Effects of Different Salt Types on Seed Germination and Seedling Growth of Kalidium foliatum Postprint

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Abstract

The petri dish method was employed to investigate the effects of different types of sodium salt stress on the seed germination rate, germination index, seedling shoot length, and root length of the desert plant Kalidium foliatum, analyzing the mechanisms by which K. foliatum seed germination and seedling growth adapt to different types of saline-alkali soils, thereby providing a scientific basis for the ecological restoration of different types of saline-alkali lands through K. foliatum cultivation. The results showed that: (1) NaCl, Na2SO4, NaHCO3, and Na2CO3 all significantly inhibited the germination rate and germination index of K. foliatum seeds. (2) Regression equation analysis revealed that the critical values for NaCl, Na2SO4, NaHCO3, and Na2CO3 tolerance during the germination period of K. foliatum were 325 mmol · L-1, 267 mmol · L-1, 245 mmol · L-1, and 166 mmol · L-1, respectively, with limit values of 671 mmol · L-1, 580 mmol · L-1, 569 mmol · L-1, and 389 mmol · L-1, respectively. Compared with neutral salts, K. foliatum seeds were more sensitive to alkaline salts during germination. (3) NaCl, Na2SO4, NaHCO3, and Na2CO3 all significantly inhibited the growth of K. foliatum seedling shoots and roots, with significant differences in the responses of K. foliatum seed germination and seedling growth to these four sodium salts. Compared with seedling shoots, seedling roots exhibited a more sensitive response, and root length could be used as a parameter for evaluating the salt tolerance of K. foliatum. The toxicity of alkaline salts was stronger than that of neutral salts. Based on the toxicity of salts to K. foliatum seed germination and seedling growth, the order was: NaCl $<$ Na2SO4 $<$ NaHCO3 $<$ Na2CO3.

Full Text

Effects of Different Salt Types on Seed Germination and Seedling Growth of *Kalidium foliatum*

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Abstract

The effects of different types of sodium salt stress on seed germination and seedling growth in the eremophyte *Kalidium foliatum* were studied by measuring the germination rate, germination index, bud length, and root length. In addition, the mechanism of seed germination and seedling growth when adapting to different types of saline-alkali land was explored; this work provides insights into the development of desert restoration and forage industry in arid areas through *K. foliatum* planting. Results showed that NaCl, Na_2SO_4, $NaHCO_3$, and Na_2CO_3 significantly inhibited the germination rate and germination index of *K. foliatum*. According to regression analysis, the critical values of NaCl, Na_2SO_4, $NaHCO_3$, and Na_2CO_3 were 325, 267, 245, and 166 mmol$\cdot$L^{-1} respectively, whereas the limit values were 671, 580, 569, and 389 mmol$\cdot$L^{-1} respectively. In addition, NaCl, Na_2SO_4, $NaHCO_3$, and Na_2CO_3 significantly inhibited the growth of *K. foliatum* shoots and roots. However, seed germination and seedling growth responses differed significantly according to the four sodium salt exposures. For example, the toxicity of alkaline salt was greater than that of neutral salt. In young seedlings, the shoots were more sensitive to salt exposure than were the roots. Furthermore, root length could be used as a parameter to evaluate the salt tolerance of *K. foliatum*. Finally, according to the degree of salt toxicity on seed germination and seedling growth, the toxicity to *K. foliatum* can be ranked as follows: NaCl $<$ Na_2SO_4 $<$ $NaHCO_3$ $<$ Na_2CO_3.

Keywords: *Kalidium foliatum*; neutral salt; alkaline salt; seed germination

Introduction

According to statistics, the global area of saline-alkali land is approximately [value] hm^2, accounting for one-tenth of the total land area; while China' s saline-alkali land area is 9.54$\times10^{6}$ hm^2, accounting for about one-tenth of the world' s saline-alkali land area [ ]. At present, how to rationally develop and utilize saline-alkali land has become one of the important issues facing agricultural and pastoral development in arid zones. Existing research shows that plants have different tolerance levels to saline-alkali environments at different growth stages, but both seed germination and seedling growth are very sensitive to saline-alkali stress. Currently, there have been many reports on the response of *Kalidium foliatum* seed germination to salt stress, with most studies focusing on the response to neutral salt stress [ ], while research on alkaline salt stress is relatively scarce. Zeng Youling et al. [ ] reported that low concentrations of NaCl significantly promoted seed germination of *K. foliatum*, and germination was highest at this salt concentration; however, both salt-free conditions and excessively high salt concentrations could have adverse effects on seed germination. At present, there are few studies on the effects of alkaline salts on seed germination and seedling growth of *K. foliatum*.

