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Salinity tolerance of five ornamental species from the Asteraceae family in seed germination and early seedling growth stages

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ABSTRACT

Purpose: Seed germination and seedling growth are recognized as the most sensitive stages of salinity for the majority of plant species. This experiment aimed to characterize the impact of various salinity levels on selected ornamental plants from the Asteraceae family including *Gazannia splendens*, *Rudbeckia hirta*, *Ageratum houstonianum, Gaillardia aristata*, and *Coreopsis grandiflora* during the seed germination stage. **Research method**: Five independent experiments were conducted in a completely randomized design (CRD), comprising seven treatments with different concentrations of sodium chloride (0, 20, 40, 60, 80, 100, and 120 mM) in four replications using Petrie plates. **Findings:** The salinity of 120 mM significantly reduced the seed germination percentage in *G. splendens, G. aristata,* and *C. grandiflora,* compared to the other species. *A. houstanianum* exhibited a stimulating effect on seed germination percentage with salinity levels ranging from 20 mM to 80 mM. Salinity stress at a concentration of 120 mM had negatively affected vegetative traits in *A. houstonianum, R. hirta, G. aristata*, and *C. grandiflora,* inhibiting the growth of plumule in *A. houstonianum and C. grandiflora.* However, traits like plumule length and seedling length in *G. splendens* remained unaffected by salinity. **Research limitations:** No limitations were identified. **Originality/Value**: Results demonstrate varied responses of ornamental plants to different salinity levels. *R. hirta* exhibited superior performance in seed germination and early seedling stages compared to other plants.

INTRODUCTION

Soil salinity is a serious abiotic stress limiting agricultural yield in arid and semi-arid areas (FAO, 2019). Approximately 20% of the world's agricultural land has saline and or sodium soils, with 25% to 30% of irrigated land being commercially unproductive because of the soil salinity. Salt stress affects plants differently across the developmental stages (Shahid et al., 2018). Understanding the threshold of salt damage at all developmental stages is crucial for studying salt tolerance during different growth phases (Hannachi & Van Labeke, 2018).

In numerous plants, the most sensitive stages to salinity stress are seed germination and seedling growth (Li et al., 2020). Plants are particularly vulnerable to environmental stress during these stages, making the sensitivity of plant species to high salt concentrations in the soil critical for successful plant establishment (Yasemin et al., 2020). Salt stress induces toxic effects in germinating seeds, significantly reducing seed germination, seedling growth, and establishment and root and shoot length under high salinity stress (Murillo-Amador et al., 2002; Liang et al., 2018; Saadatfar et al., 2023).

Seasonal flowers may encounter stress during their growth and development. The level of salt tolerance of ornamental plants depends on the species, their development, salt stress level, and environmental factors (Guo et al., 2022). Salinity diminishes growth indices in various ornamental flowers, including snapdragon, sage, petunia, violet (Villarino & Mattson, 2011), zinnia (Bizhani et al., 2013), cockscomb (Carter et al., 2005) and in marigold (Chaparzadeh et al., 2004). *Carthamus tinctorius* has been suggested as a suitable crop for saline-stressed soils, exhibiting the most significant germination (30%) at the maximum salinity level (32 dS/m) (Green et al., 2019). Gola et al. (2019) investigated the effect of salt stress at different levels of 0, 1, 3, 5, and 7 dS/m on the *G. aristata* plant and showed that salinity negatively affected seed germination and seeding growth. Zivdar et al. (2011) reported that the percentage of seed germination, germination rate, and radicle length decreased in zinnia under salinity stress. Aboutalebi Jahromi and Hosseini Farahi (2016) demonstrated that different salinity concentrations (0, 2, 4, 6, and 8 mmhos/cm) significantly decreased the parameters like plant length, number of lateral branches, fresh and dry weight of radicle, fresh and dry weight of plumule in French marigold plant. Salinity stress at different levels (0, 2, 4, 6, and 8 dS/m) reduced some biochemical characteristics including net photosynthesis, chlorophyll content, and soluble proteins while increasing proline and malondialdehyde (MDA) in sunflowers (*Helianthus annuus* L.) genotypes (Morsali Aghajari et al., 2020). In landscape design, annual and perennial ornamental flowers play a crucial role, offering a variety of colors and shapes (Dole & Wilkins, 2005). The Asteraceae family holds significant economic importance because of considerable advantageous species suited to marginal stressed lands (Garcia-Oliveira et al., 2021). *Gazannia splendens* from the Asteraceae family, native to Africa, serves as a perennial plant but is used annually in temperate regions because of winter cooling (Salehi et al., 2014). Gloriosa daisy (*Rudbeckia hirta)*, is an annual summer flower that has copious value in the landscape because of the extended flowering period (Mcdonald, 2002). Gaillardia *(Gaillardia aristata)* is an ornamental flower with a height of 30 to 50 cm. The flowers are single or double with yellow, red, or brown color. This flower is one of the hardiest garden plants that have annual and perennial varieties. *G. aristata*'s flowering period is relatively long and lasts from early summer to mid-autumn (Gawade, 2018). Ageratum (*Ageratum houstonianum)* is a summer ornamental plant native to Central and South America and usually planted on the edges of gardens or parks (Wiedenfeld & Andrade-Cetto, 2001). *Coreopsis grandiflora*, a perennial ornamental flower, exceeds 60 cm in height, producing yellow ray and disc flowers (Dole & Wilkins, 2005).

