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The Potential of Priming to Improve the Germination and Growth of Some Varieties of Wheat (*Triticum durum* Desf.)

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ABSTRACT

Seed priming is a pre-germination treatment administered through various chemical, physical and biological agents, which induce mild stress during the early phases of germination. Priming facilitates synchronized seed germination, better seedling establishment, improved plant growth and enhanced yield, especially in stressful environments.

The present work compares the effects of priming on the germination and tolerance of some Tunisian wheat varieties to saline stress, as evaluated by the germination percentage, germination index, coefficient of velocity, vigor index, seedling length, dry weight and seed water content. NaCl (100 mM) was used to induce salinity stress. Seeds of the sixth cultivar were primed with water (0 mM), sodium nitroprusside (0.06 mM), calcium silicate (8 mM), potassium nitrate (10 mM), wich not only improved the germination percentage but also considerably reduced germination time and increased germination index (GI), coefficient of velocity (CV) and vigor index indicating the potential for tolerating saline conditions. Seedling growth (seedling length, dry weight) and the water content of seeds primed with distilled water (H_2O), sodium nitroprusside (SNP), calcium silicate (Si) and potassium nitrate (KNO_3) were significantly greater than those of other non-primed seeds under saline conditions. Priming with different agents was effective, nevertheless, the best results were obtained with SNP, Si and KNO_3. On the other hand, seed priming with various priming agents has proven to be effective in inducing salt tolerance in terms of germination parameters, seedling characteristics, and water content for six local commercial wheat cultivars.

Keywords: wheat, priming, germination, H_2O, SNP, Si, KNO_3.

Abbreviations: *T* - Control; *H_2O* - Water; *SNP* - Sodium Nitroprusside; *KNO_3* - Potassium Nitrate; *Si* - Calcium Silicate; *MGT* - Mean germination time; *GP* - Germination percentage; *GI* - Germination index; *CV* - Coefficient Velocity; *VI* - Vigor index; *SL* - Shoot length; *RL* - Root length; *DW S* - Dry weight shoot; *DW R* - Dry weight root; *WC S* - Water content shoot; *WC R* - Water content root.

INTRODUCTION

Germination is a critical stage in plant growth, starting with the active uptake of water and ending with the emergence of the primary root from the seed coat. Therefore, soaking plays a vital role in germination and is affected by many environmental stresses (Atashi et al., 2014). As an environmental stress, salinity reduces seed germination. Salinity can affect the germination process, growth (Bagwasi et al., 2020) and establishment of plants by increasing osmotic pressure, which reduces water absorption, imbalances ions and causes oxidative damage (Tahjib-Ul-Arif et al., 2018). This inhibits various biochemical and physiological activities causing salt toxicity (Zörb et al., 2019). Seed priming is one of the most effective and cost-effective practices for mitigating the antagonistic effects of salinity (Aziz et al., 2021). Seed priming is a technique in which seeds hydrated by water or osmotic solutions for a pre-established time without allowing the primary root protrusion.

There are three phases (Bewley et al., 2013): (1) imbibition and imbibitional damage, (2) the lag phase, and (3) root emergence. During imbibition, the seeds are soaked in priming medium to break seed dormancy (Bewley et al., 2013), which is a

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key step for germination. During mRNA synthesis, proteins are synthesized, and mitochondrial repair and other light metabolic activities are observed.

Seed priming is not very laborious, inexpensive or low-risk. It mainly improves the germination percentage, germination rate and other growth parameters for many cereal crops, including wheat. These priming techniques include hydropriming, osmopriming and halopriming (Pradhan et al., 2017). Pre-farming seed treatments, including seed priming, allow seedling to grow quickly and evenly, improving their performance under stressful conditions (Worku et al., 2016). The dormancy of seeds that become dormant due to environmental conditions during storage, can be interrupted through several seed improvement techniques, such as seed priming, which includes hydration and dehydration treatments (Eskandari and Kazemi, 2011). Seed priming is considered a more effective technique for improving seed yield, including that of wheat under stress conditions (Toklu et al., 2015). The harmful effects of high salt absorption for plants are due to osmotic water retention and specific ionic effects on plant cells. Water is captured by osmosis in salt solutions; when the salt concentration increases, less water becomes available to the plant. In the end, poor germination and seedling development occur in saline soil. This major problem severely disrupts growth and development and reduces agricultural production (Pradhan et al., 2017). The aim of this study was to improve the germination rate and assess the effect of water priming on six different wheat varieties.

MATERIAL AND METHODS

Plant material and priming treatments

Seeds of *Triticum durum* Desf *cv*. Razzek, Mâali, Khiar, Oum Rabia, Nasr and Chili were obtained from the National Institute of Agronomic Research of Tunisia (INRAT). Seeds were sterilized with 20% bleach for 20 minutes and rinsed three times with ultrapure water. After sterilization, the seeds were treated with different priming agents such as distilled water (H_2O), sodium nitroprusside (NPS), calcium silicate (Ca_2SiO_4), and potassium nitrate (KNO_3).

The priming treatment was performed for 24 hours. After priming, seeds were rinsed three times with distilled water and dried to the initial weight of unprimed seeds for 48 h at room temperature. Then, unprimed and primed seeds were germinated in Petri dishes containing sterile filter paper. An unprimed control treatment was also used for comparison. Three replicates of Petri dishes, each containing 20 seed, constituted a group (treatment, time of pre-sowing and agent). The samples were placed in an incubator at a constant temperature of 25±2°C and then examined every 12 h to evaluate the germination of new seeds. The germination process was defined according to (Côme, 1970) as the appearance of root tips through the seed coat reaching 1 mm in length.

1. Germination assessment

We assessed the following parameters:

- The germination percentage (GP) was calculated using the following formula (Leist et al., 2003):

$$GP\ (\%) = (\text{total number of germinated seeds} / \text{total number of seeds}) \times 100$$

- Mean germination time (MGT) was calculated according to the following formula (Eliss, 2022):

$$MGT = \sum (ni/di)$$

where: ni is the number of germinated seeds and di is the day of counting.

