

Improvement of seed germination traits in canola (*Brassica napus* L.) as affected by saline and drought stressesH. Omid<sup>a\*</sup>, F. Khazaei<sup>b</sup>, S. Hamzi Alvanagh<sup>c</sup>, and H. Heidari-Sharifabad<sup>b</sup><sup>a</sup>Department of Agronomy, Faculty of Agriculture, University of Shahed, Tehran, Iran.<sup>b</sup>Seed and Plant Certification & Registration Institute, Karaj, Iran.<sup>c</sup>Department of Agronomy, Faculty of Agriculture, Tarbiat Modares University, Tehran, Iran.

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**Abstract**

In many crop species, seed germination and early seedling growth are the most sensitive stages to stress. Salinity and drought may delay the onset, reduce the rate and increase the dispersion of germination events, leading to reductions in plant growth and final crop yield. The adverse effects of salt stress can be alleviated by various measures, including seed priming (pre-sowing seed treatment). The general purpose of seed priming is to partially hydrate the seed to a point where germination processes are begun but not completed. Most priming treatments involve imbibing seed with restricted amounts of water to allow sufficient hydration and advancement of metabolic processes but preventing germination or loss of desiccation tolerance. The objective of this study was to determine factors responsible for delayed germination and early seedling growth due to salt toxicity or osmotic effect and to optimize the best priming treatment for these stress conditions. In this experiment, treated seeds (control, KNO<sub>3</sub> and hydropriming) of canola (*Brassica napus* L. cv. Okapi) were evaluated at germination and seedling growth stages for tolerance to salt (NaCl) and drought conditions (PEG-6000) at the same water potentials of 0.0, -3, -6, -9 and -12 bar. Electrical conductivity (EC) values of the NaCl solutions were 0, 3, 6, 9 and 12 dS.m<sup>-1</sup>, respectively. Results showed that germination delayed in both solutions, being variable with different priming treatments. Germination, and root and shoot length were higher, but mean germination time and unusual germination percentage were lower in NaCl than in PEG at the same water potential. Seeds were germinated at all concentrations of NaCl, but no seed germination was observed at -12 MPa of PEG treatments. NaCl had less inhibiting effect on the seedling growth than the germination. It was concluded that inhibition of germination at the same water potential of NaCl and PEG resulted from osmotic effect rather than salt toxicity. Hydro priming increased germination and seedling growth under salt and drought stresses.

**Keywords:** canola; salt and drought stress; seed treatment; germination.

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**Introduction**

Canola (*Brassica napus* L.) is one of the most important oil seed crops in Iran. One of the major problems to high yield and production is the lack of uniform establishment of canola plants due to poor weather and soil conditions (Mwale *et al.*, 2003). The seeds are occasionally sown in seedbeds having unfavorable moisture because of the lack of rainfall at sowing time (Angadi and Entz, 2002), which results in poor and non-uniform seedling emergence (Mwale *et al.*, 2003).

Winter canola is a winter annual crop that is sown late summer or early fall. When commercial production of canola was first considered in Iran, location and equal vegetation percentage were thought to be the two most important cultural decisions. Since winter wheat is commonly grown in Iran, winter wheat areas were considered most likely to be well-suited for winter canola. This has proven to be the case. Therefore, good sites for winter canola are easy for producers to identify through their experience with winter wheat production. The advantages of winter canola include lower input costs compared to other broadleaf crops in the region; the same equipment used for solid seeded crops may be

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used; winter canola facilitates the return to traditional fall-planted crops such as wheat. With the introduction of more winter hardy, drought tolerant varieties, the most critical factor in winter canola production becomes planting date (Demir Kayaa *et al.*, 2006).

Under the conditions of Iran, moisture content of soil at sowing time (from mid-April until mid-May) is most often inadequate with significant variation in micro pockets of the same field; a condition that results in irregular seed germination and stand establishment.

