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Seed Halopriming: An Efficient Technique to Improve Germination and Growth Characteristics of Ornamental Cabbage (*Brassica oleracea* L. var. acephala) Under Salt Stress

Azadeh Mousavi Bazaz[1*], Hajar Nemati[1], Amir Ali Salavati Nik[1]

[1] Department of Horticultural Science and Landscape Architecture, Faculty of Agriculture, Ferdowsi University of Mashhad, Mashhad, Razavi Khorasan, Iran. E-mail: mousaviba@um.ac.ir

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ABSTRACT

Germination is a critical stage of the growth of ornamental plants, which is susceptible to the adverse effects of salinity. Ornamental cabbage is one such important ornamental plants in green spaces, yet there is limited research on the effect of priming on its seed germination under saline conditions. This study investigated the effect of halopriming on the germination of this plant. The studied factors included four salinity levels with sodium chloride (0, 4, 8, and 12 dS/m) and four potassium nitrate priming levels (0, 50, 100, and 150 ppm), with three replications. Results indicated that the application of potassium nitrate ameliorated the negative effects of salinity on many of the studied traits. Germination percentage and rate at 4, 8, and 12 dS/m salinity levels with potassium nitrate priming at 50 and 100 ppm were significantly higher compared to the control (non-primed level), showing significant differences. The highest values for allometry coefficient and seedling tissue water content were obtained with the application of potassium nitrate at 100 ppm and 4 dS/m salinity level. Positive effects of potassium nitrate priming were also observed on root and shoot length, plant length, and root-to-shoot length ratio, mean daily germination, fresh and dry weight under most salinity levels. Based on the obtained results, the application of potassium nitrate at a concentration of 100 ppm had the greatest impact on mitigating the adverse effects of salinity stress on germination and seedling growth of ornamental cabbage.

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1. Introduction

Ornamental cabbage (*Brassica oleracea* L. var. acephala) is a decorative plant utilized worldwide in landscape due to its beautiful, colorful, and diverse foliage, as well as its cold tolerance in green spaces (Ren *et al.*, 2019; Karagöz and Dursun, 2021). Despite its close relationship with edible cabbage, it does not form a compact head and is believed to be the oldest type of cabbage (Dixon, 2017).

Salinity stress is one of the most important abiotic stresses that affects the growth and performance of plants, including those present in green spaces (Bertrand *et al.*, 2015). One of the most sensitive stages in the life of plants is the germination and establishment stage in soil (Mousavi Bazaz and Nemati, 2023). Salinity stress can lead to delayed germination, reduced germination percentage, and decreased seedling growth (Paravar and Farahani, 2017); moreover, it can reduce water uptake by plants, resulting in symptoms of drought stress (Marković *et al.*, 2022). Since approximately 6.5 percent of the world's land area is affected by salinity stress, it is considered one of the major problems in horticultural crops and green spaces (de Cássia Alves *et al.*, 2018). With the increase in population and the decrease in access to quality water, irrigation of green spaces with saline water has increased, posing serious challenges to plant establishment in these areas (Mousavi Bazaz *et al.*, 2015).

High germination rates and uniformity in germination, coupled with the application of other post-germination techniques, ensure acceptable future plant growth; on the other hand, non-uniformity in germination can lead to negative effects on subsequent plant growth, especially under adverse conditions. Priming is among the methods employed to stimulate seed germination under unfavorable conditions (Batool *et al.*, 2015). This method can be used in various forms, including hydropriming, halopriming, and hormone priming. These techniques effectively control seed water uptake, thereby promoting the necessary metabolic activity for germination without root emergence (Ren *et al.*, 2019).

Priming enhances the ability of the radicle to emerge from the seed as the first stage of germination under environmental stresses and helps plants overcome adverse environmental conditions (Moaaz Ali *et al.*, 2020). Seed priming can also increase the activity of antioxidant enzymes and enhance tolerance to abiotic stresses such as salinity and drought (Saed-Moocheshi *et al.*, 2014).

In recent years, there has been a growing trend towards the use of seed priming to reduce the effects of salinity stress on plants (Zulfiqar *et al.*, 2024). Seed priming has been reported to improve germination in crops such as *Calendula officinallis* (Bagheri *et al.*, 2022), *Zinnia* spp., *Dahlia* sp., *Impatiens* spp., *Salvia officinallis*, and *Antirrhinum majus* (Ozden *et al.*, 2017), as well as *Arachis hypogaea* (Murata *et al.*, 2008). Rapid germination of ornamental plants such as *Zinnia* spp., *Dianthus caryophyllus*, *Bellis prennis*, *Gazania* spp., *Calendula officinallis*, and *Rudbeckia* spp. accelerates the establishment of green spaces (Ghanbari and Saeedipour, 2022). Seed priming can increase the activity of antioxidant enzymes and enhance tolerance to abiotic stresses such as salinity and drought (Saed-Moocheshi *et al.*, 2014).

