Effect of priming on germination of sixth wheat varieties (Triticum durum Desf.)

Hammami Fourati
marwa.hammami.fourati@hotmail.fr
University of Tunis El Manar Faculty of Sciences of Tunis: Universite de Tunis El Manar Faculte des Sciences de Tunis
Ben Ahmed Ben Ahmed
University of Tunis El Manar Faculty of Sciences of Tunis: Universite de Tunis El Manar Faculte des Sciences de Tunis

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Research Article

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Abstract

The present work compares the effect of priming on sixth Tunisian wheat varieties under normal and salt conditions at germination stage. It revealed that salinity have significantly reduced the growth attributes like germination percentage, germination index, coefficient of velocity, vigor index, seedling length, dry weight and water content with subsequent treatments. Salinity stress was induced by using NaCl in 100 mM. Seeds of the sixth cultivars primed with water (0 mM), Sodium Nitroprusside (0.06 mM), Calcium Silicate (8 mM), Potassium Nitrate (10 mM) have not only improved 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 water content of seeds primed with H_2O, SNP, Si, KNO_3 was significantly higher than other non-primed seeds under the saline conditions. Priming with different agent was effective, nevertheless, the best results were obtained with SNP, Si and KNO_3. On the other hand, seed priming with various priming agent has proved to be effective in inducing salt tolerance in terms of germination parameters, seedling characteristics, and water content in the sixth local commercial wheat cultivars.

Introduction

Germination is a critical stage in plant growth, starting with the active uptake of water and ending with the emergence of the radicle from the seed coat. Soaking plays a vital role in germination and is affected by many environmental stresses (Atashi et al. 2014). As an environmental stress, salinity reduces plant germination. Salinity can affect the germination process, growth (Umbreen et al., 2021) and establishment of seedlings by increasing osmotic pressure, which reduces water absorption, imbalance ions and causes oxidative damage (Tahjib-Ul-Arif et al., 2018). This inhibits various biochemical and physiological activities causing salt toxicity (Zorb et al., 2019). Seed priming is one of the most effective and cost-effective practices to mitigate the antagonistic effects of salinity (Umbreen et al., 2021). Seed priming is a technique of pre-soaking seeds by certain media or solutions for a desired time to preserve the seeds for partial hydration while the protuberance of the root will not occur. This is a three-phase process: (1) seed imbibition, (2) delay phase, and (3) root emergence. During soaking, the seeds are soaked with a priming medium to break the seed dormancy, which is a key step for germination. During this mRNA synthesis, proteins are synthesized, and mitochondrial repair and other light metabolic activities are observed.

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

Materials and methods

Plant material and Priming treatments

We assessed the following parameters:

- **Germination percentage (GP)** was calculated using the following formula:

GP (%) = (total number of germinated seeds/ total seed) ×100.

- **Mean germination time (MGT):** Calculated according the formula of (R. H. and Roberts 1981):

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

Where:**ni** : number of germinated seeds and **di**: day of counting.

- **Germination index (GI):** Calculated according to the equation of (Kader and Jutzi 2004):

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

Where **Ti:** number of days after sowing and **Ni:** number of germinated seeds in the day.

- **Coefficient of velocity (CV):** Calculated according the formula of (Kader and Jutzi 2004):

CV= ($\sum$Ni/100) × ($\sum$TiNi).

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

VI= [TG (%) × seedlings length (mm)]/ 100.

Growth parameters

After 7 days, triplicate of seedlings per group (treatment, agent and pre-sowing time) were used to measure the seedling fresh weight (SFW). Then, each seedling was dried at 45°C for 72h until constant weight to quantify the seedling dry weight (SDW).

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

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

Results

Germination parameters

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

Fig 1. Showed that SNP is significantly reduced the latency time for all wheat varieties studied under salt and no salt stress in expect to chili under salt.

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

GP was significantly reduced under salt stress for the sixth varieties, Razzek Mâali Khiar and Chili were the most affected by salinity. Seed priming significantly enhanced germination percentage under all agent priming irrespective of variety ($p \leq 0.001$) (Table 1, Fig. 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 about 40h and all priming had a significant effect in reducing MGT, especially for SNP priming where we founded that MGT decreased from 40h to 17h and 18h for Razzek and Khiar respectively (Table1, Fig. 3a).

For stressed seeds (Table 1, Fig 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 showed a significant difference ($p<0.001$) on the germination index (Tables 1, Fig. 4a) especially for SNP priming agent where GI increased from 0.4h average to around 1h and then 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, Fig 5b). As well as for stressed seeds, NPS priming has a high significant effect on GI where GI increased from around 0.2h to 0.9h. In second place, Si and KNO_3 priming have a significant effect on GI also. Overall, all priming agent induced GI where the averages were higher than those of the controls.

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

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

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

The priming agents used (H_2O, SNP, Si, KNO_3) have a high significant impact on vigor index (p<0.001) (Tables 1, Fig. 6a). The vigor index is affected by pretreatment, where the averages are better than the control T_0 for all varieties except for Razzek at KNO_3 priming.

As well as, 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) (Tables 1, Fig. 6b).

Shoot and root length

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

The seedling 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, Figs. 7a, 7b).

Salinity (*S*) affected significantly shoot and root length. All priming agent (H_2O, SNP, Si, KNO_3) had a positive significative effect on shoot length in contrast to (*S*) specially for SNP priming, as well as for root length where all priming agent improved root length (Tables 1, Figs. 7c, 7d).

Dry weight

This study found that H_2O, SNP, Si and KNO_3 priming substantially increased seedling and root growth of seeds under non-saline conditions (p<0.001), particularly for Chili variety at dry weight shoot (DW S). The best average was noted at Oum Rabiaa seeds primed with KNO_3 (Table 1, Fig 8a, 8b). Results of Figure 8b indicated that salinity significantly (p<0.001) decreased shoot dry weight of plants particularly for Razzek, Khiar and Chili where percentages decline by around 30%. However, priming has compensated this decline especially Razzek and Khiar KNO_3 priming and Chili Si and KNO_3 priming.

For dry weight root (DW R) KNO_3 had the most positive effect under saline and non-saline conditions for all the sixth varieties (Tables 2, Fig. 8).

Water content

When compared to T (control) for all varieties, all treatments priming (H_2O, SNP, Si, KNO_3) increased the water content of the shoot (Tables 1, Fig. 9a). Salinity affected WC S for Razzek, Khiar, Oum Rabiaa and Nasr. However, for Mâali, WC S was increased.

For all varieties in except Chili, WC S was stimulated by priming agents (Tables 1, Fig. 9c).

SNP, Si and KNO_3 had a significant effect (p<0.001) on WC R in except Khiar with SNP priming (Tables 1, Fig. 9b). As well as, priming with different agent (SNP, Si, KNO_3) was significant in DW R averages under saline conditions (Tables 1, Fig. 9d).