- The germination index (GI): was calculated according to the equation (Kader and Jutzi, 2004):

$$GI = \sum(Ti \times Ni)$$

where Ti is the number of days after sowing and Ni is the number of germinated seeds in the day.

- Coefficient of velocity (CV): calculated according the formula of Kader and Jutzi, (2004):

$$CV = (\sum Ni/100) \times (\sum TiNi)$$

- Vigor Index (VI): determined using the formula of (Abdul-Baki and Anderson, 1970):

$$VI = [TG\ (\%) \times \text{seedling length (mm)}] / 100$$

2. Growth parameters

After 7 days, three replicate seedlings per group (10 treatments) were used to determine the seedling fresh weight (SFW). Then, each seedling was dried at 45°C for 72 h until a constant weight was reached to quantify the seedling dry weight (SDW) (Mehmood et al., 2023).

- The seed water content (WC) was calculated according to the following equation:

WC (mL) = (SFW-SDW) / SFW

Statistical Analysis

Two-way analysis of variance (ANOVA), with treatment and variety of priming and their interaction as factors, was performed for the whole dataset using XLSTAT software version 2016. The means were compared using Duncan's test at $p<0.05$ when significant differences were found. Correlation analysis was performed using the correlation test and the linear regression program in XLSTAT software (Table 1).

RESULTS AND DISCUSSION

Germination parameters

Analysis of variance revealed significant differences ($p \leq 0.001$) among the salt and NPS, Si and KNO_3 treatments and varieties for all germination attributes (Table 1). Varieties, treatment and their interaction "treatments × varieties" were highly significant for these traits ($p \leq 0.001$). The results revealed a significant effect of salt and treatment on the latency time, GP, MGT, GI, CV and VI.

Table 1. Two-way analysis of variance (ANOVA) 2 of seeds characteristics by priming agent, treatment and their interaction

	Varieties		**Treatments**		**Varieties × Treatements**	
	F-Value	*P*	*F-Value*	*P*	*F-Value*	*P*
SL	262.509	< 0.0001	1016.855	< 0.0001	15.622	< 0.0001
RL	115.608	< 0.0001	1552.690	< 0.0001	17.303	< 0.0001
DWS	1478.589	< 0.0001	2103.287	< 0.0001	1236.291	< 0.0001
DWR	2508.829	< 0.0001	2743.381	< 0.0001	1879.778	< 0.0001
WCS	228.992	< 0.0001	184.201	< 0.0001	5.770	< 0.0001
WCR	121.405	< 0.0001	367.101	< 0.0001	11.751	< 0.0001
GP	211.550	< 0.0001	455.154	< 0.0001	21.833	< 0.0001
MGT	45.558	< 0.0001	437.204	< 0.0001	15.773	< 0.0001
GI	61.745	< 0.0001	424.196	< 0.0001	16.828	< 0.0001
CV	53.055	< 0.0001	61.001	< 0.0001	14.544	< 0.0001
VI	258.512	< 0.0001	1486.797	< 0.0001	20.674	< 0.0001

Statistically non-significant at $p>0.05$; Statistically significant at $p \leq 0.05$; Statistically significant at $p \leq 0.01$; Statistically significant at $p \leq 0.001$.

The SNP significantly reduced the latency time for all the wheat varieties studied under salt and no salt stress, except for chili under salt (Figure 1).

Based on the mean values, the GP significantly increased in the different varieties pretreated with different agents (SNP, Si, KNO_3) compared with that in the T treatment (control) (Table 2, Figure 2a). The highest percentage of seed germination (≥90%) was observed in the control treatments (without stress) and the maximum decrease in germination count was recorded at treatment with 100 mM NaCl.

GP was significantly reduced under salt stress for the sixth varieties and Razzek Mâali Khiar and Chili were the most affected by salinity. Seed priming significantly enhanced the germination percentage under all agent priming conditions irrespective of variety ($p \leq 0.001$) (Table 1, Figure 2b).

In addition, the results showed high germination (MGT) and less time to be taken for germination (p<0.001), where the MGT of the control T was approximately 40 h, and all priming had a significant effect on reducing MGT, especially for SNP priming, where we found that MGT decreased from 40 h to 17 h and 18 h for Razzek and Khiar, respectively (Table 1, Figure 3a).

For stressed seeds (Table 1, Figure 3c), MGT was significantly affected by salinity especially for Mâali. In contrast, MGT was reduced for all varieties particularly with SNP priming.

All priming agent agents had a significant effect (p<0.001) on the germination index (Tables 1, Figure 4a), especially for the SNP priming agent, for which the GI increased from 0.4 h on average to approximately 1 h, after which we found Si and KNO_3 priming agents.

The germination index (GI) was significantly (p<0.001) affected by NaCl treatment (100 mM) for all varieties (Table 1, Figure 5b). In addition to stressed seeds, NPS priming had a highly significant effect on the GI, where the GI increased from approximately 0.2 h to 0.9 h. In second place, Si and KNO_3 priming had a significant effect on the GI also. Overall, all priming agents induced GI where the averages were greater than those of the controls.

The coefficient of velocity (CV) is affected by the pretreatment agents Si and KNO_3 (Table 1, Figure 5a), for Razzek the average values (128181 and 112286, respectively) are greater than those for control T. Si priming had a significant effect on Oum Rabiaa and Nasr, especially Khiar, where the average CV ranged from 83427 to 164618 (Table 1, Figure 5a).

Under salt stress, salt (S) affected the CV only for Razzek Mâali, Khiar and Chili, however, for Oum Rabiaa and Chili, the CV increased significantly (p<0.001) (Table 1, Figure 5b).

For Razzek, Khiar and Chili, all priming agents (H_2O, SNP, Si, KNO_3) significantly increased the CV. For Mâali, H_2O, Si and KNO_3 had a positive effect on the CV. For Oum Rabiaa, only silicon had an effect on the CV (p<0.001) (Table 1, Figure 5b).