Given the critical role of salinity in seed germination and seeding growth, this study aims to evaluate the effects of different concentrations of NaCl on seed germination and seeding growth stages in several selected ornamental plants from the Asteraceae family.

MATERIALS AND METHODS

Plant materials and germination assays

Seeds of *G. splendens* cv.'Sundance Red', *R. hirta* cv. 'Indian Summer', *A. houstonianum* cv. 'Blue Puffs', *G. aristate* cv. 'SpinTop Mango', and *C. grandiflora* cv. 'Early Sunrise', was purchased from Agriplus Co, Iran. The germination study was conducted under laboratory conditions. Seeds were sterilized for 20 minutes in a sodium hypochlorite solution (5%), and then they were rinsed three times with distilled water for two minutes. After sterilization, 20 seeds of each cultivar were randomly distributed into a Petrie plate on Watman filter paper and then wetted with 10 ml distilled water, or intended solutions were added to each Petrie plate depending on the treatment After closing the Petri plates with para-film, they were placed in the growth chamber at a temperature of 25°C. Seeds were considered germinated if their radicle length was at least two mm or more (Allahverdi et al., 2012)

Salinity stress treatments and experimental design

The experiment was implemented in a completely randomized design (CRD) with four replications in the Horticulture Laboratory of the Faculty of Agriculture, University of Birjand, Iran, in 2022. Irrigation water salinity stress was imposed at seven levels: zero (distilled water), 20, 40, 60, 80, 100, and 120 mM sodium chloride, with electrical conductivities equal to 0.6, 1.82, 3.65, 5.48, 7.31, 9.14, and 10.96 dS/m respectively.

Studied parameters

Various traits, including germinated seeds, radicle length, and plumule length were evaluated at 24-hour intervals up to day nine. At the end of the germination test (10th day), five randomly selected seedlings were taken from each Petrie plate to measure radicle and plumule lengths (mm) and radicle and plumule fresh weights (mg). Radicle weight, plumule weight, and dry weight of seedlings were measured using a sensitive scale with an accuracy of 0.0001 grams. Radicle and plumule length were measured with a ruler. Seed germination rate was measured using Maguire's method (Maguire, 1962) according to the following formula (1):

$$GR = \Sigma\, Ni / Di \quad (1)$$

Where: GR: germination rate (number of seeds per day)
Ni: number of germinated seeds per count
Di: number of days until the i^{th} count
Germination percentage was calculated according to the following formula (2):

$$GP = (Ni/N) \times 100 \quad (2)$$

In this formula, GP is the percentage of germination, Ni is the number of germinated seeds till i^{th} day, and N is the total number of seeds (Bajji et al., 2002).
The mean germination time was calculated based on the following equation
(3) (Ruan et al., 2002):

$$MGT = \Sigma\,(D \times N)/\Sigma N \quad (3)$$

In this equation, MGT is the mean germination time, N is the number of seeds that germinated till the D^{th} day, and D is the number of days that have passed since the beginning of the germination time.
The seed vigor index (SV) was obtained by multiplying the sum of radicle length (RL), and plumule length (PL) by germination percentage (GP) according to the following equation (4) (Bajji et al., 2002).

$$SV=(PL+RL)\times GP \quad (4)$$

Data analysis
Data were subjected to analysis of variance (ANOVA) using JMP 13 software (SAS Campus, Cary, NC, USA) and a mean comparison was conducted with the LSD test at a 5% probability level.