In many seeds, germination and subsequent seedling growth can be inhibited by mechanical restriction exerted by the seed coat (Sung and Chiu, 1995). Priming may be helpful in reducing the risk of poor stand establishment under drought and salt stresses and allow more uniform growth under conditions of irregular rainfall and drought on saline soils. Parera and Cantliffe (1994) and McDonald (1992) emphasized that hydropriming was the simplest approach to hydrate seeds and minimize the use of chemicals. However, if the seeds are not accurately hydrated, the rate of hydration cannot be exactly controlled.

Seedling establishment is a phenological stage at which drought could be particularly harmful to annual plants. Even though wheat is generally grown in water stress-prone parts of the world, soil water potential strongly affects seedling emergence (Demir Kayaa *et al.*, 2006).

Another major constraint to seed germination is soil salinity, a common problem in irrigated-areas of Iran with a low rainfall (Kaya *et al.*, 2003).

Salinity is the major environmental factor limiting plant growth and productivity (Allakhverdiev *et al.*, 2000). Soil salinity may affect the germination of seeds either by creating an osmotic potential external to the seed preventing water uptake, or through the toxic effects of  $\text{Na}^+$  and  $\text{Cl}^-$  ions on the germinating seed (Khajeh-Hosseini *et al.*, 2003). Salt and osmotic stresses are responsible for both inhibition or delayed seed germination and seedling establishment (Almansouri *et al.*, 2001). Under these stresses there is a decrease in water uptake during imbibitions and furthermore, salt stress may cause excessive uptake of ions (Demir Kayaa *et al.*, 2006; Murillo-Amador *et al.*, 2002).

Seed priming has been successfully demonstrated to improve germination and emergence in seeds of many crops, particularly vegetables and

small seeded grasses (Angadi and Entz 2002; Bradford, 1986). The beneficial effects of priming have also been demonstrated for many field crops such as wheat, sugar beet, maize, soybean and canola (Khajeh-Hosseini *et al.*, 2003; Parera and Cantliffe, 1994; Sadeghian and Yavari, 2004; Singh, 1995). Dharmalingam and Basu (1990) reported beneficial effect of a hydration-dehydration seed treatment on germination of canola. Rao *et al.* (1987) reported that primed *Brassica* seeds might reduce the risk of poor stand establishment in cold and moist soils. However, Singh and Rao (1993) stated that  $\text{KNO}_3$  effectively improved germination, seedling growth and seedling vigor index of the seeds of canola varieties with low germination. The objectives of the current study were to determine factors responsible for failure of germination of canola seeds under saline conditions by comparing seed germination under a range of osmotic potentials due to  $\text{NaCl}$  and PEG. Furthermore, the study examined the possibilities to overcome salt and drought stresses by seed hydropriming or seed treatment with  $\text{KNO}_3$ .

## Materials and Methods

This research was carried out at the Faculty of Agriculture, University of Shahed, Iran. Canola cultivar Okapi from Seeds Inc., which is commonly grown in semiarid and saline soils of Iran, was used as seed material. Germination and early seedling growth (10 days) of the cultivar were studied using distilled water (control) and under osmotic potentials of -3, -6, -9 and -12 bar, for  $\text{NaCl}$  (Coons *et al.*, 1990) or polyethylene glycol (PEG 6000) (Michel and Kaufman, 1973).  $\text{NaCl}$  concentrations had the electrical conductivity (EC) values of 0, 3, 6, 9 and 12  $\text{dS.m}^{-1}$ , respectively.

For hydropriming, canola seeds (5.5% seed moisture) were immersed in distilled water at 25°C for 18 hours under dark conditions. The hydropriming duration was determined by controlling seed imbibitions during germination. For  $\text{KNO}_3$  treatment, the seeds were immersed in 500 ppm  $\text{KNO}_3$  solution at 25°C for 2 hours in the dark (Singh and Rao, 1993). Thereafter, the seeds were rinsed with tap water three times. The treated seeds were surface-dried and dried back to their original moisture content at room temperature (about 22°C, 47% relative humidity) determined by changes in seed weight. Moisture content of untreated seeds (control, 5.5% moisture