Seed priming techniques can be included halopriming, hydropriming, osmopriming, osmo-conditioning, osmo-hardening, hormo-priming, hardening, and matri-priming. Among others, Halopriming and hydropriming refer to soaking seeds in salt solutions and water, respectively (Hamidi *et al.*, 2013). Halopriming plays a critical role in modulating enzyme activity, ensuring the production of necessary metabolites for germination (Iftikhar *et al.*, 2017). Halopriming involves pre-sowing seed treatment by soaking seeds in salt solutions, which improves germination and uniform seedling emergence under both stressful and optimal environmental conditions. Common salts used for this process include NaCl, KCl, KNO_3, and $CaCl_2$. Studies have assessed the impact of NaCl priming in combination with KNO_3 on the germination traits and early growth of four cultivars of *Helianthus annuus* L. under saline conditions, showing that primed seeds had higher germination percentages than unprimed ones (Kumari *et al.*, 2017). Previous studies have shown the positive effect of potassium nitrate (KNO3) as a substance for stability of establishment and seedling vigor (Mohammadi, 2009). On the other hand, the positive effects of halopriming with KNO3 have also been reported in plants such as *Catharanthus roseus* L (Mousavi Bazaz and Nemati, 2023), *Cannabis sativa* (Golizadeh *et al*., 2015), *Capparis spinosa* (Khan *et al*., 1999), and *Brassica oleracea* var. capitata (Batool *et al*., 2015). In *Foeniculum vulgare*, halopriming with KNO_3 reduced the length of the shoot compared to the root (Moradi and Rezvani, 2010). This compound induces auxin biosynthesis and stimulates embryo germination, On the other hand, this compound likely plays a role in balancing hormone ratios in the seed and reducing inhibitory substances such as abscisic acid (ABA) (Seyedi, 2020).

Considering the ornamental value of *Brassica oleracea* L. var. acephala in green spaces and the extensive propagation of this plant through seeds, and the lack of information on the effect of priming on seed germination under salinity stress, the present study aimed to investigate the effect of external application of potassium nitrate as a priming compound on seed germination of ornamental cabbage under saline conditions. The results of this research can contribute to the cultivation of this plant as a highly utilizable species in green spaces aiming to utilize saline water.

2. Materials and Methods

This study was conducted in February 2024 to investigate the effect of priming on the germination of ornamental cabbage (*Brassica oleracea* L. var. acephala) under saline stress conditions in the Physiology Laboratory of Horticultural Sciences at Agriculture Faculty, Ferdowsi University of Mashhad. The seeds of ornamental cabbage (*Brassica oleracea* L. var. acephala) were obtained from Pakan Seed Company, Isfahan. The experiment was conducted in a factorial experiment based on a completely randomized design with three replications. The experimental factors included four levels of salinity (0, 4, 8, and 12 dS/m) and four levels of seed priming (potassium nitrate at 0 (as control), 50, 100, and 150 ppm). Initially, the seeds were surface-sterilized with 2.5% sodium hypochlorite and then rinsed four times with sterile distilled water. After sterilization, the seeds were primed in various priming solutions for 12 hours and then air-dried at room temperature for 24 hours to reach initial moisture content (Mousavi Bazaz and Nemati, 2023). Control treatment just sterilized and rinsed. Subsequently, 20 seeds were placed in each petri dish with a diameter of 9 centimeters on two layers of Whatman filter paper, and four different levels of salinity were applied at a rate of 7.5 milliliters per petri dish. The petri dishes were sealed with parafilm after applying different salinity stresses and placed in a germinator at 25^{oc} with a 12-hour photoperiod. Germinated seeds were counted daily. The criterion for seed germination was the emergence of a 2-millimeter root radicle from the seed. At the end of the experiment, root and shoot lengths, fresh and dry weights of roots and shoots, shoot length index, tissue water content, allometry coefficient of seedlings were measured.

The evaluated traits in this experiment include: germination percentage (Equation 1), germination rate (Equation 2), average germination time (Equation 3), shoot length, root length, seedling length, root wet weight, shoot wet weight, seedling dry weight, shoot length index (Equation 4), plant tissue water content (Equation 5), alometry coefficient (Equation 6). The equations for these traits are as follows:

$$GP = (n/N) * 100 \quad (1)$$

In this equation, GP represents the germination percentage, n: the number of germinated seeds, and N: the total number of seeds (Hay and Gamble, 1987).

$$GS = \sum (ni / Ti) \quad (2)$$

GS: germination rate, ni: the number of germinated seeds in each count, and Ti: the number of days until the count (Hartmann and Kester, 1975).

$$MDT = GP / T \quad (3)$$

MDT: mean daily germination, GP: germination percentage, and T: the duration of germination period (days) (Hunter *et al.*, 1984).

$$SVI = (GP\% \times SL\ (mm)) / 100 \quad (4)$$

SVI: shoot length index, GP%: germination percentage, and SL: the average seedling length (Hunter *et al.*, 1984).

$$TWC = ((FW - DW) / FW) \times 100 \quad (5)$$

TWC: seedling tissue water content, FW and DW: respectively the fresh weight and dry weight of the seedling (Agrawal, 2003).

$$AC = Wr / Wp \quad (6)$$

AC: the allometry coefficient, Wr: the dry weight of the root, and Wp: the dry weight of the shoot (ISTA, 1979).