Correlation analysis and principal component analysis (PCA)

In order to improve our study, we completed trait-by-trait analyses using a PCA and a correlation analysis. These consider all analyzed traits: GP, MGT, GI, CV, VI, SL, RL, DW S, DW R, WC S and WC R (Table 1, Fig. 10a, 10b). 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 (Fig. 10a) under non-saline conditions and 56.60% and 14.28% respectively under saline conditions. In this study, the collection of 6th durum wheat varieties was characterized by large diversity over the two PC axes. Germination and Seedlings 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 might be discerned: the first group combined most of control (T) and hydro primed (H_2O) seeds, while the second group was mainly constituted by most primed cultivars with SNP, Si and KNO_3 under non-saline conditions (Fig. 10a). As well as, under salt conditions (Fig. 10b), two groups might be discerned: the first group combined most of cultivars stressed (*S*) and primed with H_2O, while the second groups contain 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 agent on all traits since the SNP, Si and KNO_3 treated cultivars were correlated with the studied traits for unstressed and stressed conditions.

Interestingly, under non-saline conditions, Razzek, Oum Rabiaa (SNP priming), Chili (SNP and Si priming) showed the highest values of shoot length, Razzek (SNP and KNO_3 priming) and Chili (SNP and Si priming) revealed the best averages. For dry weight shoot (DW S), Oum Rabiaa (KNO_3 priming) and Chili (with all priming agent) proved highest averages. Nasr (SNP and Si priming) had the best values for dry weight root (DW R). Khiar and Nasr (with KNO_3 priming) had the best averages for water content root (WC R).

At germination traits, Razzek, Khiar Nasr and Chili with all priming agents had the highest values in PG. For MGT, we found that Razzek, Khiar and Oum Rabiaa primed with SNP represented the best averages as well as for GI, we founded Razzek and Khiar (SNP priming). Khiar (Si priming) has highest average in CV and Razzek and Chili (SNP and Si priming) in vigor index (VI).

Under saline conditions, Razzek (SNP priming) and Chili (SNP, Si and KNO_3 priming) showed the highest values of 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 water content shoot (WC S), we identified Chili with KNO_3 priming.

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

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

DISCUSSION

Plant growth and development, as well as productivity, are predicted by seed germination. One of the most effective physiological strategies to help glycophytes adapt to saline conditions has been proposed: seed priming (Eskandari and Kazemi 2011; Kazemi and Eskandari 2012; Almutairi et al. 2020). Seed priming is a cost-effective agricultural bioaugmentation method that brings multiple benefits to plants by reduction seed germination time, improving GR and uniformity (Salah et al. 2015). Priming is exposure to a level of stress that induces a memory of the stress, preparing the plant to respond better and faster to subsequent stressful events. Additionally, the system uses no additional energy to keep the system in alarm mode, indicating that this strategy is considered cost-effective (Gurmani et al. 2018).

There are different phases to seed germination: 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 (NO donor) present the most effective agent in reducing lag phase for all wheat varieties studied in control conditions and salt stress conditions as well.

Seed priming initiates many processes related to germination, including the activity of germination enzymes that are critical for seed degradation. Molecules necessary for early and better development seedlings under salt stress. Seed priming contains a variety of organic and inorganic compounds also regulate many bacteria-related compounds genes (Ibrahim 2016).

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 durum wheat varieties tested. Meanwhile, this impact is modulated when the grains are pretreated with H_2O, SNP, Si and KNO_3. This result clearly shown 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 specially for Razzek and Khiar, this positive effect was accentuated under salt stress where the rates of germination are 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 keeps 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 in alleviating salinity-induced inhibition of germination. This finding is consistent with previous studies that demonstrated the effectiveness of SNP, Si, KNO_3 priming in reducing the inhibitory effects of salinity on seed germination of wheat (Ghobadi et al. 2012; Ayed et al. 2021; Khan et al. 2021). While the wheat tested showed significant growth and development differences 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 discovered among genotypes differences in shoot and root length were statistically significant. Furthermore, the 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 for the beneficial effect of priming on seedling growth and vigor. 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 found that SNP, Si and KNO_3 priming substantially improved emergence percentage, emergence index and decreased mean emergence time wheat 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 the potential causes for wheat improved emergence characteristics (Savvides et al. 2016).

Priming of seeds stimulate pre-germination processes in wheat that improved faster germination and seedling emergence (Ghobadi et al. 2012). Priming accelerated germination and the establishment of seedlings under stressful conditions by stimulating a number of germination processes, including enhanced water imbibition, cell division, and hydrolytic enzymes in wheat (Ahmed et al. 2012).

In this study, salt stress resulted in a significant reduction in the length and dry weight of roots and shoots in all 6th varieties. The combined effects of osmotic and ionic stress brought on 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 the salinity caused seedling length decreasing, one possible reason for the reduction in seedling length (one of the indicators of emergence) could be a reduction in turgor pressure due to slower water uptake by seedlings at relatively higher salinity, which should reduce cell enlargement as well as shorten the shoot

This study found that Hydropriming, SNP, Si and KNO_3 priming substantially increased seedling growth of wheat under salinity. Enhancement of wheat seedling growth might be due to increased cell division and elongation and 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 in seedlings.

According to Ashraf and Ali 2008; Ashraf (2009), salinity slows plant growth by influencing a number of physiological and biochemical processes, including water relations, photosynthesis, antioxidative state, and the ionic balance.

Tabassum et al. (2018) found that wheat priming with CaCl2 and hydropriming enhanced plant height, leaf area, panicle length and grain yield under terminal drought.

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 endogenous 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 principal to increased plant tolerance exposure 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 specially improved highly dry weight seedling particularly under salt stress. These finding are in agreement with those of Pawar et al. (2010) who founded that halopriming and hardening of wheat seeds by CAN (2%) could stimulate the wheat seeds by improving the vigor and germination percentage.

Conclusion

The current study aimed to assess the impact of Hydropriming, SNP, Si and KNO3 seed priming on germination attributes of wheat grown in a salinized environment. The results showed that NPS, Si and KNO3 priming treatments were effective and produced positive outcomes compared with those of hydropriming and control treatment. However, SNP (NO donor) pre-treatment was found to have 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.

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.

Declarations

Acknowledgments

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Compliance with ethical standards

This article does not contain any studies involving animals or human participants as objects of research.

Conflict of interests

The authors declare that they have no conflicts of interest.