Table 1. Mean of squares for germination characters of canola seeds treated with KNO<sub>3</sub>, hydropriming and control (untreated) at water stress induced by NaCl and PEG

| S.O.V              | df | Mean germination time | Germination coefficient | Root length | Shoot length | Fresh weight | Dry weight |
|--------------------|----|-----------------------|-------------------------|-------------|--------------|--------------|------------|
| Seed Treatment (T) | 2  | 0.264                 | 0.004                   | 0.195       | 0.027        | 0.001        | 0.018      |
| Solution (S)       | 1  | 0.607                 | 0.007                   | 0.387       | 0.000        | 0.002        | 0.001      |
| Stress (O)         | 4  | 7.640**               | 0.025**                 | 1.265**     | 0.439**      | 0.001**      | 0.254**    |
| T × S              | 2  | 0.523**               | 0.003**                 | 0.497       | 0.436        | 0.001**      | 0.067**    |
| P × O              | 8  | 1.397**               | 0.003**                 | 0.263**     | 0.334**      | 0.003**      | 0.066**    |
| S × O              | 4  | 0.315**               | 0.002**                 | 0.137**     | 0.074**      | 0.002**      | 0.077**    |
| T × S × O          | 8  | 0.778**               | 0.001**                 | 0.236**     | 0.074**      | 0.002**      | 0.058**    |
| Error              | 60 | 0.209                 | 0.006                   | 0.337       | 0.030        | 0.003        | 0.053      |

ns, \* and \*\*: not significant, significant at the 5 and 1 % levels of probability, respectively.

content), hydroprimed and KNO<sub>3</sub>-treated seeds was equilibrated at room temperature for 2 days.

Three replicates of 25 seeds were germinated between double-layered rolled Anchor germination papers with 10 ml of the respective test solutions. The papers were replaced every 2 days to prevent accumulation of salts (Rehman *et al.*, 1996). The rolled paper with seeds was put into sealed plastic bags to avoid moisture loss. Seeds were allowed to germinate at 25 ± 1°C in the dark for 7 days. Germination was considered to have occurred when the radicles were 2 mm long. Germination characters were recorded every 24 hours for 7 days. To determine the toxic effects of the solutions on germination, non-germinated seeds in each treatment were transferred to distilled water and counted 3 days later. Mean germination time (MGT) was calculated to assess the rate of germination (Ellis and Roberts, 1980). The seedlings with short, thick and spiral formed hypocotyls and stunted primary root were considered as abnormal (ISTA, 2003). Root length, shoot length and seedling fresh weight were measured after the 10th day. Three grams of the seeds from each seed treatment were placed in Petri dishes containing distilled water to determine water uptake of seeds necessary for germination. The water uptake was expressed as the percentage increase in moisture content on fresh weight basis.

The experimental plan was a three-factor fac-

torial arranged in a completely randomized design with three replications and 25 seeds per replicate. The first factor was seed treatments (control, KNO<sub>3</sub> and hydropriming), the second was the solutions (NaCl and PEG) and the third was the osmotic potential levels (0, -0.3, -0.6, -0.9 and -1.2 MPa for drought stress and 0, 3, 6, 9 and 12 dS.m<sup>-1</sup> for NaCl stress). The data were analyzed using the factorial procedure of the statistical analysis system, SAS (SAS Inst., Cary, Nc). The differences between the means were compared using LSD values (P < 0.05).

## Results and Discussion

Analysis of variance for different parameters is shown in Table 1. In main factors, the effects of osmosis factor (water potential levels) on mean germination time, germination coefficient, root length, shoot length, fresh weight and dry weight were significant (P > 0.01) and water potential of -3 bar (-0.3 Mpa) had the highest effect (Table 2). The interaction of seed treatment (T) with solution (S) was significant for on mean germination time, germination coefficient, fresh weight and dry weight (Tables 1 and 3). Also, osmotic factor had interactions with seed treatments (T) (Tables 1 and 4) and solution (S) (Tables 1 and 5).

