yield, ultimately leading to complete growth inhibition at 12 dS m<sup>-1</sup>. The observed reduction can be attributed to osmotic stress, ionic toxicity, and associated physiological disruptions that impair water uptake, nutrient balance, and cellular metabolism. Significant varietal differences were also recorded which indicates the role of genetic makeup in salinity tolerance. The variety of Pusa Narangi demonstrated the superior tolerance to salinity stress by maintaining higher growth, earlier flowering, and greater yield under saline conditions, followed by Pusa Bahar, while Double Orange was highly sensitive. Therefore, Pusa Narangi can be recommended for cultivation in moderately saline soils, and the findings provides the valuable insights for varietal selection and management strategies in salt-affected regions.

### Authors' contributions

Ajay Kumar: Carried out the experiment and wrote initial draft of the manuscript; Amit Kanawjia: Conceptualization, planning and supervision of the experiment; Ajay Kumar Singh: Review and editing; Vishal Chugh: Data recording and analysis; Balaji Vikram: Data recording and interpretation of the findings; Kumari Anjali: Literature searches and summarizing relevant studies; Nikita Maurya: Methodology support and assistance in experimental procedures; Piyush Singh: Statistical analysis and validation of results.

**Research content:** The research content is original and has not been published anywhere else.

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**Data availability:** This article includes all the original data generated in this research and no data has been taken from any other source.

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