References

1. Abdul-Baki AA, Anderson JD (1970) Viability and Leaching of Sugars from Germinating Barley 1. Crop Sci 10:31–34
2. Afzal I, Rehman HU, Naveed M, Basra SMA (2016) Recent advances in seed enhancements. New Chall Seed Biol-Basic Transl Res Driv Seed Technol 47–74

3. Ahmed Z, Sheikh MA, Hameed A, ud Din S (2012) Investigation of antioxidant enzymes and biochemical changes in the wheat seeds (freed) induced by different pre-sowing treatments. World Appl Sci J 18:31–36
4. Almutairi AW, El-Sayed AE-KB, Reda MM (2020) Combined effect of salinity and pH on lipid content and fatty acid composition of Tisochrysis lutea. Saudi J Biol Sci 27:3553–3558. https://doi.org/10.1016/j.sjbs.2020.07.027
5. Ashraf M (2009) Biotechnological approach of improving plant salt tolerance using antioxidants as markers. Biotechnol Adv 27:84–93
6. Ashraf M, Ali Q (2008) Relative membrane permeability and activities of some antioxidant enzymes as the key determinants of salt tolerance in canola (Brassica napus L.). Environ Exp Bot 63:266–273
7. Atashi S, Bakhshandeh E, Zeinali Z, et al (2014) Modeling seed germination in Melisa officinalis L. in response to temperature and water potential. Acta Physiol Plant 36:605–611. https://doi.org/10.1007/s11738-013-1436-1
8. Ayed S, Othmani A, Bouhaouel I, et al (2021) Effect of silicon (Si) seed priming on germination and effectiveness of its foliar supplies on durum wheat (Triticum turgidum L. ssp. durum) genotypes under semi-arid environment. Silicon 1–11
9. Eskandari H, Kazemi K (2011) Effect of seed priming on germination properties and seedling establishment of cowpea (Vigna sinensis). Not Sci Biol 3:113–116
10. Ghobadi M, Shafiei-Abnavi M, Jalali-Honarmand S, et al (2012) Does KNO3 and hydropriming improve wheat (Triticum aestivum L.) seeds germination and seedlings growth? Ann Biol Res 3:3156–3160
11. Gurmani AR, Khan SU, Ali A, et al (2018) Salicylic acid and kinetin mediated stimulation of salt tolerance in cucumber (Cucumis sativus L.) genotypes varying in salinity tolerance. Hortic Environ Biotechnol 59:461–471
12. Habib N, Akram MS, Javed MT, et al (2016) Nitric oxide regulated improvement in growth and yield of rice plants grown under salinity stress: antioxidant defense system. Appl Ecol Env Res 14:91–105
13. Habib N, Ali Q, Ali S, et al (2021) Seed Priming with Sodium Nitroprusside and H2O2 Confers Better Yield in Wheat Under Salinity: Water Relations, Antioxidative Defense Mechanism and Ion Homeostasis. J Plant Growth Regul 40:2433–2453. https://doi.org/10.1007/s00344-021-10378-3
14. Hussain S, Zheng M, Khan F, et al (2015) Benefits of rice seed priming are offset permanently by prolonged storage and the storage conditions. Sci Rep 5:8101. https://doi.org/10.1038/srep08101
15. Ibrahim EA (2016) Seed priming to alleviate salinity stress in germinating seeds. J Plant Physiol 192:38–46
16. Kader MA, Jutzi SC (2004) Effects of thermal and salt treatments during imbibition on germination and seedling growth of sorghum at 42/19 C. J Agron Crop Sci 190:35–38
17. Kaya MD, Okçu G, Atak M, et al (2006) Seed treatments to overcome salt and drought stress during germination in sunflower (Helianthus annuus L.). Eur J Agron 24:291–295

18. Kazemi K, Eskandari H (2012) Does priming improve seed performance under salt and drought stress. J Basic Appl Sci Res 2:3503–3507
19. Khan MN, Alamri S, Al-Amri AA, et al (2021) Effect of nitric oxide on seed germination and seedling development of tomato under chromium toxicity. J Plant Growth Regul 40:2358–2370
20. Migahid MM, Elghobashy RM, Bidak LM, Amin AW (2019) Priming of Silybum marianum (L.) Gaertn seeds with H2O2 and magnetic field ameliorates seawater stress. Heliyon 5:e01886. https://doi.org/10.1016/j.heliyon.2019.e01886
21. Mirza SR, Ilyas N, Batool N, et al (2016) Seed priming: technology to improve wheat growth under abiotic stress condition. Int J Biosci 9:268–275
22. Pawar KN, Sajjan AS, Prakash BG (2010) Influence of seed hardening on growth and yield of sunflower. Karnataka J Agric Sci 16:
23. Pradhan V, Rai PK, Bara BM, Srivastav DD (2017) Influence of halopriming and organic priming on germination and seed vigour in blackgram (Vigna mungo L.) Seeds. J Pharmacogn Phytochem 6:537–540
24. R. H. E, Roberts EH (1981) Seed ageing, survival, and the improved seed viability equation; forty years on. Seed Sci Technol Neth
25. Salah SM, Yajing G, Dongdong C, et al (2015) Seed priming with polyethylene glycol regulating the physiological and molecular mechanism in rice (Oryza sativa L.) under nano-ZnO stress. Sci Rep 5:14278
26. Savvides A, Ali S, Tester M, Fotopoulos V (2016) Chemical priming of plants against multiple abiotic stresses: mission possible? Trends Plant Sci 21:329–340
27. Shekoofa A, Bijanzadeh E, Emam Y, Pessarakli M (2013) EFFECT OF SALT STRESS ON RESPIRATION OF VARIOUS WHEAT LINES/CULTIVARS AT EARLY GROWTH STAGES. J Plant Nutr 36:243–250. https://doi.org/10.1080/01904167.2012.739244
28. Tabassum T, Farooq M, Ahmad R, et al (2018) Terminal drought and seed priming improves drought tolerance in wheat. Physiol Mol Biol Plants 24:845–856. https://doi.org/10.1007/s12298-018-0547-y
29. Toklu F, BALOCH FS, Karaköy T, Özkan H (2015) Effects of different priming applications on seed germination and some agromorphological characteristics of bread wheat (Triticum aestivum L.). Turk J Agric For 39:1005–1013
30. Worku A, Ayalew D, Tadesse T (2016) Germination and early seedling growth of bread wheat (Triticum aestivum L) as affected by seed priming and coating. J Biol Agric Healthc 6:27–33

Table

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
S/R ratio	71,896	< 0.0001	65.704	< 0.0001	4.039	< 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.