The priming agents used (H_2O, SNP, Si, KNO_3) had a highly significant impact on the vigor index (p<0.001) (Table 1, Figure 6a). The vigor index was affected by pretreatment and the average vigor index was greater than that of the T_0 control for all varieties except for Razzek under KNO_3 priming.

In addition, under salt stress all priming agents had a positive effect on VI, particularly, at SNP priming for Razzek, Mâali, Khiar, Nasr and Chili. For Oum Rabiaa, Si priming had the most positive effect (p<0.001) (Table 1, Figure 6b).

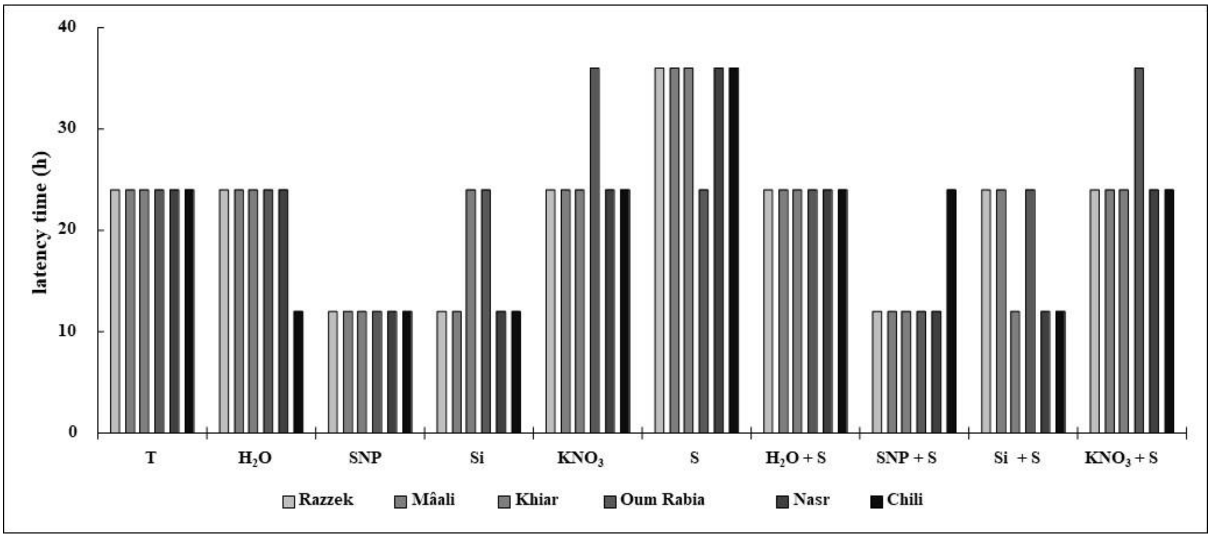

Figure 1. The latency time of *Triticum durum* varieties primed with different agents (SNP, Si, KNO_3) at 24 h with (a) and without salt stress (b). The data are the means of 3 ± SE.

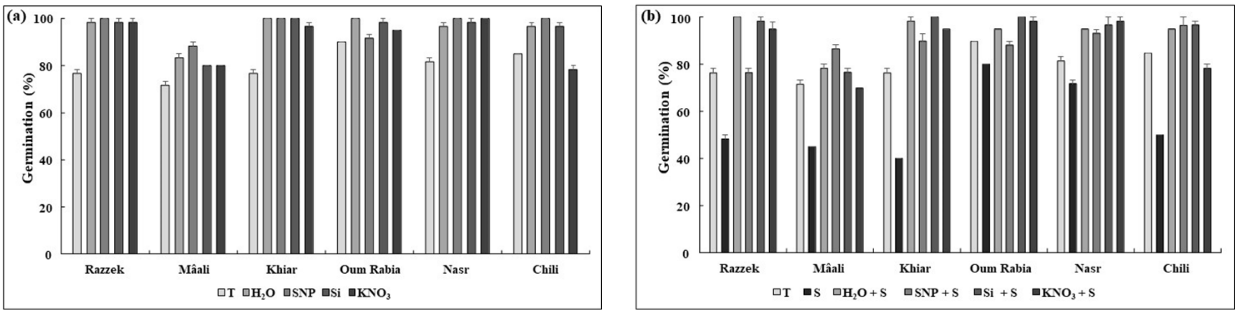

Figure 2. Germination percentage of *Triticum durum* varieties primed with different agents (SNP, Si, KNO_3) at 24 h with (a) and without salt stress (b). The data are the means of 3 ± SE.
Values followed by at least one letter are not significantly different at *p<0.05* according to Duncan's test.

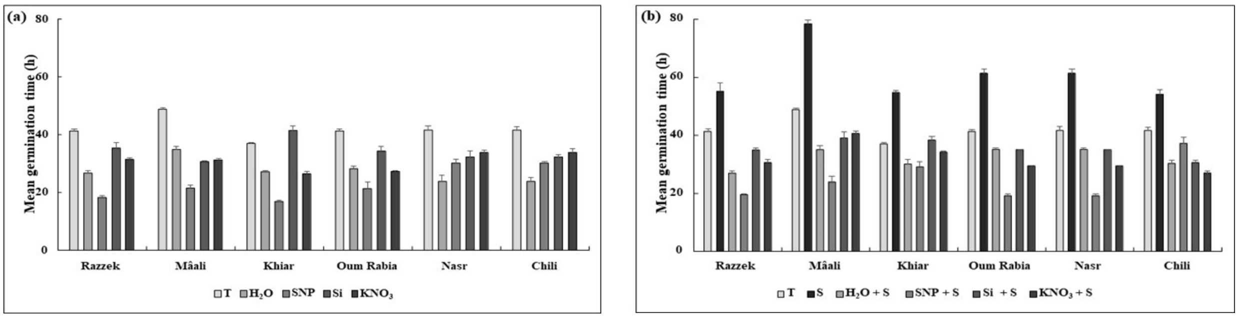

Figure 3. Mean germination time of *Triticum durum* varieties primed with different agents (SNP, Si, KNO_3) at 24 h with (a) and without salt stress (b). The data are the means of 3 ± SE.
Values followed by at least one letter are not significantly different at *p<0.05* according to Duncan's test.