A significant three-way interaction (seed treatment, solution and stress) was found (P <

Table 2. Mean comparisons of germination characters of canola treated- and untreated-seeds

| Stress | Germination time (day) | Germination coefficient | Root length (cm) | Shoot length (cm) | Fresh weight (gr) | Dry weight (gr) |
|--------|------------------------|-------------------------|------------------|-------------------|-------------------|-----------------|
| 0      | 2.504 c                | 0.402ab                 | 3.914 ab         | 1.162b            | 0.035b            | 1.933c          |
| -3     | 2.487c                 | 0.411a                  | 4.244 a          | 1.422a            | 0.041a            | 2.106b          |
| -6     | 2.622 bc               | 0.389 ab                | 4.176a           | 1.373a            | 0.040a            | 2.133ab         |
| -9     | 2.834 b                | 0.364 b                 | 4.012a           | 1.153b            | 0.040a            | 2.267a          |
| -12    | 3.271a                 | 0.318 c                 | 3.571ab          | 1.058b            | 0.033b            | 2.122ab         |

Means followed by the same letters in each column are not significantly different (LSD test, 5 %).

Table 3. Mean comparisons for germination characters of canola seeds treated with KNO<sub>3</sub>, hydropriming and control (untreated) at solution under water stress induced by NaCl and PEG

| Seed treatment (T) | Solution (S) | Germination time (day) | Germination coefficient | Root length (Cm) | Shoot length (Cm) | Fresh weight (gr) | Dry weight (gr) |
|--------------------|--------------|------------------------|-------------------------|------------------|-------------------|-------------------|-----------------|
| Control            | NaCl         | 2.883a                 | 0.362ab                 | 4.123a           | 1.253a            | 0.038ab           | 2.187a          |
|                    | PEG-6000     | 2.535b                 | 0.400a                  | 3.967a           | 1.233a            | 0.036b            | 2.087a          |
| KNO <sub>3</sub>   | NaCl         | 2.659ab                | 0.386ab                 | 3.909a           | 1.220a            | 0.036b            | 2.047a          |
|                    | PEG-6000     | 2.684ab                | 0.384ab                 | 4.117a           | 1.296a            | 0.037ab           | 2.127a          |
| Hydropriming       | NaCl         | 2.934a                 | 0.354b                  | 3.721a           | 1.227a            | 0.041a            | 2.093a          |
|                    | PEG-6000     | 2.765ab                | 0.374ab                 | 4.062a           | 1.172a            | 0.034b            | 2.133a          |

Means followed by the same letters in each column are not significantly different (LSD test, 5 %)

Table 4. Mean comparisons for germination characters of canola seeds treated with KNO<sub>3</sub>, hydropriming and control (untreated) under various water potential levels

| Seed treatment (T) | Stress | Germination time (day) | Germination coefficient | Root length (Cm) | Shoot length (Cm) | Fresh weight (gr) | Dry weight (gr) |
|--------------------|--------|------------------------|-------------------------|------------------|-------------------|-------------------|-----------------|
| Control            | 0      | 2.682 bcd              | 0.374 abc               | 4.042 abc        | 1.227cde          | 0.035def          | 2.067abcde      |
|                    | -3     | 2.428 d                | 0.416 a                 | 4.087 abc        | 1.428ab           | 0.041abc          | 2.050bcde       |
|                    | -6     | 2.642 bcd              | 0.387 ab                | 4.433 a          | 1.345abc          | 0.042abc          | 2.167abc        |
|                    | -9     | 2.803 bcd              | 0.373 abc               | 3.825 abcd       | 1.113def          | 0.035def          | 2.200abc        |
|                    | -12    | 2.985 abc              | 0.354 abcd              | 3.838 abcd       | 1.100def          | 0.032ef           | 2.200abc        |
| KNO <sub>3</sub>   | 0      | 2.440 d                | 0.412 a                 | 3.948 abcd       | 1.078def          | 0.036cdef         | 1.900de         |
|                    | -3     | 2.447 d                | 0.412 a                 | 4.248 ab         | 1.488a            | 0.037cde          | 2.100abcd       |
|                    | -6     | 2.517 cd               | 0.403 a                 | 4.082 abc        | 1.443ab           | 0.039bcd          | 2.167abc        |
|                    | -9     | 2.618b cd              | 0.387 ab                | 4.257 ab         | 1.218bcd          | 0.037cde          | 2.317a          |
|                    | -12    | 3.337 a                | 0.311 cd                | 3.532 cd         | 1.008f            | 0.035def          | 1.950cde        |
| Hydropriming       | 0      | 2.392 d                | 0.420 a                 | 3.752 bcd        | 1.180cdef         | 0.035def          | 1.833e          |
|                    | -3     | 2.585 bcd              | 0.404 a                 | 4.340 ab         | 1.350abc          | 0.044ab           | 2.167abc        |
|                    | -6     | 2.707 bcd              | 0.377 abc               | 4.013 abcd       | 1.330abc          | 0.039bcd          | 2.067abcde      |
|                    | -9     | 3.075 ab               | 0.331 bcd               | 3.955 abcd       | 1.073def          | 0.045a            | 2.283ab         |
|                    | -12    | 3.490 a                | 0.287 d                 | 3.343 d          | 1.065ef           | 0.031f            | 2.217ab         |