Figures

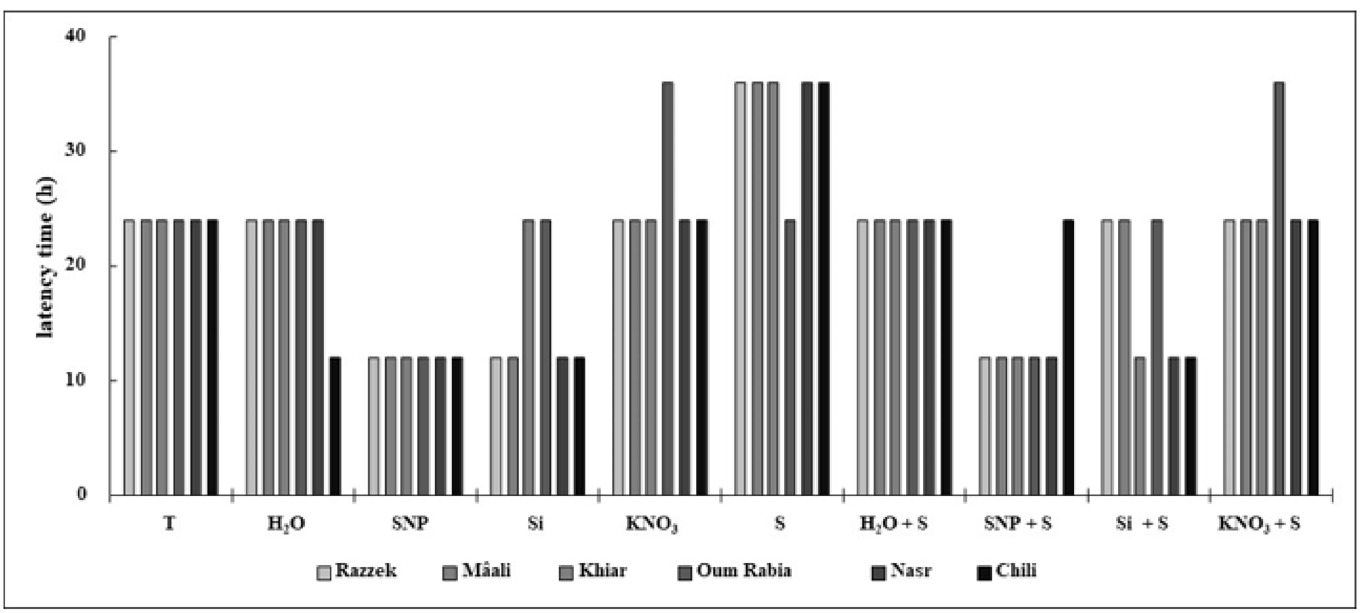


Figure 1

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

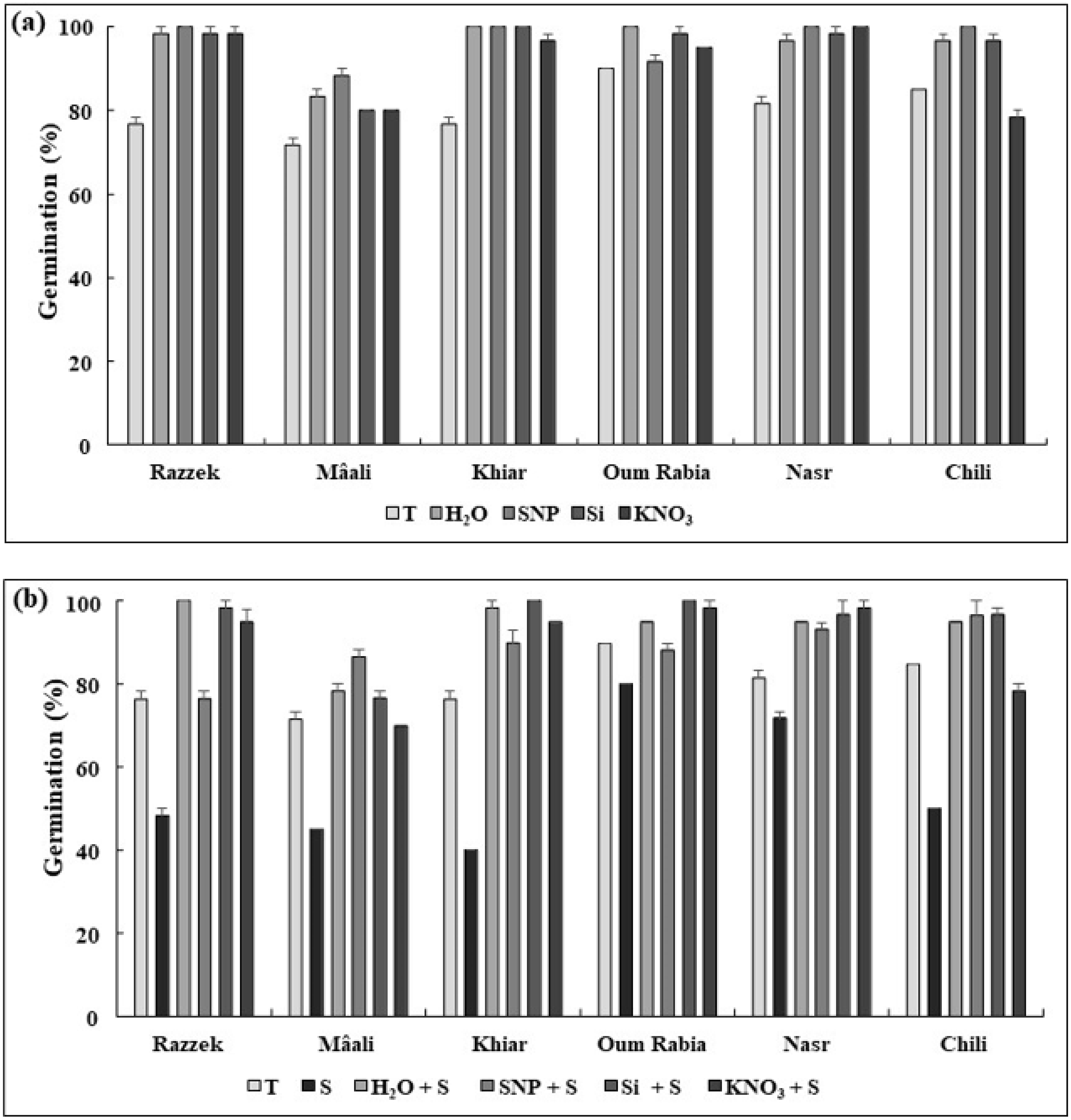


Figure 2

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