2.1. Data analysis

For statistical analysis, the normality of data was first ensured, and then the data were analyzed using SAS software version 9.4. Mean comparison was conducted using LSD test at the 1% probability level. Excel software was utilized for plotting graphs.

3. Results

The results of the analysis of variance indicated that salinity stress significantly affected all investigated traits, including germination percentage, germination rate, seedling length index, tissue water content, allometry coefficient, seedlings fresh weight, mean daily germination, root length, shoot length, root-to-shoot length ratio, seedling length, and fresh weight of roots and shoots at the 1% significance level (Table 1). Furthermore, it was observed that the interactive effect of salinity and priming was significant for traits such as germination percentage, germination rate, seedling length index, tissue water content, seedling length, allometry coefficient, fresh and dry weight of seedlings, mean daily germination, root length, shoot length, root-to-shoot length ratio, and fresh weight of roots and shoots at the 1% significance level (Table 1).

3.1. Germination rates and percentage

After analyzing the data for germination percentage and rate, it was revealed that with an increase in salinity levels, both germination percentage and rate decreased, and these differences among levels were statistically significant. The lowest germination percentage was observed at a salinity level of 12 dS/m along with 150 ppm of KNO_3, while the highest germination percentage was observed at non-saline stress level with 100 ppm potassium nitrate (Fig. 1). Across all applied salinity levels, the seeds primed with 150 ppm and 100 ppm KNO_3

exhibited the lowest and highest germination percentage, respectively (Fig. 1 and 2). In general, primed seeds with potassium nitrate at 50 and 100 ppm exhibited higher germination percentages compared to unprimed seeds at all salinity levels (Fig. 1).

Table 1. Analysis of variance for germination and seedling growth characteristics of Ornamental cabbage under priming and salinity stress

Sources of variation	df	Mean square							
		Germination percentage	Germination rate	Seedling length index	Allometric coefficient	Seedling tissue water content	Seedling fresh weight	Seedling dry weight	Mean daily germination
Salinity stress (S)	3	1751.05**	28.35**	5.303**	0.0923**	8.44**	0.0113**	0.000001 **	70.03**
Priming (P)	3	989.33**	5.75**	0.256**	0.0005**	0.23 ns	0.00009 ns	0.000000 ns	10.15 **
Interaction effect (S*P)	9	23.50 **	0.76 **	0.119**	0.0016**	1.00**	0.0015**	0.000002 **	9.02 **
Error	32	8.06	0.11	0.011	0.00009	0.17	0.00002	0.000000	0.77
CV (%)		4.92	5.44	11.78	9.76	0.43	3.52	13.41	6.71

Table 1. Continued

Sources of variation	df	Mean square							
		Seedling root length	Seedling shoot length	Root length/shoot length	Seedling length	root fresh weight	shoot fresh weight	Seedling root length	Seedling shoot length
Salinity stress (S)	3	11.32**	61.76**	0.769**	125.68**	0.00151**	0.0048**	3	11.32**
Priming (P)	3	0.20 **	1.17 *	0.016 **	0.60 ns	0.00001 ns	0.0002 **	3	0.20 **
Interaction effect (S*P)	9	0.55 **	1.71**	0.067**	3.19**	0.00013**	0.0011**	9	0.55 **
Error	32	0.03	0.28	0.001	0.37	0.000003	0.00001	32	0.03
CV (%)		6.36	12.05	7.63	8.21	8.32	3.27		6.36

The lowest germination rate was observed at a salinity level of 12 dS/m along with 150 ppm KNO_3, while the highest germination percentage was observed at a non-saline stress level with 100 ppm potassium nitrate (Fig. 2). Across all applied salinity levels, the lowest and highest germination rate were associated with seeds primed with 150 ppm and 100 ppm potassium nitrate, respectively (Fig. 1 and 2). Generally, seeds primed with 50 and 100 ppm KNO_3 exhibited higher germination rate compared to non-primed seeds at all salinity levels (Fig. 2).