Means followed by the same letters in each column are not significantly different (LSD test, 5 %).

Table 5. Interaction mean comparisons for germination characters of canola seeds treated with KNO<sub>3</sub>, hydropriming and control (untreated) under various water potential levels

| Solution (S)               | Stress | Germination time (day) | Germination coefficient | Root length (Cm) | Shoot length (Cm) | Fresh weight (gr) | Dry weight (gr) |
|----------------------------|--------|------------------------|-------------------------|------------------|-------------------|-------------------|-----------------|
| NaCl (dS.m <sup>-1</sup> ) | 0      | 2.542bc                | 0.399ab                 | 3.779abc         | 1.162cde          | 0.036bcd          | 1.889c          |
|                            | -3     | 2.668bc                | 0.386ab                 | 4.179ab          | 1.463a            | 0.042a            | 2.067bc         |
|                            | -6     | 2.690bc                | 0.382ab                 | 4.242ab          | 1.318abc          | 0.040ab           | 2.078bc         |
|                            | -9     | 2.946ab                | 0.352bc                 | 3.971ab          | 1.236bcd          | 0.041ab           | 2.367a          |
|                            | -12    | 3.300a                 | 0.317c                  | 3.418c           | 0.988f            | 0.032e            | 2.144b          |
| PEG-6000 (bar)             | 0      | 2.484c                 | 0.405ab                 | 4.049ab          | 1.161cde          | 0.035bcd          | 1.978bc         |
|                            | -3     | 2.306c                 | 0.435a                  | 4.309a           | 1.381ab           | 0.040ab           | 2.144b          |
|                            | -6     | 2.553bc                | 0.396ab                 | 4.110ab          | 1.428a            | 0.040ab           | 2.189ab         |
|                            | -9     | 2.722bc                | 0.376b                  | 4.053ab          | 1.070ef           | 0.037bcd          | 2.167ab         |
|                            | -12    | 3.241a                 | 0.318c                  | 3.723bc          | 1.128def          | 0.034de           | 2.100bc         |

Means followed by the same letters in each column are not significantly different (LSD test, 5 %).

0.05) for all the investigated characters (Tables 1 and 6). The mean germination time (MGT) increased with the decrease in osmotic potential in both NaCl and PEG solution; however, PEG delayed it more compared to NaCl (Table 1). Both priming (seed treatments) shortened the time to seed germination. Hydropriming resulted in the accelerated germination for both NaCl and PEG,

especially under low osmotic potential. Water uptake of the primed seeds did not change significantly ( $P < 0.05$ ), while the time to seed germination for hydropriming, KNO<sub>3</sub> and control was delayed by 12, 18 and 38 h, respectively (data not shown). Germination coefficient was influenced by salt and osmotic stresses, but inhibition was greater in PEG than in salt.