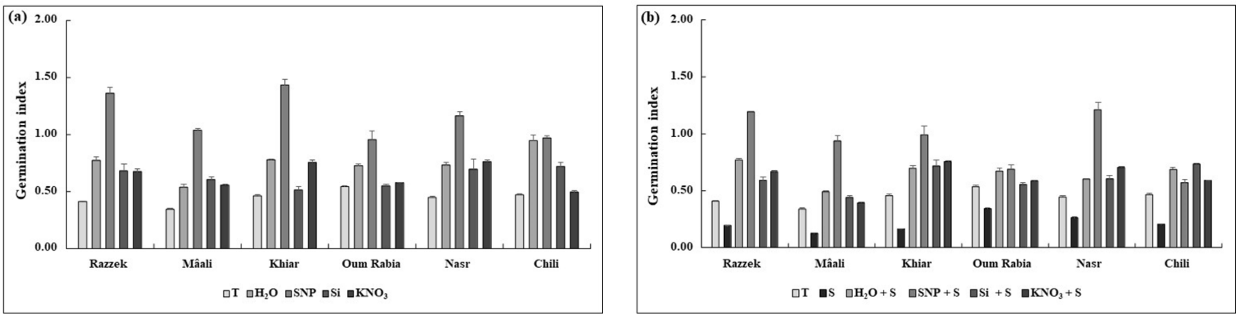

Figure 4. Germination index of *Triticum durum* varieties primed with different agents (SNP, Si, KNO_3) at 24 h with (a) and without salt stress (b). The data are the means of 3 ± SE.
Values followed by at least one letter are not significantly different at *p<0.05* according to Duncan's test.

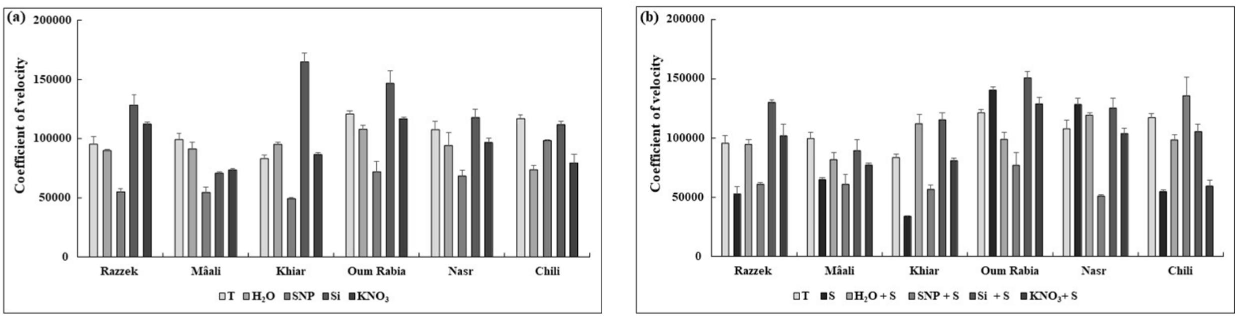

Figure 5. Coefficient of velocity of *Triticum durum* varieties primed with different agents (SNP, Si, KNO_3) at 24 h with (a) and without salt stress (b). The data are the means of 3 ± SE.
Values followed by at least one letter are not significantly different at *p<0.05* according to Duncan's test.

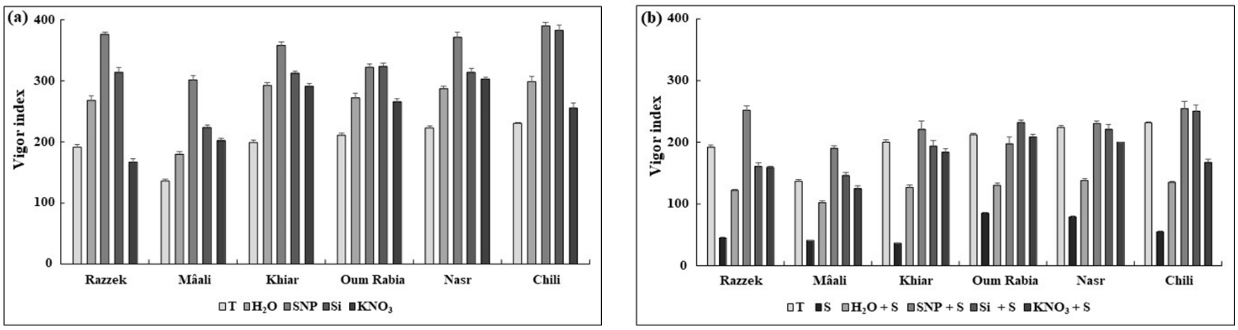

Figure 6. Vigor index of *Triticum durum* varieties primed with different agents (SNP, Si, KNO_3) at 24 h with (a) and without salt stress (b). The data are the means of 3 ± SE. Values followed by at least one letter are not significantly different at *p<0.05* according to Duncan's test.

Shoot and root length

The priming treatments (H_2O, SNP, Si, KNO_3) had a significant effect on growth performance and the interaction between varieties and treatments was highly significant (*p*<0.001) (Table 1).

The growth performances of control T (for all varieties) and different agent H_2O, SNP, Si and KNO_3 priming were shown by a shoot length is significantly influenced by priming specially for SNP priming, as well as for root length (Tables 1, Figures 7a, 7b).

Salinity (*S*) significantly affected shoot and root length. All priming agents (H_2O, SNP, Si, KNO_3) had a positive significant effect on shoot length, in contrast to (*S*), especially for SNP priming, as well as on root length, where all priming agents improved root length (Table 1, Figures 7c, 7d).