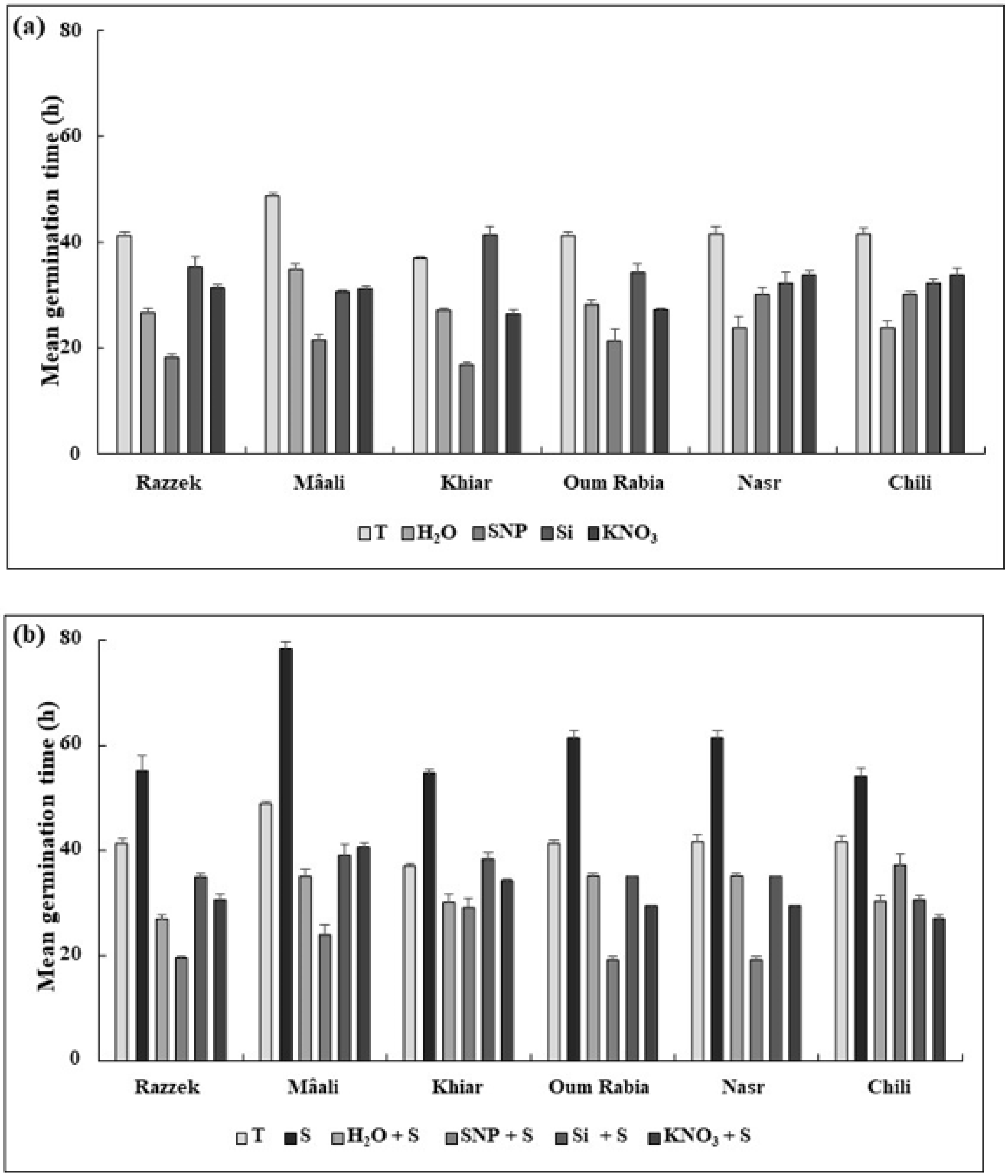


Figure 3

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

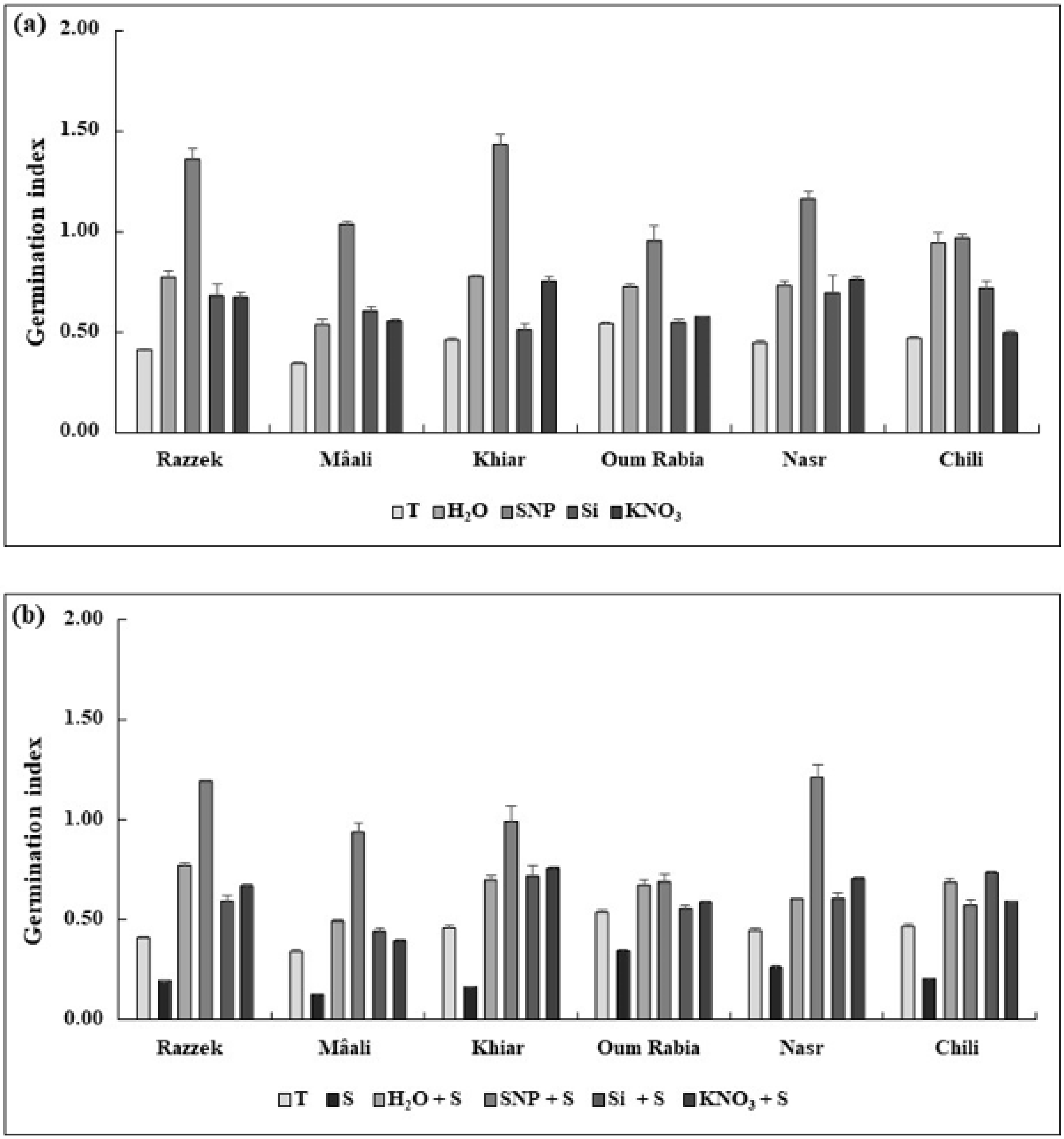
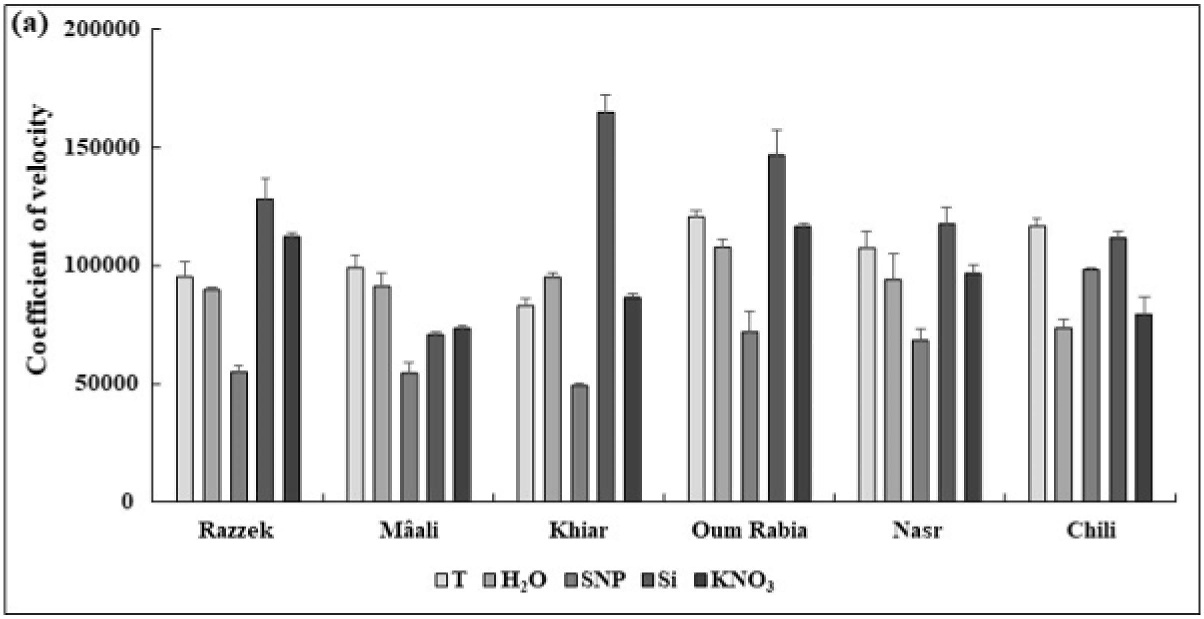