Table 6. Mean comparisons of interaction for germination characters of canola seeds treated with KNO<sub>3</sub>, hydropriming and control (untreated) at solution under water stress induced by NaCl and PEG

| Seed treatment<br>(T) | Solution<br>(S)            | Stress                     | Germination<br>time (day) | Germination<br>coefficient | Root length<br>(cm) | Shoot length<br>(cm) | Fresh weight<br>(gr) | Dry weight<br>(gr) |           |
|-----------------------|----------------------------|----------------------------|---------------------------|----------------------------|---------------------|----------------------|----------------------|--------------------|-----------|
| KNO <sub>3</sub>      | NaCl (dS.m <sup>-1</sup> ) | 0                          | 2.677cdef                 | 0.375abcde                 | 3.910abcdef         | 1.207cdefg           | 0.035defghji         | 2.000cde           |           |
|                       |                            | -3                         | 2.587cdef                 | 0.391abc                   | 4.183abcde          | 1.370abcde           | 0.040bcdefg          | 2.067bcde          |           |
|                       |                            | -6                         | 2.800abcdef               | 0.370abcde                 | 4.707a              | 1.300abcdef          | 0.044ab              | 2.233abcd          |           |
|                       |                            | -9                         | 3.103abcde                | 0.344bcde                  | 4.157abcde          | 1.360abcde           | 0.039bcdefg          | 2.467a             |           |
|                       |                            | -12                        | 3.250abc                  | 0.329cde                   | 3.657bcdef          | 1.027fgh             | 0.031hij             | 2.167abcde         |           |
|                       | PEG-6000 (bar)             | 0                          | 2.687cdef                 | 0.372abcde                 | 4.173abcde          | 1.247bcdefg          | 0.036cdefghi         | 2.133abcde         |           |
|                       |                            | -3                         | 2.270f                    | 0.441ab                    | 3.990abcdef         | 1.487abc             | 0.042bcd             | 2.033bcde          |           |
|                       |                            | -6                         | 2.483def                  | 0.404abc                   | 4.160abcde          | 1.390abcde           | 0.039bcdefg          | 2.100abcde         |           |
|                       |                            | -9                         | 2.513cdef                 | 0.403abc                   | 3.493def            | 0.868h               | 0.030ij              | 1.933cde           |           |
|                       |                            | -12                        | 2.720cdef                 | 0.379abcde                 | 4.017abcdef         | 1.173efg             | 0.034fghij           | 2.233abcd          |           |
|                       | Control                    | NaCl (dS.m <sup>-1</sup> ) | 0                         | 2.500def                   | 0.403abc            | 3.983abcdef          | 1.127efgh            | 0.039bcdefg        | 1.867de   |
|                       |                            |                            | -3                        | 2.497def                   | 0.405abc            | 3.913abcdef          | 1.460abcd            | 0.040bcdef         | 2.067bcde |
|                       |                            |                            | -6                        | 2.510cdef                  | 0.404abc            | 4.110abcde           | 1.370abcde           | 0.036cdefghi       | 2.033bcde |
|                       |                            |                            | -9                        | 2.653cdef                  | 0.382abcd           | 4.030abcdef          | 1.170efg             | 0.031hij           | 2.233abcd |
| -12                   |                            |                            | 3.137abcd                 | 0.337cde                   | 3.510cdef           | 0.973gh              | 0.033ghij            | 2.033bcde          |           |
| PEG-6000 (bar)        |                            | 0                          | 2.380ef                   | 0.421abc                   | 3.913abcdef         | 1.030fgh             | 0.034fghij           | 1.933cde           |           |
|                       |                            | -3                         | 2.397def                  | 0.419abc                   | 4.583ab             | 1.517ab              | 0.033fghij           | 2.133abcde         |           |
|                       |                            | -6                         | 2.523cdef                 | 0.401abc                   | 4.053abcde          | 1.517ab              | 0.042bcde            | 2.300abc           |           |
|                       |                            | -9                         | 2.583cdef                 | 0.393abc                   | 4.483abc            | 1.370abcde           | 0.041bcdef           | 2.400ab            |           |
|                       |                            | -12                        | 3.537a                    | 0.337cde                   | 3.510bcdef          | 1.043fgh             | 0.037bcdefgh         | 1.867de            |           |
| Hydropriming          | NaCl (dS.m <sup>-1</sup> ) | 0                          | 2.397def                  | 0.420abc                   | 3.443ef             | 1.153efg             | 0.035defghij         | 1.800e             |           |
|                       |                            | -3                         | 2.920abcdef               | 0.363abcde                 | 4.440abcd           | 1.560a               | 0.045ab              | 2.067bcde          |           |
|                       |                            | -6                         | 2.760bcdef                | 0.371abcde                 | 3.910abcdef         | 1.283abcdef          | 0.039bcdefg          | 1.967cde           |           |
|                       |                            | -9                         | 3.080abcde                | 0.331cde                   | 3.727bcdef          | 1.177defg            | 0.051a               | 2.400ab            |           |
|                       |                            | -12                        | 3.513a                    | 0.265e                     | 3.087f              | 0.963gh              | 0.033ghij            | 2.233abcd          |           |
|                       | PEG-6000 (bar)             | 0                          | 2.387ef                   | 0.421abc                   | 4.060abcde          | 1.207cdefg           | 0.034efghij          | 1.867de            |           |
|                       |                            | -3                         | 2.250f                    | 0.447a                     | 4.353abcde          | 1.140efgh            | 0.043abc             | 2.267abc           |           |
|                       |                            | -6                         | 2.653cdef                 | 0.383abcd                  | 4.117abcde          | 1.377abcde           | 0.038bcdefg          | 2.167abcde         |           |
|                       |                            | -9                         | 3.070abcde                | 0.331cde                   | 4.183abcde          | 0.970gh              | 0.039bcdefg          | 2.167abcde         |           |
|                       |                            | -12                        | 3.468ab                   | 0.290de                    | 3.600cdef           | 1.167efg             | 0.029j               | 2.200abcd          |           |