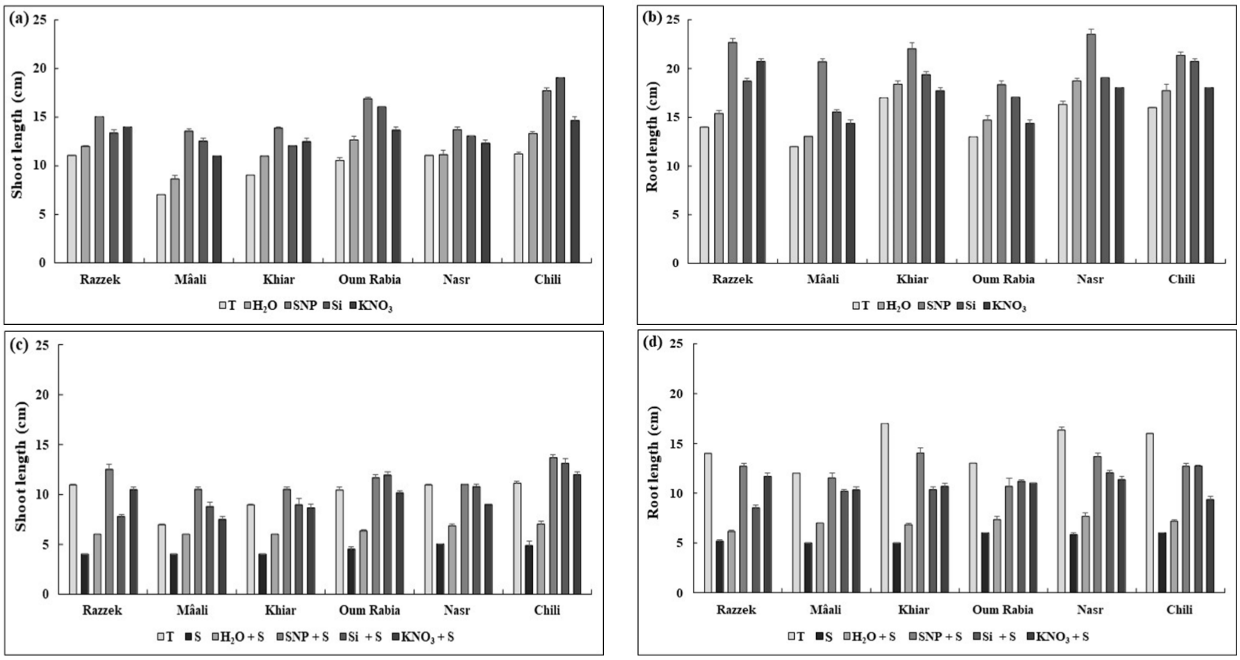

Figure 7. Shoot and root length of the 6[th] variety of *Triticum durum* primed with different agents (SNP, Si, KNO_3) at 24 h with control seeds (0 mM NaCl) shoot (a) and root (b) and treated seeds with 100 mM NaCl shoot (c) and root (d). The data are the means of 3 ± SE. Values followed by at least one letter are not significantly different at *p<0.05* according to Duncan's test.

Dry weight

This study revealed that H_2O, SNP, Si and KNO_3 priming substantially increased the growth of seedlings and roots of seeds under non-saline conditions (p<0.001), particularly the dry weight shoot (DW S) of the Chili variety. The greatest average was noted for Oum Rabiaa seeds primed with KNO_3 (Table 1, Figures 8a, 8b). Figure 8b shows that salinity significantly (p<0.001) decreased the shoot dry weight of the plants, particularly those of Razzek, Khiar and Chili, where the percentages decreased by approximately 30%. However, priming compensated for this decline, especially Razzek and Khiar KNO_3 priming and Chili Si and KNO_3 priming. KNO_3 had the most positive effect on dry weight roots (DWR) under saline and non-saline conditions for all sixth varieties (Table 2, Figure 8).

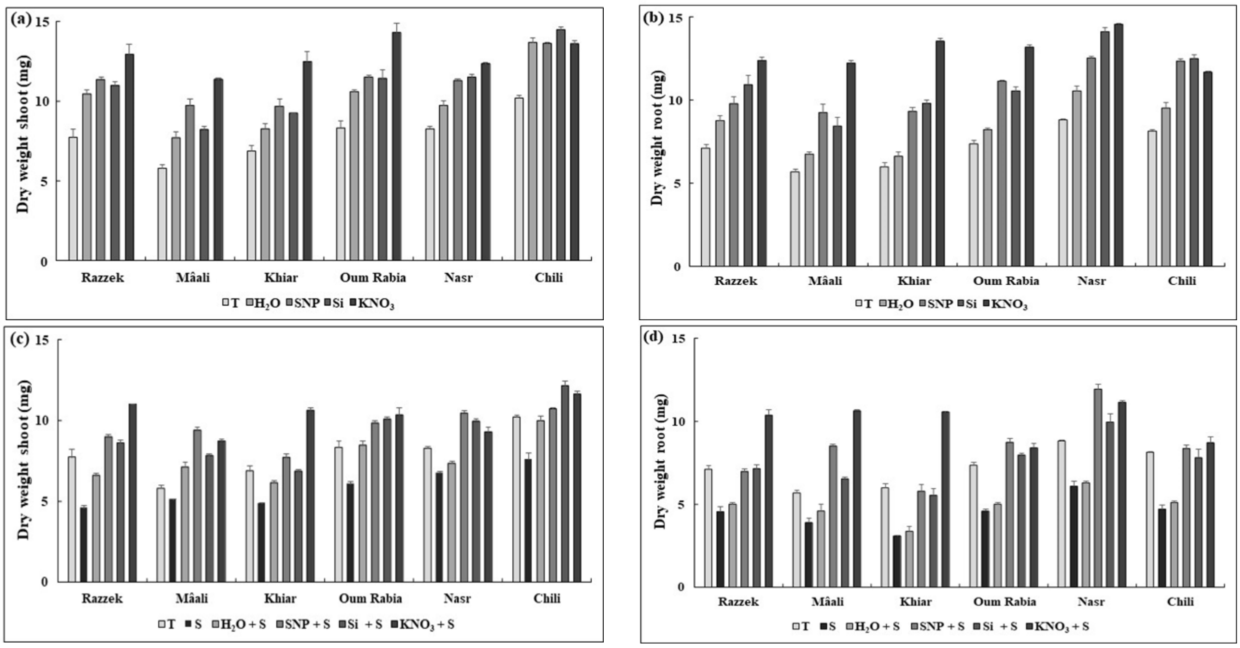

Figure 8. Dry weight of the variety of *Triticum durum* primed with different agents (SNP, Si, KNO_3) at different times (6, 12, 24 h) with control seeds (0 mM NaCl) shoot (a) and root (b) and treated seeds with 100 mM NaCl shoot (c) and root (d). The data are the means of 3 ± SE. Values followed by at least one letter are not significantly different at *p<0.05* according to Duncan's test.