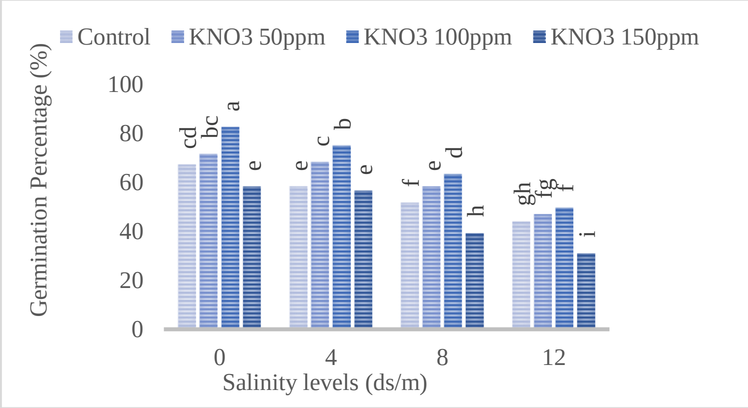

Fig. 1. Interaction effect of seed priming and salinity stress on Ornamental cabbage germination percentage, similar letters have no significant difference at 1% probability.

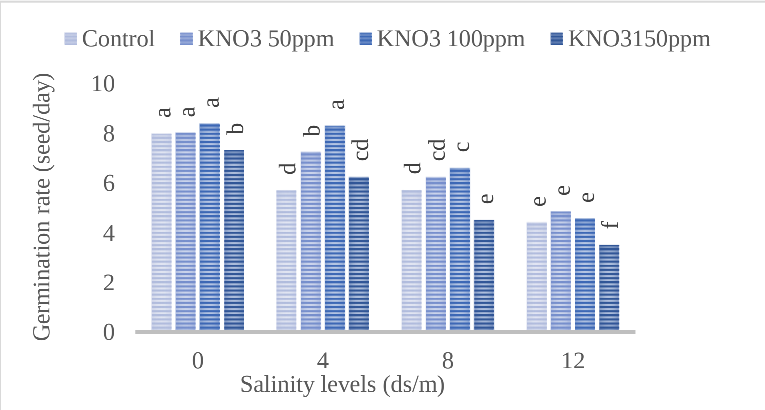

Fig. 2. Interaction effect of seed priming and salinity stress on Ornamental cabbage germination rate, similar letters have no significant difference at 1% probability.

3.2. Seedling length index

The interactive effect of salinity stress and priming was statistically significant at the 1% probability level for the seedling length index (Table 1). With increasing salinity levels, the seedling length index decreased. The highest level for this trait was observed at the non-saline stress level with 100 ppm potassium nitrate, followed by the level with 50 ppm potassium nitrate, which had a significant difference compared to non-primed seeds for this trait (Fig. 3). At salinity levels of 0, 4, 8 and 12 dS/m, the seedling length index in primed seeds with 100 ppm KNO_3 was higher compared to non-primed (control) seeds and had a significant difference between each other at 0, and 8 dS/m (Fig. 3).

3.3. Allometry Coefficient

The interactive effect of salinity stress and priming on the allometry coefficient was significant (Table 1). The lowest value for this trait was observed at the salinity level of 12 dS/m with 50 ppm KNO_3 (Fig. 4). The highest values for this trait at salinity levels of 4, 8, and 12 dS/m, were observed in seeds primed with 100 ppm potassium nitrate, non-primed seeds, and 150 ppm potassium nitrate, respectively (Fig. 4).

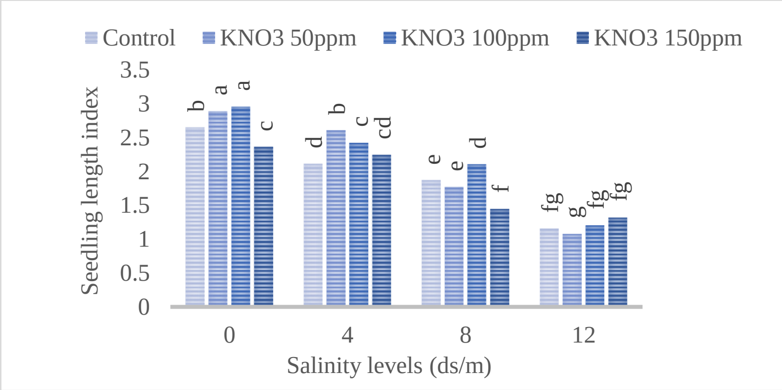

Fig. 3. Interaction effect of seed priming and salinity stress on Ornamental cabbage seedling vigor index, similar letters have no significant difference at 1% probability