Means followed by the same letters in each column are not significantly different (LSD test, 5 %).

Seeds were able to germinate at -1.2 MPa of PEG. KNO<sub>3</sub> showed more germination under all osmotic potentials of NaCl solutions, but germination coefficient drastically declined and delayed with the increase in osmotic stress reduced by PEG at lower than -0.6 MPa. Considering seed treatments, KNO<sub>3</sub> gave higher germination coefficient only in PEG solution. KNO<sub>3</sub> and hydropriming decreased the abnormal germination in NaCl, while they failed to reduce it in PEG. Increased water stress was accompanied with an increase in abnormal germination in both solutions (data not shown). Although root length was affected by salt and osmotic stresses, significant and higher inhibition due to PEG was very evident ( $P < 0.05$ ). At -0.9 MPa, root growth stopped after emergence of root or primary root from the seed. Greater reduction in shoot length due to PEG compared to salt was very evident ( $P < 0.05$ ) with no recorded shoot growth at -0.6 MPa of PEG (Table 5). However, hydropriming enhanced shoot growth at -0.6 MPa of PEG. Also, hydropriming exhibited higher shoot growth

at all concentrations of NaCl. Depending on the decrease in shoot and root length, seedling fresh weight gradually declined with the decreasing osmotic potential of solutions (Table 6). Higher seedling fresh weights were recorded from NaCl compared to osmotic stress at or above -0.6 MPa of PEG.

Both seed treatments showed enhanced performance under stress conditions. Mean germination time was shortened by seed priming, but stress conditions delayed it considerably. Compared to PEG, MGT for NaCl was shorter at equivalent osmotic potential. This could be explained by more rapid water uptake in hydroprimed seeds because germination for hydropriming, KNO<sub>3</sub> and control started at 12, 18 and 38 h, respectively (data not shown). It supports that hydropriming caused more rapid water uptake than the amount of water for germination. Sung and Chiu (1995) observed that MGT was accelerated by hydropriming without changing the amount of water uptake in watermelon. Hydropriming clearly improved both rate of germina-

tion and mean germination time both under salt and drought stress conditions. Furthermore, hydropriming resulted in the increase in normal germination. The results are consistent with the findings of Thornton and Powell (1992) about *Brassica* and those of Srinivasan *et al.* (1999) about mustard. Fujikura *et al.* (1993) indicated the beneficial effects of hydropriming on aged or unaged seeds with respect to germination and percentage of normal seedlings in cauliflower. Furthermore, Sadeghian and Yavari (2004) reported that increasing drought stress resulted in increasing abnormal seedlings in sugar beet. It was concluded that superiority of hydropriming on germination could be due to soaking time effects rather than  $\text{KNO}_3$  treatment because hydroprimed seeds compared to  $\text{KNO}_3$ -treated seeds were allowed to imbibe water for a longer time and went through the first stage of germination without protrusion of radicle. Akinola *et al.* (2000) reported that longer duration of exposure to seed treatment resulted in higher cumulative germination in wild canola. Caseiro *et al.* (2004) found that hydropriming was the most effective method for improving seed germination of onion, especially when the seeds were hydrated for 96 hours compared to 48 hours. The beneficial effects of  $\text{KNO}_3$  on germination were found in the current study.