Water content

Compared with the T treatment (control) for all the varieties, all the treatments (H_2O, SNP, Si and KNO_3) increased the water content of the shoot (Table 1, Figure 9a). Salinity affected the WC S for Razzek, Khiar, Oum Rabiaa and Nasr. However, for Mâali, the WC S increased.

For all varieties except for Chili, WC S was stimulated by priming agents (Table 1, Figure 9c).

SNP, Si and KNO_3 had a significant effect (p<0.001) on WC R, except in Khiar , which was subjected to SNP priming (Tables 1, Figure 9b). Additionally, priming with different agents (SNP, Si, KNO_3) wad significant effect on the average in DW R under saline conditions (Table 1, Figure 9d).

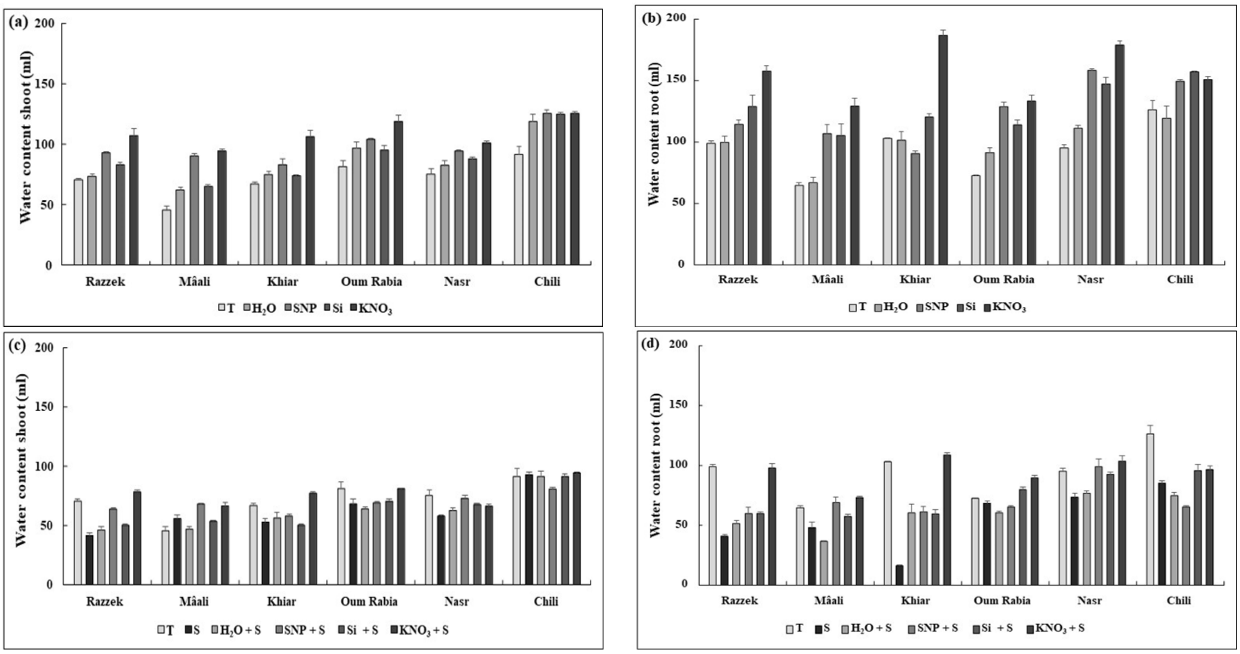

Figure 9. Water content of *Triticum durum* varieties primed with different agents (SNP, Si KNO_3) at different times (6, 12, 24 h) with control seeds (0 mM NaCl) shoot (a) and root (b)and treated seeds with 100 mM NaCl shoot (c) and root (d). The data are the means of 3 ± SE. Values followed by at least one letter are not significantly different at *p<0.05* according to Duncan's test.

Correlation analysis and principal component analysis (PCA)

To improve our study, we completed trait-by-trait analyses using PCA and correlation analysis. The following traits were analyzed: GP, MGT, GI, CV, VI, SL, RL, DW S, DW R, WC S and WC R (Table 1, Figure 10). The first and the second principal components (PC-1 and PC-2) accounted for 55.81% and 19.78%, respectively, of the total data variance (Figure 10a) under non-saline conditions and 56.60% and 14.28%, respectively, under saline conditions. In this study, the collection of 6^{th} durum wheat varieties was characterized by high diversity over the two PC axes. Germination and seedling traits varied among the eight Tunisian durum wheat varieties under stressed and non-stressed conditions. PCA could further classify the sixth durum wheat cultivars and two groups could be discerned: the first group combined most of the control (T) and hydro primed (H_2O) seeds, while the second group was mainly composed of the most primed cultivars with SNP, Si and KNO_3 under non-saline conditions (Figure 10a). Additionally, under salt conditions (Figure 10b), two groups might be discerned: the first group combined most of the cultivars stressed (*S*) and primed with H_2O, while the second group contained the most primed cultivars with SNP, Si and KNO_3. Therefore, the PCA results confirmed the noteworthy beneficial effect of SNP, Si and KNO_3 priming agents on all traits since the SNP, Si and KNO_3 treated cultivars were correlated with the studied traits under both unstressed and stressed conditions.

Interestingly, under non-saline conditions, Razzek, Oum Rabiaa (SNP priming) and Chili (SNP and Si priming) had the greatest shoot length, and Razzek (SNP and KNO_3 priming) and Chili (SNP and Si priming) had the greatest average shoot length. For dry weight shoot (DW S), Oum Rabiaa (KNO_3 priming) and Chili (with all priming agents) had the greatest averages. Nasr (SNP and Si priming) had the greatest effect on the dry weight root (DW R). Khiar and Nasr (with KNO_3 priming) had the greatest average water content root (WC R).