RESULTS

G. splendens
The analysis of variance (Table 1) showed that, except for plumule and seedling length, which were not significant, the other investigated traits showed a significant difference at the 1% probability level. The comparison of mean data (Table 2) demonstrated that with the increase in salt concentration, the percentage and rate of seed germination decreased. The lowest seed germination percentage (6.25%) and rate (1 seed per day) were observed in 120 mM treatment. The mean germination time at 80 mM concentration showed a significant increase compared to the control. The highest (2.59) and the lowest (0.21) seed germination index was observed in the control and 120 mM NaCl treatments, respectively. The increase in salinity concentration decreased the fresh and dry weight of the radicle. So the lowest fresh and dry weight of the radicle (0.007 and 0.0004 grams) was obtained from the 120 mM treatment. The control treatment had the highest fresh (0.0207 g) and (0.0015 g) dry weights of the plumule, and the lowest fresh weight (0.005 g) and dry weight (0.0002 g) of plumule was obtained from 120 mM treatment. The highest salinity level decreased radicle length by 42.28% compared to the control (Table 2).

R. hirta
Variance analysis of the obtained data (Table 1) revealed that the effect of salinity levels was significant at the 1% probability level for all investigated traits. The comparison of mean data (Table 2) showed that the percentage of seed germination at salinity levels of 20, 40, 60, and 80 mM did not differ significantly from the control. However, with an increase in the salinity level to 100 and 120 mM, a striking decrease in seed germination percentage was observed. The seed germination rate descended with an increase in salinity level, reducing by 67 and 55% at the levels of 100 and 120 mM, respectively, compared to the control. At 100 and 120 mM salinity levels, there was a 58 and 44% increase in mean germination time, respectively, compared to the control, while the rest of the salinity levels did not show any significant difference from the control. The highest (5.22) and lowest (0.16) seed germination index were obtained from the control and 120 mM NaCl treatment, respectively. The highest radicle (0.015 g) and plumule (0.0096 g) fresh weights were obtained from 20 mM NaCl treatment, whereas the lowest fresh weight of radicle (0.009 g) and plumule (0.004 g) were obtained from 120 mM NaCl treatment. Also, the highest and the lowest dry weight of the radicle (0.001 g and 0.0007 g) were obtained from the control and 120 mM NaCl concentrations, respectively. The highest and the lowest dry weight of the plumule (0.0009 g and 0.00032 g)

were recorded from the control and 100 mM NaCl concentrations, respectively. Radicle length decreased with increasing salinity, reaching a 98% decrease at 100 mM NaCl compared to the control. Plumule length decreased by 78% in the 120 mM treatment compared to the control. Seedling length also declined by 94% at 100 mM NaCl compared to the control (Table 2).

Table 1. Variance analysis of salinity stress effects on germination characteristics of some ornamental plants of the Asteraceae family.

Mean of squares								
G. splendens	Source of variance	df	Germination percentage	Germination rate	Mean germination time	Seed vigor index	Radicle fresh weight	Radicle dry weight
	Salinity	6	943.24^{**}	25.01^{**}	0.77^{**}	2.07^{**}	$6.74e^{-7**}$	$1.99e^{-6**}$
	Error	21	59.89	3.12	0.18	0.25	0.0003	$4.58e^{-8}$
	Source of variance	df	Plumule fresh weight	Plumule dry weight	Radicle length	Plumule length	Seedling length	
	Salinity	6	0.00018^{**}	1.01^{**}	1.25^{**}	0.084^{ns}	1.77^{ns}	
	Error	21	$17.34e^{-6}$	$2.1e^{-8}$	0.31	0.064	0.96	
R. hirta	Source of variance	df	Germination percentage	Germination rate	Mean germination time	Seed vigor index	Radicle fresh weight	Radicle dry weight
	Salinity	6	112.81^{**}	18.74^{**}	0.90^{**}	15.83^{**}	0.00002^{**}	$5.59e^{-8**}$
	Error	21	861.3	1.52	0.088	0.21	$1.38e^{-6}$	$6.52e^{-9}$
	Source of variance	df	Plumule fresh weight	Plumule dry weight	Radicle length	Plumule length	Seedling length	
	Salinity	6	$9.22e^{-6**}$	$1.42e^{-7**}$	20.76^{**}	0.23^{**}	25.01^{**}	
	Error	21	$1.03e^{-6}$	$1.58e^{-8}$	0.05	0.0019	0.05	
A. houstonianum	Source of variance	df	Germination percentage	Germination rate	Mean germination time	Seed vigor index	Radicle fresh weight	Radicle dry weight
	Salinity	6	502.97^{**}	25.26^{**}	0.59^{*}	2.47^{**}	$1.38e^{-6**}$	$2.44e^{-10**}$
	Error	21	38.09	2.04	0.17	0.04	$3.13e^{-8}$	$5.86e^{-9}$
	Source of variance	df	Plumule fresh weight	Plumule dry weight	Radicle length	Plumule length	Seedling length	
	Salinity	6	$2.56e^{-8**}$	$1.40e^{-10**}$	0.02^{**}	0.33^{**}	5.86^{**}	
	Error	21	$7.58e^{-10}$	$5.67e^{-12}$	4.98	0.004	0.03	
G. aristata	Source of variance	df	Germination percentage	Germination rate	Mean germination time	Seed vigor index	Radicle fresh weight	Radicle dry weight
	Salinity	6	1926.69^{**}	37.88^{**}	2.51^{**}	8.44^{**}	0.0002^{**}	1926.69^{**}
	Error	21	144.58	4.03	5.41	0.46	5.00001	$5.17e^{-8}$
	Source of variance	df	Plumule fresh weight	Plumule dry weight	Radicle length	Plumule length	Seedling length	
	Salinity	6	37.88^{**}	2.51^{**}	8.44^{**}	0.0002^{**}	1926.69^{**}	
	Error	21	0.000014	$7.52e^{-8}$	0.23	0.008	0.29	
C. grandiflora	Source of variance	df	Germination percentage	Germination rate	Mean germination time	Seed vigor index	Radicle fresh weight	Radicle dry weight
	Salinity	6	3189.58^{**}	48.5^{**}	0.83^{**}	4.72^{**}	$6.74e\text{-}6^{**}$	$6.17e\text{-}8^{**}$
	Error	21	21.46	11.98	0.17	0.105	2.2e-7	1.36e-8
	Source of variance	df	Plumule fresh weight	Plumule dry weight	Radicle length	Plumule length	Seedling length	
	Salinity	6	3.6^{**}	$2.82e\text{-}9^{**}$	4.14^{**}	0.25^{**}	6.23^{**}	
	Error	21	4.11e-7	4.12e-11	0.11	0.006	0.16	