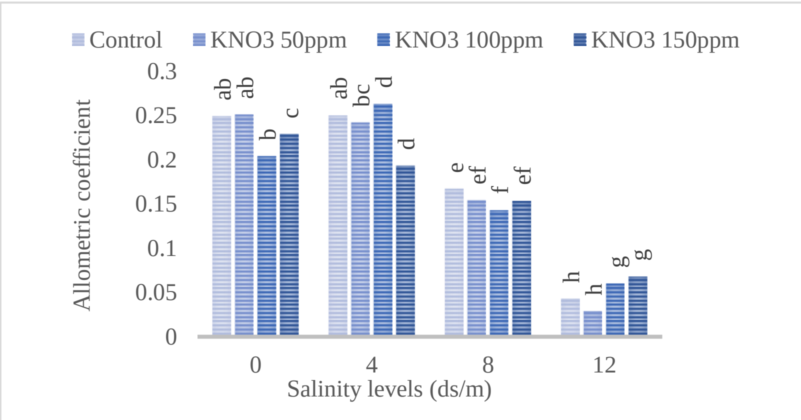

Fig. 4. Interaction effect of seed priming and salinity stress on Ornamental cabbage Allometry index, similar letters have no significant difference at 1% probability.

3.4. Seedling water tissue content

At the non-saline stress level, the application of KNO_3 did not have a significant effect on the tissue water content of the seedlings. However, at salinity levels of 4, 8, and 12 dS/m, the application of potassium nitrate improved the tissue water content of the seedlings in some concentrations (Fig. 5). The highest tissue water content of the seedlings was recorded at the salinity level of 4 dS/m with the application of 100 ppm KNO_3, while the lowest level for this trait was observed at the salinity level of 12 dS/m and at 0 ppm KNO_3. At 4 and 12 dS/m of salinity levels, the tissue water content of the seedlings was higher compared to control in all levels of KNO_3 (Fig. 5).

3.5. Seedling Fresh weight

The lowest value for the seedling fresh weight was observed at the salinity level of 12 dS/m and under non-primed conditions (0 ppm KNO_3), and had a significant difference with the application of KNO_3 priming at levels of 50 and 100 ppm (Fig. 6). The highest values for this trait were also recorded at the salinity level of 4 dS/m, with the application of 50 ppm KNO_3 (Fig. 6). Additionally, at non-salinity stress level, the lowest seedling fresh weight was associated with non-primed conditions (Fig. 6).

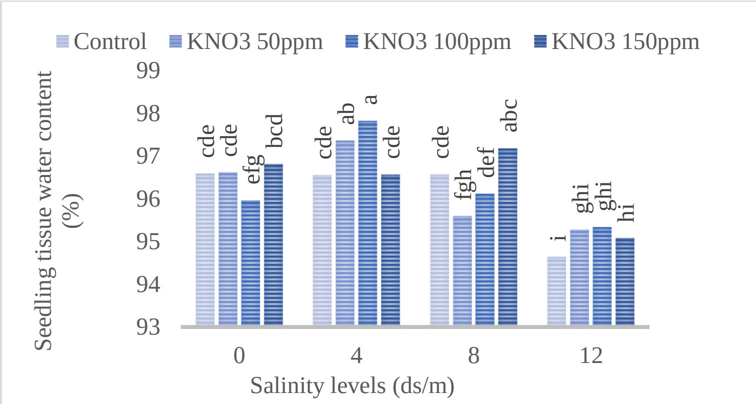

Fig. 5. Interaction effect of seed priming and salinity stress on Ornamental cabbage seedling tissue water content, similar letters have no significant difference at 1% probability.

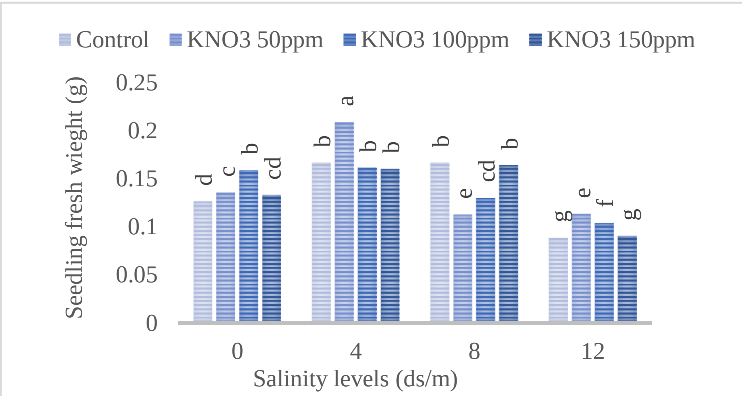

Fig. 6. Interaction effect of seed priming and salinity stress on Ornamental cabbage seedling fresh weight, similar letters have no significant difference at 5% probability.

3.6. Mean daily germination

The highest value for this trait was recorded at salinity levels of 4, 8, and 12 dS/m for primed seeds with 50 and 100 ppm KNO_3 and unprimed seeds, respectively (Fig. 7). As salinity level increased, the mean daily germination decreased, and the lowest value observed at a salinity level of 12 dS/m and primed seeds with 150 ppm KNO_3, which significantly differed from other salinity levels (Fig. 7).