Figure 4

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



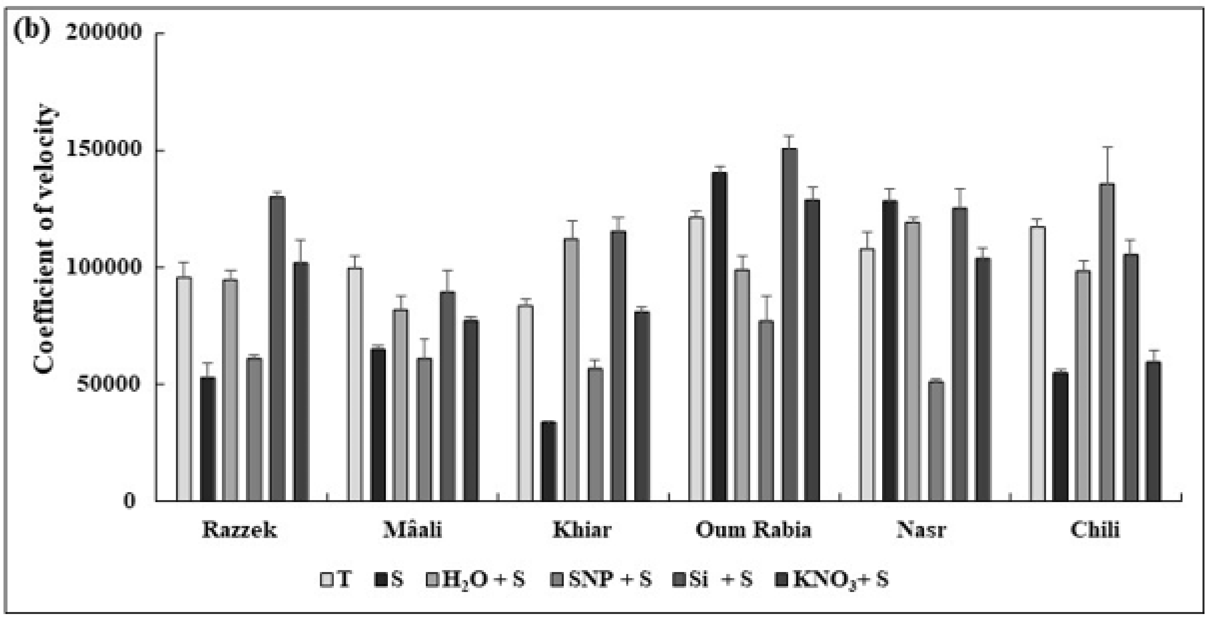
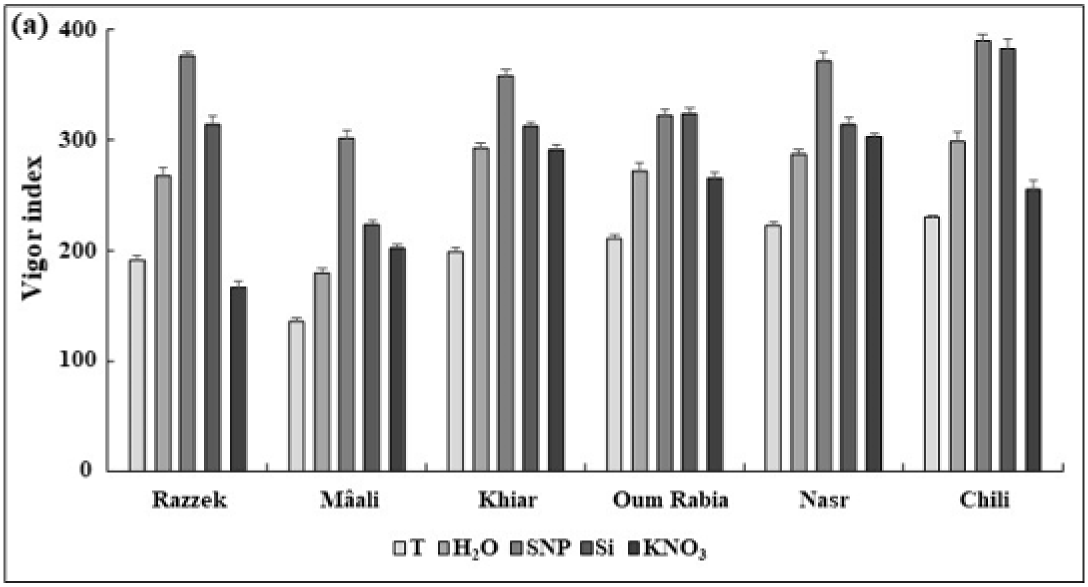