** Significance at the 1% probability level, * Significance at the 5% probability level, and ^{ns} is non-significance.

Table 2. Mean comparison of salinity effects on seed germination properties of *G. splendens* and *R. hirts.*

	Salinity (mM)	Germination percentage (%)	Germination rate (seed per day)	Mean germination time (seed per day)	Seed vigor index	Radicle fresh weight (g)	Radicle dry weight (g)
G. splendens	0	57.5^{a}	9.16^{a}	1.61^{c}	2.59^{a}	0.035^{a}	0.0025^{a}
	20	41.25^{b}	4.5^{b}	2.24^{abc}	1.73^{b}	0.034^{a}	0.0022^{b}
	40	36.25^{b}	4.09^{b}	2.31^{ab}	1.13^{b}	0.024^{b}	0.0018^{c}
	60	36.66^{b}	5.48^{b}	1.93^{bcd}	1.1^{b}	0.022^{bc}	0.0017^{c}
	80	37.5^{b}	3.35^{bc}	2.83^{a}	1.38^{b}	0.019^{cd}	0.0012^{d}
	100	42.5^{b}	5.75^{b}	1.96^{bcd}	1.44^{b}	0.017^{d}	0.001^{d}
	120	6.25^{c}	1.00^{c}	1.5^{d}	0.21^{c}	0.007^{e}	0.0004^{e}
	Salinity (mM)	Plumule fresh weight (g)	Plumule dry weight (g)	Radicle length (cm)	Plumule length (cm)	Seedling length (cm)	
	0	0.0207^{a}	0.0015^{a}	3.24^{a}	1.05^{a}	4.29^{a}	
	20	0.0205^{a}	0.0014^{a}	3.31^{a}	0.9^{a}	4.21^{a}	
	40	0.0130^{b}	0.001^{b}	3.30^{a}	0.72^{a}	4.02^{a}	
	60	0.0202^{a}	0.0014^{a}	3.32^{a}	0.67^{a}	4.00^{a}	
	80	0.008^{c}	0.0007^{c}	3.07^{a}	0.67^{a}	3.75^{a}	
	100	0.007^{c}	0.0006^{c}	2.60^{ab}	0.77^{a}	3.37^{a}	
	120	0.005^{c}	0.0002^{d}	1.87^{b}	0.66^{a}	2.53^{a}	
R. hirta	Salinity (mM)	Germination percentage (%)	Germination rate (seed per day)	Mean germination time (seed per day)	Seed vigor index	Radicle fresh weight (g)	Radicle dry weight (g)
	0	83.75^{a}	9.02^{a}	2.22^{b}	5.22^{a}	0.014^{ab}	0.001^{a}
	20	70.00^{ab}	7.63^{ab}	2.29^{b}	4.38^{b}	0.015^{a}	0.0009^{a}
	40	72.50^{a}	7.11^{b}	2.37^{b}	3.79^{b}	0.013^{bc}	0.0009^{ab}
	60	82.50^{a}	7.37^{ab}	2.44^{b}	4.31^{b}	0.013^{bc}	0.0008^{bc}
	80	81.25^{a}	7.36^{ab}	2.36^{b}	2.81^{c}	0.012^{c}	0.0008^{bc}
	100	56.25^{bc}	4.04^{c}	3.20^{a}	0.36^{b}	0.01^{d}	0.0007^{cd}
	120	45.00^{c}	3.00^{c}	3.40^{a}	0.16^{d}	0.009^{d}	0.0007^{d}
	Salinity (mM)	Plumule fresh weight (g)	Plumule dry weight (g)	Radicle length (cm)	Plumule length (cm)	Seedling length (cm)	
	0	0.009^{ab}	0.0009^{a}	5.28^{a}	0.93^{a}	6.21^{a}	
	20	0.0096^{a}	0.0006^{b}	5.37^{a}	0.86^{b}	6.23^{a}	
	40	0.008^{ab}	0.00055^{bc}	4.42^{b}	0.80^{b}	5.22^{b}	
	60	0.007^{b}	0.00055^{bcd}	4.53^{b}	0.69^{c}	5.22^{b}	
	80	0.008^{ab}	0.00050^{bcd}	2.82^{c}	0.65^{c}	3.47^{c}	
	100	0.007^{b}	0.00032^{d}	0.12^{d}	0.52^{d}	0.65^{d}	
	120	0.004^{c}	0.00037^{cd}	0.16^{d}	0.20^{e}	0.36^{d}	