3.7. Seedling dry weight

The lowest value for the seedling dry weight was observed at the salinity level of 0 dS/m and under 200 ppm KNO_3 (Fig. 8). The highest values for this trait at the salinity level of 0, 4, 8, and 10 dS/m, were recorded with the application of 150, 100, 200 and 100 ppm KNO_3, respectively (Fig. 8).

3.8. Seedling length

The length of the seedlings decreased with increasing salinity levels, but KNO_3 priming had a positive effect on the seedling length at some salinity levels. For instance, at the 4 dS/m salinity level, seeds primed with potassium nitrate at levels of 50, 100, and 150 ppm had greater seedling lengths compared to the control, and similarly, at the 12 dS/m salinity level, priming with 150 ppm KNO_3 resulted in significantly longer seedlings compared to other levels (Fig. 9). Among different treatments, the highest seedling length was observed with KNO_3 priming at 50 ppm and at non-salinity level, while the lowest was observed at 12 dS/m salinity level with KNO_3 at 50 ppm (Fig. 9).

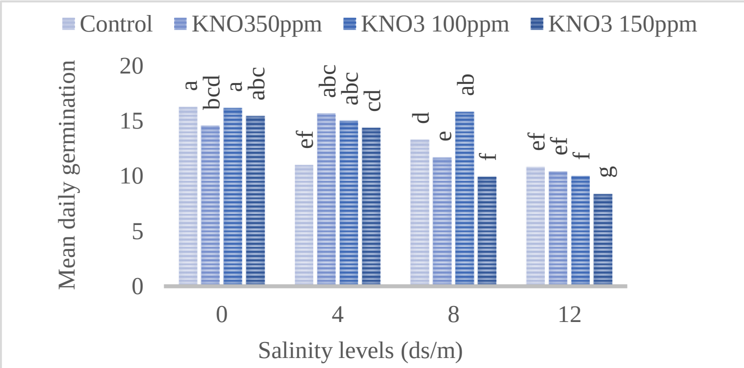

Fig. 7. Interaction effect of seed priming and salinity stress on Ornamental cabbage Mean daily germination, similar letters have no significant difference at 1% probability.

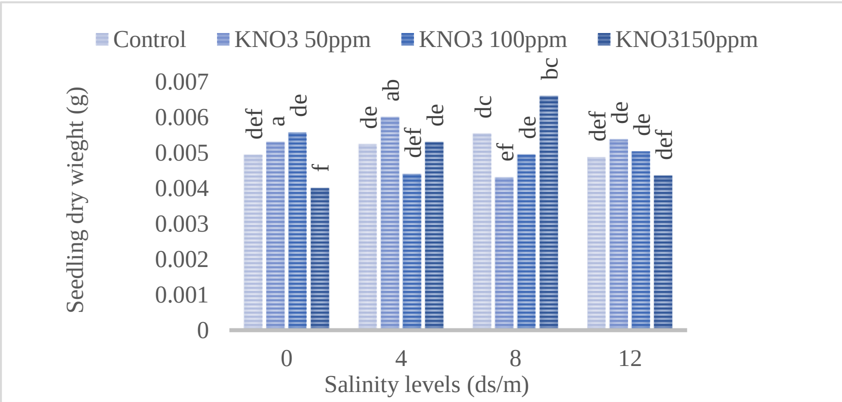

Fig. 8. Interaction effect of seed priming and salinity stress on Ornamental cabbage Seedling dry weight, similar letters have no significant difference at 1% probability.

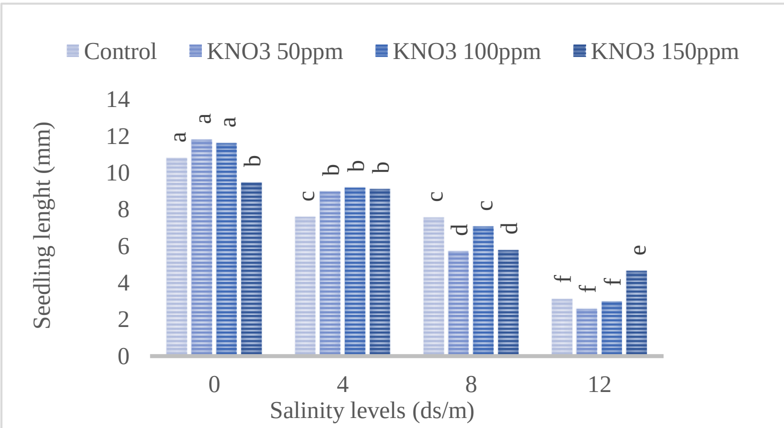

Fig. 9. Interaction effect of seed priming and salinity stress on Ornamental cabbage seedling length, similar letters have no significant difference at 5% probability

Regarding other traits including root length, shoot length, Root-to-shoot length ratio, root and shoot fresh weights, the interactive effects of salinity and priming were significant at the 1% probability level (Table 2). At 4, 8, and 12 dS/m salinity level, the highest root length was observed with the application of 150 ppm KNO_3, non-primed conditions, and 150 ppm KNO_3, respectively. Similarly, the highest shoot length was obtained with the application of 100 ppm potassium nitrate, non-primed conditions, and 150 ppm potassium nitrate, respectively (Table 2). For the fresh weight of roots and shoots, the highest values were observed at 4 dS/m salinity level with 100 ppm potassium nitrate. At non-salinity levels, priming also led to an increase in these traits compared to non-primed seeds (Table 2).