Figure 5

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



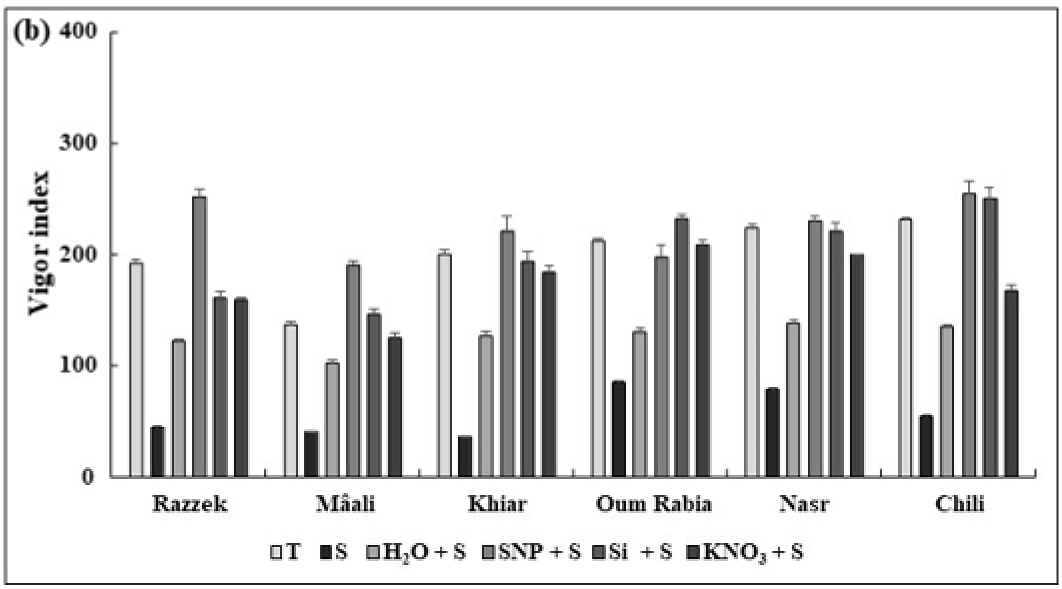


Figure 6

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

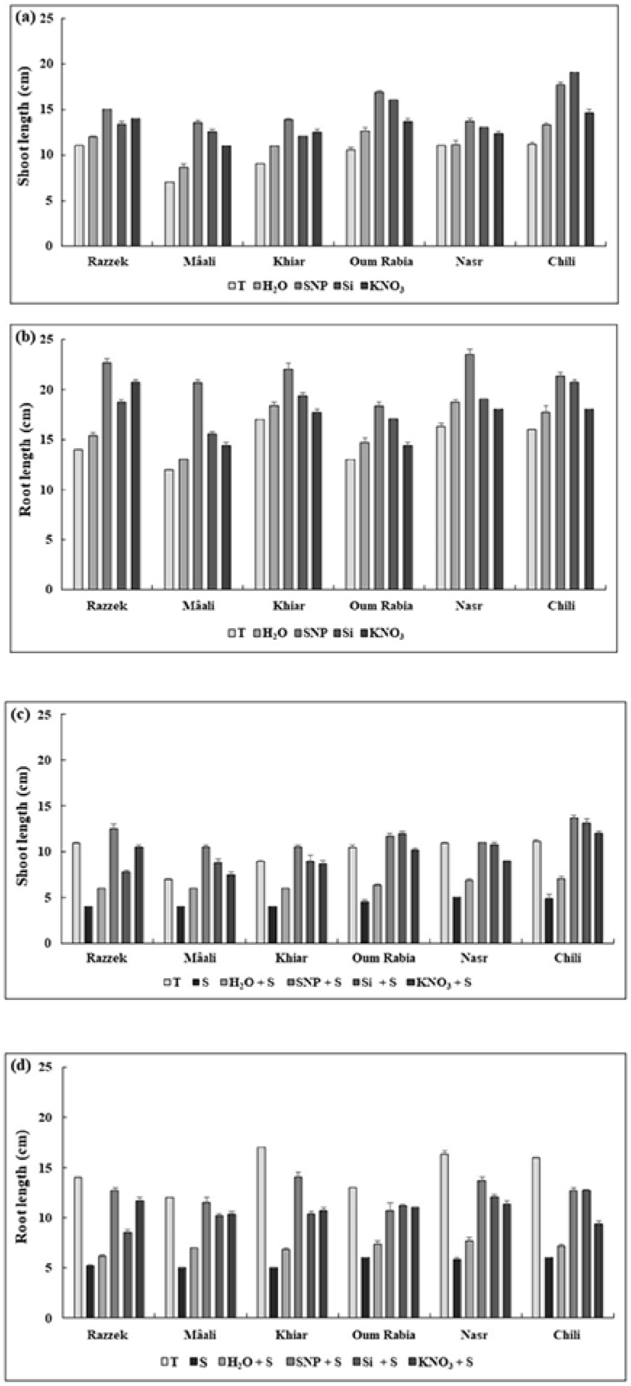


Figure 7

Shoot and root length of 6th varieties 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). Data are means of 3 ± SE. Values followed by at least one letter are not significantly different at p<0.05 according to Duncan's test.

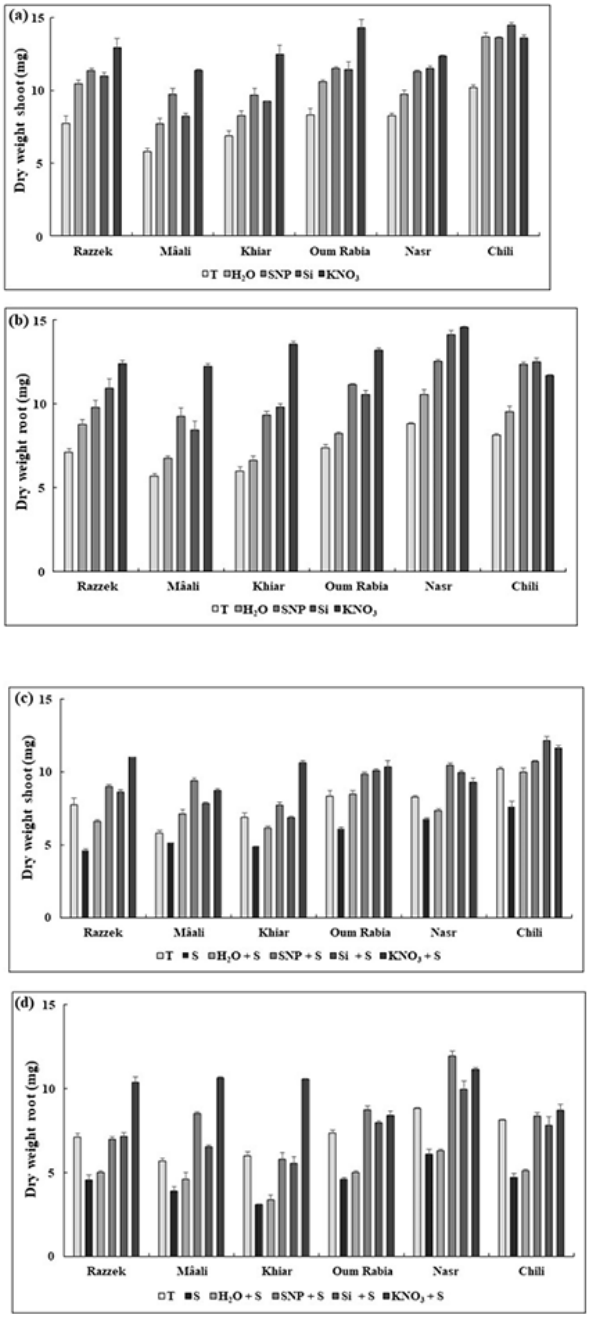


Figure 8

Dry weight of 6th varieties 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). Data are means of 3 ± SE. Values followed by at least one letter are not significantly different at $p<0.05$ according to Duncan's test.