In each column, the means with at least one similar letter are not significant based on the LSD test at the 5% probability level.

A. houstonianum

Variance analysis of the obtained data (Table 1) demonstrated that the effect of salinity levels on all investigated traits was significant at the 1% and 5% probability levels. The comparison of mean data (Table 3) showed that the highest seed germination percentage (75.75%) was obtained from 80 mM NaCl concentration, while the lowest (43.75%) was observed at 120 mM concentration. The 60 mM NaCl concentration had the highest seed germination rate, which did not show a statistically considerable difference with 80 mM NaCl concentration. The lowest and highest mean germination times were related to 40 and 120 mM salinity, respectively. With the increase in salinity, the seed germination index significantly decreased, so the control and 20 mM salinity with 2.24 had the highest and 120 mM had the lowest seed germination index. With increasing salinity, the fresh and dry weight of radicles decreased from 0.0021 and 0.00014 g in control to 0.0004 and 0.00003 g at 120 mM salinity, respectively. The highest fresh weight (0.00019 g) and dry weight (0.000000 g) of the plumules were obtained from the 60 mM NaCl concentration, showing no significant difference from the control treatment, while the lowest was obtained at 120 mM NaCl.

Treatment with 120 mM salinity reduced the length of the radicle and seedling by 85% and 87%, respectively, compared to the control (Table 3).

G. aristata

Variance analysis of the obtained data (Table 1) showed that the effect of salinity levels on all investigated traits was significant. The comparison of mean data (Table 3) revealed that with increasing salinity levels, seed germination percentage and rate decreased. Treatment with 120 mM salinity decreased the seed germination percentage and germination rate by 60 and 96%, respectively, compared to the control. The mean germination time did not show a significant difference from the control to 100 mM NaCl, while it showed a considerable increase when the control compared to the salinity level of 120 mM NaCl. The highest seed vigor index (3.93) was related to the control treatment, and the lowest (0.007) was observed in the 120 mM NaCl treatment. The lowest fresh and dry weights of radicle were observed at 120 mM salinity level. The fresh and dry weight of the plumule decreased with increasing salinity levels, although in some cases, this decrease did not show a significant difference compared to the control. The length of radicle and seedling at salinity levels of 20, 40, 60, and 80 mM NaCl did not differ significantly compared to the control but showed a noticeable decline at higher salinity levels. With the increase in salinity concentration, the plumule length decreased, and the lowest value (0.11 cm) was obtained from the 120 mM treatment (Table 3).