Kalidium foliatum is an important halophyte in arid regions, belonging to the perennial Chenopodiaceae family, *Kalidium* genus, with ecological functions of windbreak and sand fixation [ ], mainly distributed in saline-alkali soils, salinized sandy lands, salinized deserts, and saline lake margins in Xinjiang, Qinghai, and Gansu. At the same time, *K. foliatum* can be used as salt-containing forage, serving as one of the main livestock forages in arid regions, and its seeds can be used as high-quality feed for livestock [ ]. As a native plant in arid regions, *K. foliatum* can grow on saline-alkali land, and simultaneously needs to absorb large amounts of salt ions from the saline soil to maintain growth, thereby reducing soil salt content and improving soil physicochemical properties and increasing soil organic matter [ ]. Therefore, planting *K. foliatum* on saline-alkali land can, on the one hand, improve the saline-alkali land, and on the other hand, provide large amounts of forage, achieving both ecological and economic benefits.

Therefore, this study focuses on analyzing and comparing the effects of different forms of sodium salts on seed germination and seedling growth of *K. foliatum*, aiming to explore the effects of different types of salt stress on seed germination and seedling growth of halophytes, in order to provide a scientific basis for planting forage *K. foliatum* on saline-alkali land.

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1. Materials and Methods

1.1 Seed Collection

At the end of [month], fully mature *K. foliatum* seeds were collected from the Halophyte Garden at Karamay Agricultural Park. The seeds were placed at room temperature, air-dried, cleaned of impurities, sorted, and stored in bags for later use.

1.2 Germination Experiment

Uniformly sized, plump *K. foliatum* seeds were selected and placed in petri dishes (diameter [value] cm) lined with filter paper, with [value] seeds per dish. Sodium chloride (NaCl) and sodium sulfate (Na_2SO_4) (neutral sodium salts), and sodium bicarbonate ($NaHCO_3$) and sodium carbonate (Na_2CO_3) (alkaline sodium salts) were selected as treatment salts. Distilled water was used as the control (CK). Salt solutions at concentrations of [value] mmol · L^{-1} were used to saturate the filter paper. [value] replicates were set up, and the dishes were placed in an incubator with 12 h light/12 h dark conditions. The number of germinated seeds was counted daily, with radicle emergence from the seed coat used as the germination standard. Final germination rate was calculated, and bud length and root length were measured.

1.3 Germination Parameters and Bud/Root Length Measurement

Accumulative germination rate (%) = (daily count of germinated seeds / total number of tested seeds) × 100%; Final germination rate (%) = (total number of germinated seeds / total number of tested seeds) × 100%; Germination index (GI) = Σ(G /D), where G is the number of germinated seeds on day t, and D is the corresponding germination day.

1.4 Data Analysis

SPSS 16.0 statistical software was used for one-way and two-way ANOVA. Duncan' s multiple comparison test was applied at a significance level of $P < 0.05$. SigmaPlot 12.5 was used for graphing.

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2. Results

2.1 Effects of Different Salt Types on Seed Germination Characteristics

The final germination rate and germination index of *K. foliatum* seeds were significantly affected by salt concentration, salt type, and their interaction (Table 1). At 100 mmol · L^{-1}, NaCl and Na_2SO_4 did not significantly reduce the germination rate of *K. foliatum* seeds, which were 84.0% and 85.0% respectively, compared to the control (86.0%). However, $NaHCO_3$ and Na_2CO_3 significantly reduced germination rates to 76.0% and 66.0% respectively. As salt concentration increased, the germination rate and germination index of *K. foliatum* seeds decreased significantly under all salt treatments (Table 2).

2.2 Regression Analysis Between Germination Rate and Salt Concentration

Through regression analysis of the relationship between *K. foliatum* seed germination rate and different salt concentrations, the inhibitory effects of NaCl, Na_2SO_4, $NaHCO_3$, and Na_2CO_3 on seed germination were analyzed. The results showed that as salt concentration increased, the germination rate of *K. foliatum* decreased, and germination rate was significantly negatively correlated with NaCl, Na_2SO_4, $NaHCO_3$, and Na_2CO_3 concentrations (Fig. 2). The salt tolerance critical value and limit value during seed germination refer to the salt concentrations corresponding to germination rates of 50% and 10%, respectively. According to the regression equations, the salt tolerance critical values of *K. foliatum* seeds during germination for NaCl, Na_2SO_4, $NaHCO_3$, and Na_2CO_3 were 325, 267, 245, and 166 mmol · L^{-1}, respectively, and the limit values were 671, 580, 569, and 389 mmol · L^{-1}, respectively. Based on the critical and limit values for seed germination under different salts, the salt tolerance of *K. foliatum* can be ranked as: NaCl > Na_2SO_4 > $NaHCO_3$ > Na_2CO_3.