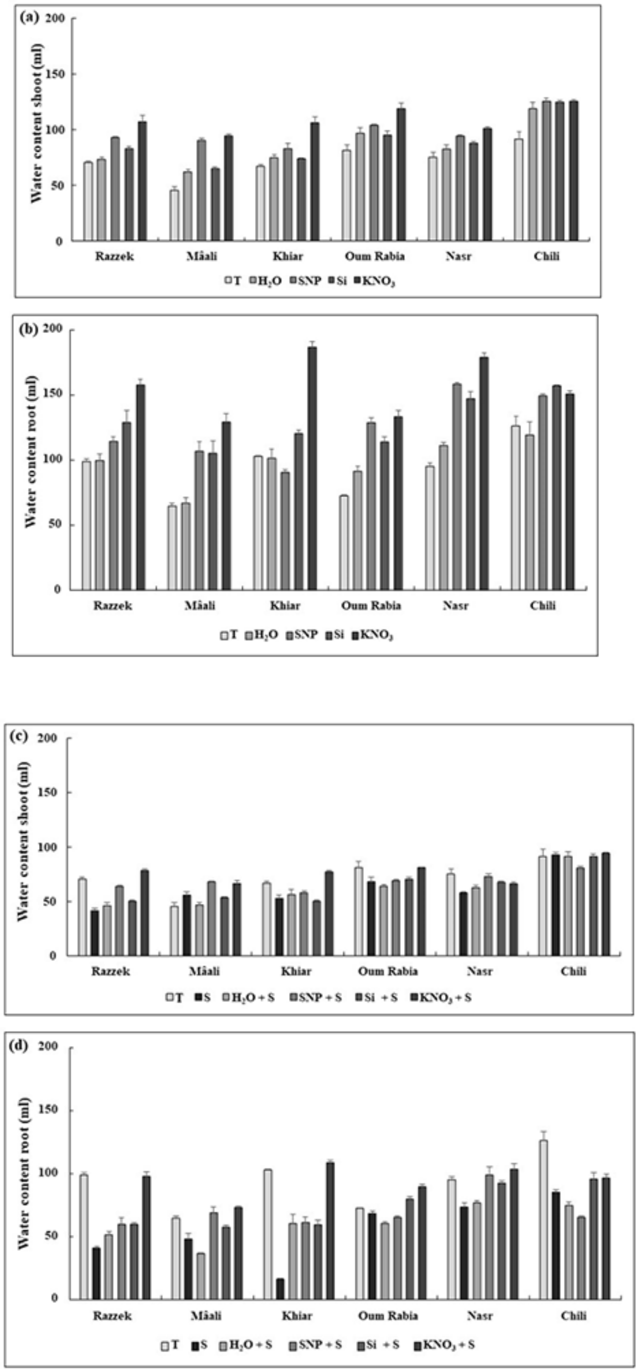


Figure 9

Water content of 6th varieties 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). Data are means of 3 ± SE. Values followed by at least one letter are not significantly different at p<0.05 according to Duncan's test.

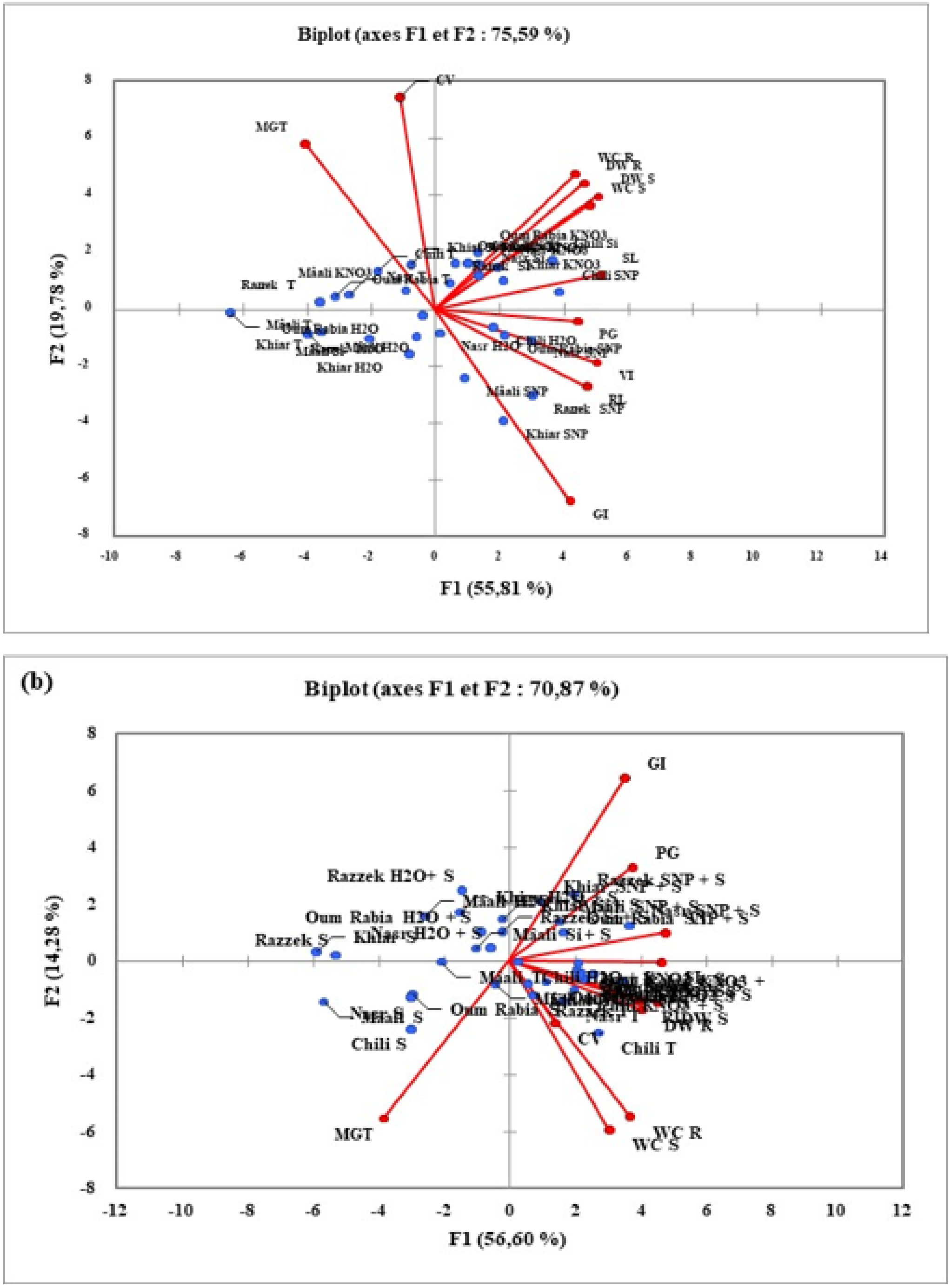


Figure 10

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