Effects of Salt-Drought Coupled Stress on Seed Germination and Seedling Growth of *Salsola ferganica* (Postprint)

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Abstract

This study employed a two-factor combination experiment to investigate the effects of salt (NaCl) and drought (PEG 6000) on seed germination and seedling growth of Salsola ferganica. The results showed: Seed germination of Salsola ferganica could tolerate relatively high concentrations of NaCl and PEG stress. Under low-concentration NaCl or PEG stress, the germination rates of de-winged and winged seeds showed no significant difference compared with the control; under high-concentration NaCl or PEG treatments, the germination rate of de-winged seeds remained above 35%, demonstrating strong salt and drought tolerance; under combined salt-drought treatments, different low concentrations of PEG could significantly alleviate the inhibitory effect of medium-concentration NaCl on seed germination. With increasing NaCl concentration, the recovery germination rate of winged seeds gradually increased, whereas that of de-winged seeds remained at a relatively low level; as PEG concentration increased, the recovery germination capacity of both seed types decreased significantly; under combined salt-drought treatments, the recovery germination rates of both seed types showed the same trend as under NaCl stress alone. NaCl or PEG exerted stronger effects on de-winged seed seedlings than on winged seed seedlings, particularly under PEG treatment; with increasing NaCl or PEG concentration, the plant height and root length of seedlings from both seed types decreased; under combined salt-drought treatments, low-concentration NaCl had a smaller effect on de-winged seed seedlings than on winged seed seedlings (except for the 100 $mmol \cdot L^{-1}$ NaCl + 25 $g \cdot L^{-1}$ PEG treatment), medium-concentration NaCl had a stronger effect on de-winged seed seedlings than on winged seed seedlings, and under high-concentration NaCl treatments, the plant height and root length of seedlings from both seed types decreased with increasing PEG concentration. These results demonstrate that Salsola ferganica possesses strong salt and drought tolerance during the germination and seedling stages, and that salt-drought combination can alleviate salt ion toxicity to some extent, which

holds important ecological significance for its survival through early harsh environments; the seed wing plays an important role in enabling seeds to enter secondary dormancy under stress, thereby replenishing the soil seed bank.

Full Text

Effect of Salt Coupled with Drought Stress on Seed Germination and Seedling Growth of *Salsola ferganica*

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Abstract

In this study, the effects of different stress conditions—salt (NaCl), drought (PEG6000), or salt coupled with drought—on seed germination (SG) and seedling growth (SG) of *Salsola ferganica* were investigated. Results showed that: (1) Seed germination of *S. ferganica* could tolerate relatively high NaCl and PEG concentrations. There was no effect of low NaCl and PEG concentrations on SG; however, at higher concentrations, SG was significantly decreased but still exceeded 35%, suggesting that *S. ferganica* was salt- or drought-tolerant. Under salt stress coupled with drought stress, the inhibition of seed germination was significantly relieved by increasing the PEG concentration under low and medium concentrations of NaCl. (2) Under NaCl stress, the recovery rate of winged perianth (WWP) seeds increased with increasing NaCl concentration, while that of de-winged perianth (NWP) seeds remained at low level. With increasing PEG concentration, however, the recovery rates of both WWP and NWP seeds were significantly decreased. The recovery of germination of WWP and NWP seeds under salt coupled with drought stress was similar to that under NaCl stress. (3) The effect of NaCl or PEG treatment on the growth of seedlings from NWP seeds of *S. ferganica* was stronger than that from WWP seeds. With increasing NaCl or PEG concentration, the growth of plant height and root length of seedlings from both WWP and NWP were inhibited. Under salt stress coupled with drought stress, the effect of low NaCl concentration on the growth of WWP seedlings was less than that of NWP seeds (except for 100 mmol·L ^{1} NaCl + 25 g·L ^{1} PEG). The effect of NaCl concentration on seedlings from NWP seeds was stronger than that on WWP seeds. With increasing PEG concentration at high NaCl level, the growth of plant height and root length of seedlings from WWP and NWP were inhibited. In conclusion, *S. ferganica* was much more tolerant to salt and drought in seed germination and seedling growth. Salt stress coupled with drought stress could relieve salt ion toxicity to some extent, which has important ecological significance for *S. ferganica* to survive the early harsh environment. Moreover, the fruit wing plays an important role in putting the seed to dormancy under stress and then replenishing the soil seed

bank.