Root-to-shoot length ratio increased with increasing salinity levels, and at 12 dS/m salinity level in all priming and non-priming levels had greater value compared to other salinity levels (Table 2). The highest and lowest values for this trait were observed at salinity levels of 12 dS/m and 50 ppm KNO_3, and 4 dS/m salinity level with 100 ppm KNO_3, respectively (Table 2).

Table 2. Interaction effect of seed priming and salinity stress on Ornamental cabbage

Factors		Parameters				
Salinity (dS/m)	Priming (ppm)	Root length (mm)	Shoot Length (mm)	Shoot fresh weight (g)	Root fresh weight (g)	Root-to-shoot length ratio
0	0	4.30 ^{a}	6.50 ^{b}	0.104 ^{fg}	0.022 ^{e}	-0.376 ^{hi}
0	50	4.24 ^{a}	7.56 ^{a}	0.109 ^{efg}	0.027 ^{cd}	-0.429 ^{ij}
0	100	4.00 ^{a}	7.61 ^{a}	0.133 ^{c}	0.025 ^{d}	-0.441 ^{j}
0	150	3.62 ^{b}	5.83 ^{bc}	0.108 ^{efg}	0.025 ^{de}	-0.397 ^{hij}
4	0	3.30 ^{cd}	4.29 ^{d}	0.136 ^{bc}	0.030 ^{b}	-0.250 ^{de}
4	50	3.53 ^{bc}	5.44 ^{c}	0.168 ^{a}	0.041 ^{a}	-0.315 ^{fg}
4	100	2.73 ^{e}	6.44 ^{b}	0.123 ^{d}	0.038 ^{a}	-0.722 ^{k}
4	150	3.68 ^{b}	5.43 ^{c}	0.132 ^{c}	0.028 ^{bc}	-0.365 ^{gh}
8	0	3.25 ^{cd}	4.31 ^{d}	0.136 ^{bc}	0.031 ^{b}	-0.273 ^{ef}
8	50	2.22 ^{f}	3.49 ^{de}	0.103 ^{gh}	0.010 ^{g}	-0.375 ^{ghi}
8	100	3.13 ^{d}	3.94 ^{de}	0.113 ^{e}	0.017 ^{f}	-0.192 ^{d}
8	150	2.69 ^{e}	3.10 ^{ef}	0.142 ^{b}	0.022 ^{e}	-0.085 ^{c}
12	0	1.58 ^{g}	1.53 ^{gh}	0.081 ^{i}	0.007 ^{h}	0.041 ^{b}
12	50	1.43 ^{g}	1.14 ^{h}	0.110 ^{ef}	0.003 ^{i}	0.232 ^{a}
12	100	1.63 ^{g}	1.34 ^{h}	0.097 ^{h}	0.007 ^{h}	0.206 ^{a}
12	150	2.27 ^{f}	2.38 ^{fg}	0.078 ^{i}	0.012 ^{g}	0.020 ^{b}

Similar letters have no significant difference at 1% probability.

4. Discussion

Priming with KNO_3 has shown enhancement in both germination and growth parameters of ornamental cabbage seeds across various traits under investigation. Previous research documented in other literature also indicates the impact of priming on metabolic alterations such as DNA repair and heightened RNA biosynthesis (Bray, 2017) as well as the activation of respiration in seeds (Moaaz Ali *et al.*, 2020). Seeds in a desiccated state exhibit restricted metabolic functions, leading to the dormancy of defense mechanisms at the cellular level. Nevertheless, priming exhibits a favorable influence on the resistance of seedlings to salinity by inducing positive stimulatory effects during the initial phases of germination (Ozden *et al.*, 2017).

The data obtained from this experiment indicated that priming with 100 ppm KNO_3 performed better compared to other priming levels used in the experiment for most of the studied traits. Our study aligns with other researches where the use of KNO_3 at levels higher than 1% led to a decrease in germination parameters (Abnavi and Ghobadi, 2012). In these studies, the application of KNO_3 higher than 0.75% in tomato (Moaaz Ali *et al.*, 2020) and higher than 1% in wheat (Abnavi and Ghobadi, 2012) resulted in reduced germination percentage, indicating the unsuitability of external KNO_3 application at levels higher than a certain threshold. Among different concentrations of KNO_3 (1, 2, and 3%) used for priming in curly cabbage seeds, KNO_3 at 1% concentration was the most effective (Batool *et al.*, 2015).