In terms of germination traits, Razzek, Khiar Nasr and Chili with all priming agents had the highest values in the PG. In terms of MGT, we found that Razzek, Khiar and Oum Rabiaa, which were primed with SNP, had the greatest averages, and in terms of the GI, we found Razzek and Khiar (SNP priming). Khiar

(Si priming) had the highest average in CV and Razzek and Chili (SNP and Si priming) had the highest average in the vigor index (VI).

Under saline conditions, Razzek (SNP priming) and Chili (SNP, Si and KNO_3 priming) plants presented the greatest shoot length.

For dry weight shoot (DW S), we found only Chilly (Si and KNO_3 priming). For dry weight root (DW R), we found Nasr (SNP and Si priming). For the water content shoot (WC S), we identified Chili with KNO_3 priming.

With respect to germination traits, under saline conditions, we noted that Razzek (H_2O priming), Khiar and Oum Rabiaa (Si priming) had the highest germination percentage (GP) values. For the mean germination time (MGT), we noted Razzek and Khiar (SNP priming).

For the germination index (GI), we founded Razzek and Nasr (SNP priming). Chili (SNP priming) had the highest average in coefficient of velocity (CV), Razzek and Chili SNP and Si priming) in vigor index.

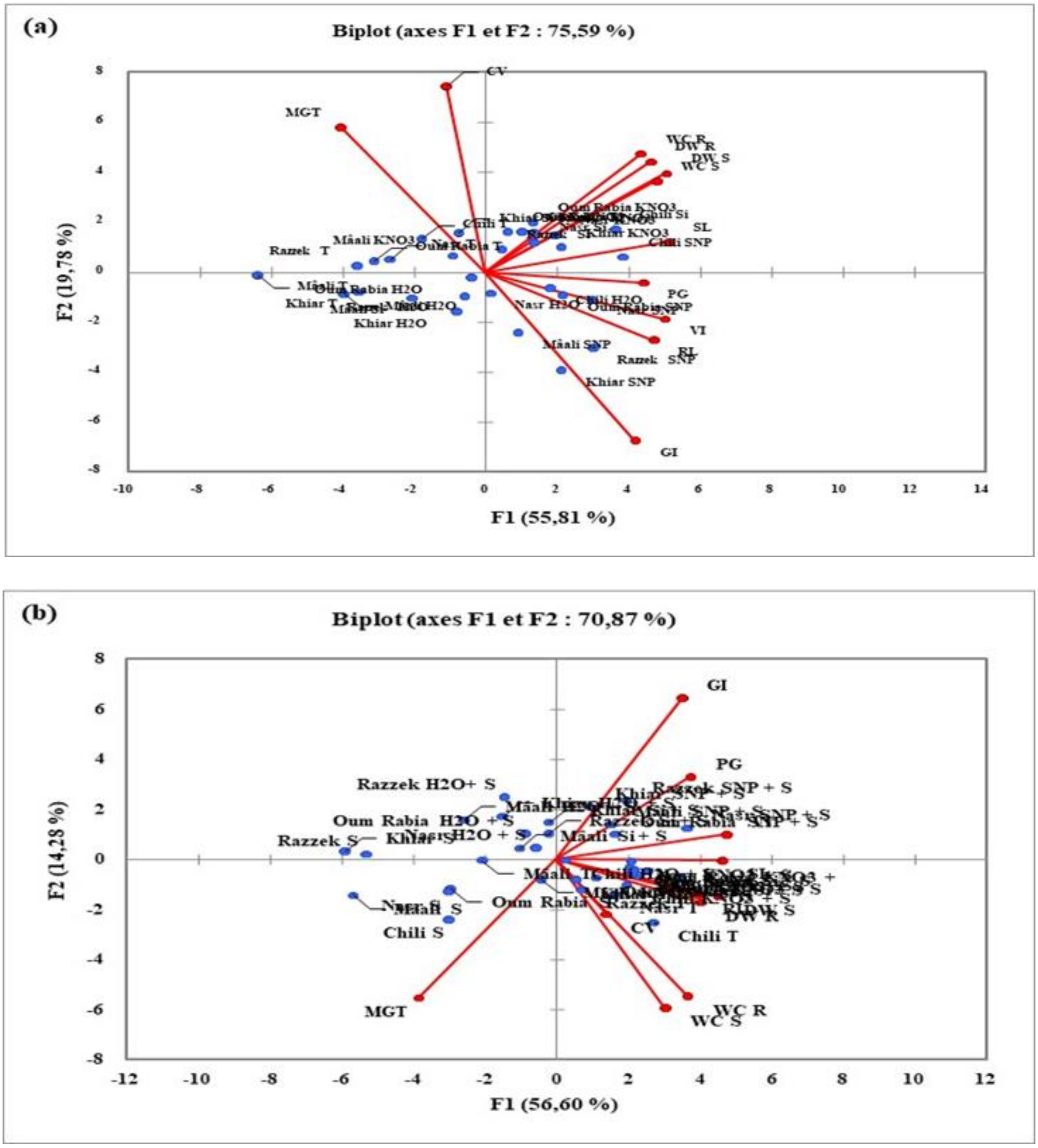

Figure 10. Principal component analysis showing the distribution of germination and growth traits and the sixth durum wheat varieties with (a) and without (b) salt stress

Plant growth and development, as well as productivity, are predicted by seed germination. One of the most effective physiological strategies for helping glycophytes adapt to saline conditions has been proposed: seed priming (Eskandari and Kazemi, 2011; Kazemi and Eskandari, 2012; Almutairi et al., 2020).

There are different phases to seed germination (Bewley et al., 2013): phase I of imbibition is a physical process involving the intake of water; Phase II of lag is a phase of minimal net water uptake during which the seed transitions from a dormant to a germinating state; and Phase III of growth is a phase of significantly increased water uptake related to radicle protrusion and growth. The most prominent phase of priming is the lag phase, which provides a head start and initiates an early activation event by restoring metabolic activity in response to stress. This occurs through stress memory.