Keywords: *Salsola ferganica*; seed germination; osmotic stress; ion toxicity; winged perianth seed; Gurbantunggut Desert

1. Materials and Methods

Seeds of *Salsola ferganica* were selected with sizes ranging from 3.0 to 4.5 mm and stored at 4°C prior to the experiments. Germination tests were conducted under controlled conditions of 12 h light/12 h dark photoperiod at 25°C, 50% relative humidity, and light intensity of 100 mol · m ^{2} · s ^{1} provided by LED light sources (RXZ-500D-LED). Seeds were hydrated for 24 hours and observations were made over a 15-day period.

Stress treatments were applied as follows: NaCl at concentrations of 50, 100, 300, 500, 700, and 1000 mmol · L ^{1}; PEG6000 at concentrations of 25, 50, 100, 150, 200, and 300 g · L ^{1}; and combined NaCl+PEG treatments including 100 mmol · L ^{1} + 25 g · L ^{1}, 100 mmol · L ^{1} + 50 g · L ^{1}, 100 mmol · L ^{1} + 100 g · L ^{1}, and 300 mmol · L ^{1} + 100 g · L ^{1}. The corresponding osmotic potentials were -24, -49, -149, -248, -347, and -496 kPa for NaCl treatments, and -20, -50, -150, -300, -500, and -1000 kPa for PEG treatments, respectively.

Germination percentage was calculated as RSn = (RSPQ / ¸PQ) × 100%, where RSPQ is the number of germinated seeds and ¸PQ is the total number of seeds. The recovery rate was assessed when germination fell below 5% or exceeded 70%. Statistical analyses were performed using SPSS 22.0 software with One-way, Two-way, and Three-way ANOVA as appropriate. Graphs were prepared using GraphPad Prism Version 5.01.

2. Results

2.1 Seed Germination Low concentrations of NaCl (<100 mmol · L ^{1}) did not significantly affect seed germination of *S. ferganica*, whereas higher concentrations inhibited germination, though rates remained above 35% even at 1000 mmol · L ^{1} NaCl. Similarly, PEG treatments below 50 g · L ^{1} had minimal impact, but higher concentrations progressively reduced germination percentages.

Under combined salt and drought stress, an interesting interaction was observed. At low to medium NaCl concentrations, increasing PEG levels significantly relieved the inhibitory effects on germination. However, at high NaCl concentrations (300 mmol · L ^{1}), additional PEG stress exacerbated the inhibition.

The recovery rates of germination differed significantly between winged perianth (WWP) and de-winged perianth (NWP) seeds. Under NaCl stress alone, WWP seeds showed increased recovery rates with rising NaCl concentrations, while NWP seeds maintained consistently low recovery rates. Under PEG stress, both seed types exhibited significantly decreased recovery rates. Under combined stress, the recovery pattern resembled that under NaCl stress alone, with WWP seeds showing superior recovery capacity.

2.2 Seedling Growth The effects of stress treatments on seedling growth were more pronounced for seedlings derived from NWP seeds compared to those from WWP seeds. Both NaCl and PEG stresses inhibited plant height and root length in a concentration-dependent manner for both seed types.

Under combined salt and drought stress, low NaCl concentrations (100 mmol·L ^{1}) had less inhibitory effect on WWP seedling growth compared to NWP seedlings, except for the treatment combination of 100 mmol·L ^{1} NaCl + 25 g·L ^{1} PEG. At high NaCl concentrations, increasing PEG levels further inhibited both shoot and root growth regardless of seed type. The differential response between WWP and NWP seedlings suggests that the fruit wing provides a protective advantage during early seedling establishment under stressful conditions.

Figures

[Figure 3: see original paper] Effect of salt or drought stress on seedling growth of *S. ferganica*

[Figure 4: see original paper] Effect of salt coupled with drought stress on seed germination of *S. ferganica*

[Figure 5: see original paper] Effect of salt coupled with drought stress on seed germination rate of *S. ferganica*

[Figure 6: see original paper] Effect of salt coupled with drought stress on seedling growth of *S. ferganica*

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