Hydropriming shortened MGT; however, final germination was higher from  $\text{KNO}_3$ , suggesting non-toxicity of  $\text{KNO}_3$  due to ion accumulation in the embryo (Demir and Van de Venter, 1999).

Seeds always germinated better in NaCl than in PEG at the equivalent water potential, as found earlier on soybean by Khajeh-Hosseini *et al.* (2003). This may be due to the uptake of  $\text{Na}^+$  and  $\text{Cl}^-$  ions by the seed, which maintains a water potential gradient allowing water uptake during seed germination. Lower germination percentage obtained from PEG compared with NaCl at equivalent water potential in each priming method suggested that the adverse effects of PEG on germination were due to osmotic effect rather than specific ion accumulation. These results agree with Murillo-Amador *et al.* (2002) in cowpea, and Demir and Van de Venter (1999) in watermelon. They affirmed that drought or salinity may influence germination by decreasing the water uptake. Moreover, the present study revealed that PEG had no toxic effects because all seeds germinated when PEG stress was removed. Mehra *et al.* (2003) and Michel (1983) indicated that PEG molecules do not enter the seed and Khajeh-

Hosseini *et al.* (2003) found that there was no toxicity of PEG. Under salt stress,  $\text{Na}^+$  and  $\text{Cl}^-$  may be taken up by the seed and the toxic effect of NaCl might appear. However, our findings at high salinity concentrations showed that the decrease in germination characters was not significant. The main effect of seed treatments was an increase in germination coefficient; however, post-germination growth was also increased. Hydropriming improved seedling fresh weight under osmotic stress. Considering both seed treatments, it was concluded that hydropriming improved root growth and gave the highest root length in both solutions. El-Midaoui *et al.* (2003) reported that root and shoot growth significantly decreased by osmotic stress at -0.6 MPa and above induced by PEG 6000. Murillo-Amador *et al.* (2002) found that seedling growth of cowpea was inhibited by both NaCl and PEG, but higher inhibition occurred due to PEG. Sung and Chiu (1995) proposed that emergence force and seedling growth were strengthened by hydropriming in watermelon. Seedling growth severely diminished with increased drought stress and genetic differences were found in sugar beet (Sadeghian and Yavari, 2004).

## Conclusion

It was observed that hydropriming practically ensured rapid and uniform germination accompanied with low abnormal seedling percentage in line with Shivankar *et al.* (2003) and Singh. (1995). They emphasized that it had high potential in improving field emergence and ensured early flowering and harvest under stress conditions, especially in dry areas. Our findings revealed that the inhibition of germination at equivalent water potential of NaCl and PEG was resulted from osmotic effect rather than salt toxicity. Both seed treatments gave better performance than control (untreated) under salt and drought stresses with clear effectiveness of hydropriming in improving the germination percentage at low water potential. In commercial production of canola in Iran, seed costs are a major input price, often exceeding \$200–\$360 per ha because the price of canola seed was \$10 to \$17 per kg in 2006. To achieve a uniform plant density in the case of drought, growers tend to sow 16  $\text{kg.ha}^{-1}$  of seed while only 8  $\text{kg.ha}^{-1}$  is needed. Hydrated seeds with higher germination percentage under drought and salt stresses represent a potential saving of \$125–\$212 per ha. It also in-

creased tolerance of seeds to salt and water stresses. In addition, the reported protocol is simple and cheap and does not require expensive chemicals and sophisticated equipment. The protocol has practical importance and could be recommended to farmers to achieve higher germination and uniform emergence under field conditions.

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