The lag phase of germination is shorter in primed seeds, and there is also an increase in the rate of enzyme activation, DNA repair, and metabolite accumulation-all of which are critical to effective germination (Hussain et al., 2015). In the present study, SNP (a NO donor) was the most effective agent for reducing the lag phase for all wheat varieties studied under both control conditions and salt stress conditions.

In the current study, salt stress (*S*), caused a pronounced inhibition of germination and its characteristics, mainly GP, MGT, GI, CV and VI for all the tested durum wheat varieties. Moreover, this impact is modulated when the grains are pretreated with H_2O, SNP, Si and KNO_3. This result clearly showed that the negative impact of NaCl on seed germination characteristics can be significantly reduced by using SNP, Si and KNO_3 (Eskandari and Kazemi, 2011).

In the present study, following hydropriming (H_2O), SNP, Si and KNO_3 priming, seeds always germinated better than unprimed seeds (T) for all varieties of wheat, especially, for Razzek and Khiar. This positive effect was accentuated under salt stress where the rates of germination doubled for all varieties and with all priming agents (H_2O, SNP, Si, KNO_3).

This uptake may be the cause of the improved germination performance in NaCl compared to distilled water, which maintains a water potential gradient that permits water uptake during seed germination (Kaya et al., 2006).

Salinity has been shown to reduce seed germination in a variety of plants, including wheat (Afzal et al., 2016). To improve the germination rate of seeds under saline conditions, various seed preparation treatments have been used (Eskandari and Kazemi, 2011). In this work seed priming with SNP, Si and KNO_3 proved to be superior to hydropriming treatments for alleviating salinity-induced inhibition of germination. This finding is consistent with previous studies that demonstrated the effectiveness of SNP, Si and KNO_3 priming in reducing the inhibitory effects of salinity on the germination of wheat seeds (Ghobadi et al., 2012; Ayed et al., 2021; Khan et al., 2021). However, the tested wheat plants exhibited significant differences in growth and development in response to salt stress (reflecting the differences in physiological and biochemical characteristics that occur during salt tolerance).

Twenty wheat cultivars were examined by Shekoofa et al. (2013), who reported that differences in shoot and root length among genotypes were statistically significant. Furthermore, plants with more effective germination capacities produced more total dry biomass at higher salinity concentrations (Mirza et al., 2016).

The role of hydropriming, SNP, Si and KNO_3 priming in improving shoot dry weight under salinity was direct evidence of the beneficial effect of priming on seedling growth and vigor. The shoot dry weight of the 6 wheat varieties tested was significantly improved by hydropriming, SNP, Si and KNO_3 priming. This finding is in agreement with previous researchers who reported the positive effects of priming on shoot dry weight under salinity (Mirza et al., 2016).

This study revealed that SNP, Si and KNO_3 priming substantially improved the emergence percentage and emergence index and decreased the mean emergence time of wheat plants under salt. Higher cell division and elongations, water imbibition by seeds, DNA and RNA repair and synthesis, and higher activity of reserve mobilizing enzymes such acid phosphatase, dehydrogenase, α-amylase, and β-amylase in primed seeds are potential causes of improved emergence characteristics in wheat (Savvides et al., 2016).

In this study, salt stress significantly reduced in the length and dry weight of roots and shoots in all 6^{th} varieties. The combined effects of osmotic and ionic stress caused by limited uptake of water and nutrients, decreased turgor pressure, decreased photosynthetic activity, excessive accumulation of Na^+ and Cl^-, and damage to cell membranes under salt stress are responsible for this decline in physical growth.

According to Migahid et al. (2019), increasing salinity caused a decrease in seedling length. One possible reason for the reduction in seedling length (an indicator of emergence) could be a reduction in turgor pressure due to slower water uptake by seedlings at relatively higher salinities, which should reduce cell enlargement as well as shorten shoot.

This study revealed that hydropriming, SNP, Si and KNO_3 priming substantially increased seedling growth of wheat under salinity. The enhancement of wheat seedling growth might be due to increased cell division and elongation and the activation of ROS scavenging enzymes in primed seeds. Potassium nitrate, silicon and sodium nitroprusside stimulated wheat seedling growth by serving as nutrients and initiators of essential emergence and growth processes.

SNP (NO donor) is endogenous plant molecules with regulatory functions in plant abiotic stress tolerance (Habib et al., 2021). Exogenous application of low concentrations of these molecules initially results in an increase in their endogenous concentrations but does not subsequently inhibit plant growth. Increasing concentrations of these compounds are also found in unprimed plants exposed to various abiotic stresses. However, in this case plant growth is inhibited. On this basis it can be concluded that plant pretreatment chemical agents can activate moderate stress stimulation, similar to adaptation responses, ultimately leading to increased plant tolerance to abiotic challenges (Habib et al., 2016).

Maximum seedling length was obtained from seeds primed with nitroprusside (SNP) under non-salt stress, however, under salt stress, maximum seedling growth was obtained from seeds primed with silicon (Si). Priming with KNO_3 especially improved the dry weight of seedlings, particularly under salt stress. These findings are in agreement with those of Pawar et al. (2010), who reported that the halopriming and hardening of wheat seeds by CAN (2%) could stimulate the growth of wheat seeds by improving their vigor and germination percentage.

CONCLUSIONS

The current study aimed to assess the impact of hydropriming, SNP, Si and KNO_3 seed priming on the germination attributes of wheat plant grown in a saline environment. The results showed that the NPS, Si and KNO_3 priming treatments were effective and produced positive outcomes compared with those of the hydropriming and control treatments. However, pretreatment with SNP (a NO donor) had a more pronounced effect on the germination of salt-stressed wheat plants. These findings provide valuable insights into the effectiveness of priming treatments for salt resistance in wheat and can serve as a basis for future research. Further studies should be conducted in open-field settings to gain a better understanding of the effects of water, SNP, Si and KNO_3 priming treatments on wheat and other crops.

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