In primed seeds of *primula* spp., the average emergence time, plant dry weight, and plant length were lower with potassium nitrate priming at 2 and 4% compared to other treatments, showing significant differences (Sajedi and Ghazi Nezami, 2019).

In this study, positive effects of potassium nitrate application on plant growth were observed under salinity levels of 4 and 8 dS/m, where primed seeds with this compound exhibited better seedling growth. KNO_3 act as an osmotic enhancer, thereby increasing water absorption and stimulating the germination of *Avena sativa* seeds (Sajedi and Ghazi Nezami, 2019). The positive effect of KNO_3 may be attributed to hormonal balance in the seed and a reduction in growth-inhibiting substances. KNO_3 plays a vital role in protoplasm formation and new cell formation, leading to increased plant length and serving as an essential element for plant growth. Also these positive effects may also result from increased enzyme activity in the embryonic axis, enhancing the transfer of compounds such as proteins and amino acids towards the embryonic axis (Ahmadvand *et al.*, 2023). The increase in germination rate with priming in this study may be due to increased activity of degrading enzymes such as α-Amylase, increased ATP levels, increased RNA and DNA synthesis, as well as increased number and performance of mitochondria (Bagheri *et al.*, 2022). Another reason for the superiority of seeds primed with potassium nitrate could be the achievement of hormonal balance in the seed and a reduction in growth-inhibiting substances such as abscisic acid, leading to the breaking of seed dormancy and acceleration of germination (Mojarab *et al.*, 2017).

The positive effect of priming on seedling length has been reported by other researchers (Abbasi Bideli and Ebdali Mashhadi, 2017; Alves *et al.*, 2021; Ebrahimi *et al.*, 2023). Potassium can increase the integrity of the membrane in plants under both normal and stressed conditions and also helps to repair the damaged membrane in seeds with low vigor (Batool *et al.*, 2015). On the other hand, KNO_3 prevents the accumulation of toxic ions in the embryo and can act as a stimulus for oxygen absorption or as a phytochrome cofactor (Mojarab *et al.*, 2017).

In this experiment the positive impact of priming on plant dry and fresh weight content was observed. Seed priming leads to an increase in reserve materials, proteins, and nucleic acids in the germinated seed, thereby enhancing the structure, establishment, and final performance of the plant (Paravar and Farahani, 2017).

Thus, it can be stated that halopriming with potassium nitrate plays an initial role in regulating enzyme activities through the production of germination metabolites in required amounts. The increase in root and shoot length with halopriming may also be due to cell wall extension stimulated by priming (Ren *et al.*, 2019).

5. Conclusion

The results of the current study showed that seed priming with potassium nitrate at 50 and 100 ppm improved germination-related traits and seedling growth. This increase in germination percentage and rate can accelerate of the seedling in absorption of water and nutrients. The increase in root-to-shoot length ratio indicates that at higher salinity levels, root growth exceeded compared to shoot growth, which may serve as a mechanism for salt stress tolerance in the plant, which needs more studies about it. The use of potassium nitrate may possibly mitigate the adverse effects of salinity stress resulting from sodium chloride application in the plant and seed environment. The application of suitable levels of halopriming compounds such as potassium nitrate is important. As observed in this study, the use of higher levels (150 ppm) of potassium nitrate resulted in a decrease in several of the studied traits. Due to the affordability and availability of potassium nitrate, its application as a priming agent to alleviate the negative effects of salinity stress caused by sodium chloride consumption in ornamental cabbage is feasible across a wide range of area. Attention to the effective level of this compound for effective germination is important.

Author Contributions

Conceptualization, Azadeh Mousavi Bazaz; methodology, Azadeh Mousavi Bazaz, Hajar Nemati and Amirali Salavati; software, Azadeh Mousavi Bazaz and Hajar Nemati; validation, Azadeh Mousavi Bazaz and Amirali Salavati.; formal analysis, Azadeh Mousavi Bazaz and Hajar Nemati; investigation, Azadeh Mousavi Bazaz; resources, Azadeh Mousavi Bazaz; data curation, Hajar Nemati and Amirali Salavati; writing-original draft preparation, Azadeh Mousavi Bazaz, Hajar Nemati and Amirali Salavati; writing—review and editing, Azadeh Mousavi Bazaz; visualization, Azadeh Mousavi Bazaz; Azadeh Mousavi Bazaz; project administration, Azadeh Mousavi Bazaz; funding acquisition, Azadeh Mousavi Bazaz
All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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Conflict of interest

The authors declare no conflict of interest.

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