[Figure 2: see original paper]

2.3 Effects of Different Salt Types on Shoot and Root Length of *K. foliatum* Seedlings

The shoot length and root length of *K. foliatum* seedlings were significantly affected by salt concentration, salt type, and their interaction (Table 1). At low concentrations (100 mmol · L^{-1}), NaCl and Na_2SO_4 did not significantly inhibit shoot and root growth, while $NaHCO_3$ and Na_2CO_3 significantly reduced shoot and root length. As salt concentration increased, shoot and root length decreased significantly under all salt treatments. At 200 mmol · L^{-1}, NaCl, Na_2SO_4, $NaHCO_3$, and Na_2CO_3 reduced shoot length by 21.60%, 24.13%, 44.62%, and 50.21%, respectively, and root length by 33.01%, 27.59%, 68.84%, and 60.71%, respectively. At 300 mmol · L^{-1}, shoot length decreased by 30.49%, 32.18%, 73.08%, and 82.11%, respectively, and root length by 54.40%, 47.36%, 80.01%, and 86.23%, respectively. These results indicate that root length was more sensitive to salt stress than shoot length, and the inhibitory effects of different salts on seedling growth can be ranked as: NaCl < Na_2SO_4 < $NaHCO_3$ < Na_2CO_3.

[Figure 3: see original paper]

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3. Discussion

Currently, research on *K. foliatum* has mainly focused on forage science [ ], saline-alkali land restoration [ ], and biology [ ]. This study investigated the effects of neutral and alkaline salts on seed germination and seedling growth of *K. foliatum*. Salt stress has obvious inhibitory effects on seed germination and seedling growth of halophytes, mainly manifested as reduced germination rate, delayed germination time, extended germination period, and inhibited shoot and root growth, which is consistent with most reported results [ ]. *K. foliatum* seeds showed characteristics of low concentration promotion and high concentration inhibition. Within the 0–200 mmol · L^{-1} salt concentration range, the germination rate of *K. foliatum* still exceeded [value]%. The salt tolerance critical value during seed germination was 325 mmol · L^{-1}, and the limit value was 671 mmol · L^{-1}, which is higher than other halophytes such as *Tamarix hispida*, *Lycium ruthenicum*, and *Apocynum venetum* [ ].

The responses of *K. foliatum* seed germination and seedling growth to the four salt stresses showed significant differences, with alkaline salt toxicity being greater than neutral salt toxicity. The germination index, as an important indicator of seed quality, is often considered to reflect seedling emergence uniformity—higher germination indices indicate more uniform emergence. The germination index of *K. foliatum* showed significant differences in response to different concentrations and salt types, indicating that besides the toxicity of Na^+ inhibiting seed germination and seedling growth, the high pH of alkaline salts also inhibits seed germination and seedling growth, similar to the inhibitory effects reported in other plants such as *Lycium ruthenicum*, *Lolium multiflorum*, and *Elytrigia elongata* [ ]. Different concentrations and salt types significantly delayed seedling emergence time of *K. foliatum*, with higher salt concentrations resulting in less uniform emergence, and emergence uniformity under alkaline salt treatments being significantly lower than under neutral salt treatments.

Due to differences among plant species, different tissues and organs respond differently to salt stress. In some plants, the above-ground parts are more sensitive to salt stress than roots when young, while in other plants, roots are more sensitive than above-ground parts. Under different salt types and concentrations, the reduction in root length of *K. foliatum* seedlings was significantly greater than that in shoot length, indicating that roots are more sensitive to salt than above-ground parts in this species. This may be because *K. foliatum*, as a typical euhalophyte, needs to absorb and accumulate large amounts of salt ions in vacuoles during its growth and development to maintain normal osmotic potential in cell sap, thereby alleviating salt damage to seedling cotyledons [ ]. Therefore, compared with shoot length and germination rate, root length better reflects the salt-alkali tolerance of *K. foliatum* during germination.

4. Conclusion

Kalidium foliatum seeds showed high salt-alkali tolerance during germination. The responses to different salt types showed significant differences, with neutral salt toxicity being weaker than alkaline salt toxicity. Root length is more suitable as an indicator for evaluating the salt-alkali tolerance of *K. foliatum*. Therefore, *K. foliatum* seedlings can grow normally in saline-alkali land with salt content of 200 $mmol \cdot L^{-1}$.

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Note: Figure translations are in progress. See original paper for figures.