C. grandiflora

Variance analysis of the obtained data (Table 1) demonstrated that the effect of salinity levels on all investigated traits was significant. The comparison of mean data (Table 4) revealed that the seed germination percentage and rate decreased with increasing salinity. The highest mean germination time was obtained from the level of 80 mM NaCl. The seed vigor index showed no significant difference with the control up to the salinity level of 40 mM, but other levels illustrated a significant difference with the control. The lowest seed seed vigor index was obtained at the salinity of 120 mM. As salinity levels increased, the fresh and dry weights of radicle and plumule decreased, reaching the lowest values for these traits at 120 mM salinity. With increasing salinity, the length of the radicle, plumule, and seedling respectively decreased from 3, 0.8, and 3.8 cm in the control to 0.7, 0.0, and 0.7 cm in 120 mM salinity (Table 4).

Table 3. The effects of salinity stress on the seed germination characteristics of *A. houstonianum* and *G. aristata*.

	Salinity (mM)	Germination percentage (%)	Germination rate (seed per day)	Mean germination time (seed per day)	Seed vigor index	Radicle fresh weight (g)	Radicle dry weight (g)
A. houstonianum	0	58.57^{bc}	8.52^{b}	1.88^{ab}	2.24^{a}	0.0021^{a}	0.00014^{a}
	20	67.50^{ab}	10.35^{ab}	1.69^{bc}	2.24^{a}	0.0018^{b}	0.00012^{ab}
	40	53.75^{bc}	9.68^{ab}	1.26^{c}	1.56^{b}	0.0016^{bc}	0.00011^{b}
	60	67.5^{ab}	11.57^{a}	1.45^{bc}	1.55^{b}	0.0014^{c}	0.0001^{b}
	80	73.75^{a}	11.11^{a}	1.85^{abc}	1.31^{b}	0.0011^{d}	0.00008^{c}
	100	47.5^{de}	6.3^{c}	2.06^{ab}	0.48^{c}	0.0009^{d}	0.00007^{c}
	120	43.75^{e}	4.78^{c}	2.43^{a}	0.21^{c}	0.0004^{e}	0.00003^{d}
	Salinity (mM)	**Plumule fresh weight (g)**	**Plumule dry weight (g)**	**Radicle length (cm)**	**Plumule length (cm)**	**Seedling length (cm)**	
	0	0.00019^{a}	0.00001^{5a}	3.47^{a}	0.35^{b}	3.82^{a}	
	20	0.00016^{ab}	0.000013^{ab}	2.97^{b}	0.32^{bc}	3.30^{b}	
	40	0.00012^{bc}	0.00001^{bc}	2.65^{c}	0.25^{cd}	2.9^{c}	
	60	0.00019^{a}	0.000014^{a}	1.55^{d}	0.90^{a}	2.45^{d}	
	80	0.00008^{c}	0.000008^{c}	1.4^{d}	0.22^{d}	1.77^{e}	
	100	0.00001^{d}	0.000003^{d}	0.92^{e}	0.1^{e}	1.02^{f}	
	120	0.0^{d}	0.0^{d}	0.5^{f}	0.0^{f}	0.5^{g}	
G. aristata	**Salinity (mM)**	**Germination percentage (%)**	**Germination rate (seed per day)**	**Mean germination time (seed per day)**	**Seed vigor index**	**Radicle fresh weight (g)**	**Radicle dry weight (g)**
	0	66.25^{a}	10.05^{a}	1.64^{b}	3.93^{a}	0.03^{a}	0.002^{a}
	20	63.75^{a}	6.13^{b}	2.32^{b}	3.69^{a}	0.027^{ab}	0.0018^{ab}
	40	45.00^{b}	5.92^{b}	1.82^{b}	2.45^{b}	0.027^{ab}	0.0016^{bc}
	60	45.00^{b}	5.55^{b}	2.31^{b}	2.36^{b}	0.023^{bc}	0.0015^{bc}
	80	41.66^{b}	4.66^{bc}	2.15^{b}	2.17^{b}	0.02^{c}	0.0013^{cd}
	100	18.75^{c}	2.3^{cd}	2.24^{b}	0.56^{c}	0.11^{d}	0.001^{d}
	120	6.25^{c}	0.36^{d}	4.33^{a}	0.037^{c}	0.007^{d}	0.0005^{e}
	Salinity (mM)	**Plumule fresh weight (g)**	**Plumule dry weight (g)**	**Radicle length (cm)**	**Plumule length (cm)**	**Seedling length (cm)**	
	0	0.018^{b}	0.0011^{ab}	4.69^{a}	1.22^{a}	5.92^{a}	
	20	0.018^{b}	0.0010^{ab}	4.76^{a}	0.97^{b}	5.73^{a}	
	40	0.019^{b}	0.0010^{ab}	4.63^{a}	0.87^{bc}	5.51^{a}	
	60	0.02^{a}	0.0013^{a}	4.57^{a}	0.76^{cd}	5.34^{a}	
	80	0.0015^{b}	0.001^{a}	4.52^{a}	0.69^{d}	5.21^{a}	
	100	0.009^{c}	0.0008^{b}	2.49^{b}	0.52^{e}	3.01^{b}	
	120	0.003^{c}	0.0002^{c}	0.28^{c}	0.11^{f}	0.39^{c}	

Table 4. The effects of salinity stress on the seed germination characteristics of *C .grandiflora*.

	Salinity (mM)	Germination percentage (%)	Germination rate (seed per day)	Mean germination time (seed per day)	Seed vigor index	Radicle fresh weight (g)	Radicle dry weight (g)
C. grandiflora	0	71.25^{bc}	8.9^{a}	2.01^{c}	2.71^{a}	0.0045^{a}	0.00038^{a}
	20	80.00^{a}	9.37^{a}	2.05^{c}	2.77^{a}	0.0044^{a}	0.00039^{a}
	40	78.33^{ab}	7.67^{a}	2.49^{bc}	2.34^{a}	0.004^{ab}	0.00031^{ab}
	60	65.00^{c}	7.39^{a}	2.10^{c}	1.68^{b}	0.0034^{bc}	0.00024^{ab}
	80	48.75^{d}	4.02^{b}	3.17^{a}	1.03^{c}	0.003^{cd}	0.00036^{a}
	100	30.00^{e}	2.65^{b}	2.96^{ab}	1.50^{d}	0.0026^{d}	0.00019^{bc}
	120	2.50^{f}	0.20^{c}	2.5^{abc}	0.005^{e}	0.0008^{e}	0.00005^{c}
	Salinity (mM)	**Plumule fresh weight (g)**	**Plumule dry weight (g)**	**Radicle length (cm)**	**Plumule length (cm)**	**Seedling length (cm)**	
	0	0.0009^{a}	0.000072^{ab}	3^{a}	0.8^{a}	3.8^{a}	
	20	0.0008^{b}	0.000075^{a}	2.92^{ab}	0.53^{b}	3.46^{a}	
	40	0.00077^{bc}	0.00067^{ab}	2.45^{bc}	0.4^{c}	2.85^{b}	
	60	0.00074^{cd}	0.000063^{b}	2.1^{cd}	0.47^{bc}	2.57^{bc}	
	80	0.00065^{d}	0.00005^{c}	1.63^{de}	0.47^{bc}	2.11^{cd}	
	100	0.0004^{e}	0.00003^{d}	1.42^{e}	0.23^{d}	1.65^{d}	
	120	0.0^{f}	0.0^{e}	0.7^{f}	0.0^{e}	0.7^{e}	

In each column, the means with at least one similar letter are not significant based on the LSD test at the 5% probability level.

DISCUSSION

The percentage and rate of germination of plant seeds are crucial for an agronomic perspective. Salinity stress significantly impacts the germination and early growth of seedlings. The decline in seed germination percentage and rate, along with the increase in the time required to reach the final germination due to salinity stress, poses critical limits in semi-arid areas with limited favorable conditions around the seeds. Plants that can germinate and thrive in saline conditions play an essential role in enhancing growth and productivity (Carpýcý et al., 2009).

In this study, salinity reduced the percentage and rate of seed germination in all tested ornamental plants, and with increasing salinity, the percentage and rate of germination decreased. For instance, the salinity of 120 mM NaCl in *G. splendens*, *G. aristata,* and *C. grandiflora* significantly reduced the percentage of germination compared to other ornamental species. However, *A. houstonianum* and *R. hirta* exhibited favorable germination under salt-stress conditions. Similar findings were reported by Gholizadeh et al., (2016), indicating that increased salinity led to the lowest germination percentage of *Echinacea purpurea* seeds obtained from a salinity of 12 dS/m. The germination rate of Zinnia decreased from 92.17% to 58% with an increase in salinity from zero to 12 dS/m (Zivdar et al., 2011), aligning with the observed trends in this study. Numerous studies on sunflowers also support the correlation between increased salinity stress and decreased germination rate (Hafeez et al., 2017; Kaya et al., 2019; Li et al., 2020). The reduction in seed germination with increased salt concentration is attributed to physicochemical and the toxic-osmotic effects of the solutes in the saline solution. In fact, with the increase in osmotic pressure (more negative osmotic potential), which results from the increase in salinity, the seed water absorption stage is disturbed. Slow water absorption affects the activities within the seed, leading to an increased time for radicle emergence and a subsequent decrease in the germination rate (Ajmal Khan et al., 2006). On the other hand, the presence of a high concentration of anions and cations (especially sodium and chlorine) in the growth medium prevent seed germination by toxicity effect (Rajabi Dehnavi et al., 2020). Besides, salinity prevents the movement of essential reserve materials to the embryo (Duarte et al., 2006; Xiong et al., 2024).

The seed vigor index reflects a seed's ability to germinate and sprout after planting and to maintain this potential during storage after harvesting (Wang et al., 2018). In all the tested ornamental plants, with increasing salinity levels, the seed vigor decreased compared to the control. The further reduction of seed vigor at higher levels of salinity is most likely because of the low osmotic potential of the root that prevent water absorption, the toxicity of chlorine and sodium ions, or the disruption of enzyme activity (Qian et al., 2000; Rouhi et al., 2011).

In *C. grandiflora* and *A. houstonianum*, 120 *mM* salinity inhibited plumule growth. In addition, the fresh and dry weight of radicles and plumules in various plants decreased with increasing salinity levels. The present results are consistent with the decrease in dry weight of *G. aristata* aerial parts caused by irrigation with NaCl solution (Niu & Rodriguez, 2006). Torbaghan (2012) on marigolds reported that salinities of 3 and 10 dS/m had the highest and lowest plumule weight, respectively. With the increase in salinity level to 7 dS/m, the fresh weight of *G. aristata*'s plumule decreased (Gola et al., 2019). In another experiment, the fresh and dry weight of the *Calendula* radicle declined with a rising salinity level to 8 dS/m (Jamali et al., 2021). Also, a report demonstrated that the salinity stress of 6 dS/m decreased the fresh weight of French marigold radicle and plumule (Aboutalebi Jahromi & Hosseini Farahi, 2016). Adding NaCl to the nutrient solution reduced the dry weight of *G. splendens* plants, so that the salinity of 7.5 dS/m reduced the dry weight of the plant by 32% compared to the salinity of 2 dS/m (García-Caparrós et al., 2017). This study's results are consistent with the findings of researchers on *Oenothera bennise* L. (Sikha et al., 2014; Moosavi et al., 2012). Salinity stress disrupts cell membranes, reduces enzyme activities, and decreases accessible water in growing plants, preventing the normal growth of radicles and plumules (Farooq & Azam, 2006). Also, salinity stress reduces the growth of plants by disrupting water absorption and toxicity caused by ions (Yokoi, 2002; Okcu et al., 2005; Taiz & Zeiger, 2006).

Except for the *G. splendens* plant, whose plumule and seedling length were not affected by salinity stress, other ornamental species decreased their radicle, plumule, and seedling length with increasing salinity. In *A. houstonianum* and *C. grandiflora* plants, salinity at 120 mM prevented the growth of the plumule. Reduction of radicle and plumule length with increasing salt stress has been proven by numerous researchers. In this regard, it has been reported that the radicle length of zinnia and Catharanthus decreased with increasing salinity levels (Marković et al., 2022). The results of Shila et al. (2016) illustrated a significant effect of salinity on the radicle length of sunflower, and the maximum radicle length was obtained from a concentration of 20 mM sodium chloride and the minimum radicle length was obtained from a concentration of 320 mM (Shila et al., 2016). Salinity changes the anatomical structure of the radicle and leads to a decrease in the number of cells in the xylem and the number of layers of the parenchyma cortex (Benidire et al., 2015). By limiting the activity of the cell wall and changing the amount of effective proteins in the wall, salt stress reduces the activity of meristems and consequently decreases cell division (Kaya et al., 2006). On the other hand, the high accumulation of salts in the cell wall changes the metabolic activities and limits the elastic property of the cell wall. In addition, the secondary cell wall is formed earlier and the cell wall becomes stiff. For this reason, the effect of osmotic pressure on cell wall elongation is less and the plumule length is reduced (Naseer et al., 2001).

CONCLUSION

According to the obtained results, the response of ornamental plants to different salinity levels varied. *R. hirta* exhibited superior performance in both seed germination and seedling growth traits than other plants. Thus, it had high germination up to an 80 mM salinity level and continued to grow at 120 mM salinity. *A. Houstonianum* showed high seed germination at 80 mM salinity, but seedlings did not thrive at 120 mM salinity. *G. splendens* and *G. aristata* did not have high seed germination, but seedling growth occurred at 60 mM salinity. *C. grandiflora* did not show proper seed germination and seedling growth at 20 mM salinity. Therefore, *R. hirta* appears to be more resistant to salt stress compared to other plants.

Conflict of interest

The authors declare no conflict of interest.

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