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Response of Three Camphor Populations Germination to Different Temperatures and Polyethylene Glycol Induced Drought Stress

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ABSTRACT

Plants are sensitive to environmental factors the most at the germination stage. This experiment was conducted to assess the germination of camphor populations collected from different habitats in Iran. The experiment was conducted in factorial in the form of a completely randomized design with three replications. Treatments included population (from Arak, Hamedan and Shahrekord habitats), temperature (10, 25 and 35°C) and drought stress induced by polyethylene glycol (0, -2, -4, -6, -8, -10 and -12 osmotic potential bars). Results indicated the significant effect of habitat, temperature and drought on all the measured traits. The interactions had also a significant effect on most of the measured traits. Seeds of samples collected from Shahrekord habitat had the highest germination. Among the temperature treatments, 25°C was the most favorable for seeds germination. Results also indicated that increasing drought stress level decreased seed germination.

Keywords: abiotic stress, adaptation, *Camphorosma monspeliaca*, habitat.

INTRODUCTION

Germination is the primary and a very sensitive growth stage in plants life cycle [5]. Plants are easily affected by environmental factors especially temperature and moisture. As the germination process is initiated by water absorption, water deficiency at this stage affects plant and reduces germination rate, depending on the severity and duration of the stress [2, 4, 15, 16].

Polyethylene glycol (PEG) is a non-poisonous substance which does not penetrate into plant tissue. Therefore, PEG acts unlike substances such as sodium chloride, mannitol and sucrose which penetrate into plant tissue and induce plant reaction. Using substances with high molecular weight and without effect on plant nutrition and absorption is under attention for stress studies [6]. PEG is a natural substance which is important in drought stress studies. Different experiments have tried to evaluate the tolerance of various plant cultivars to drought using PEG [7, 10, 11, 13]. Okcu et al. [8] studied the effects of drought stress on germination and growth of pea seedlings and concluded that stress inhibited stem growth more than root growth. Ghani et al. [1] evaluated the effect of 0, -5, -7, -9 and -20 osmotic potential bars induced by PEG on six *Achillea* species and found that the highest germination rate was achieved in the control; no seed germinated in -20 bars. Fallahi et al. [9] studied the effect of different levels of drought stress (0, -2, -4, -6, -7, -10 and -12 bars) and salinity stress (0, 50, 100, 150, 200, 250, 300 and 350 mM) on germination and growth of *Salvia sclarea* and reported the significant effect of treatments. They observed that the highest germination rate was achieved in the control, and the lowest germination rate was achieved in -12 bar drought and 350 mM salinity. Moreover, more severe stress levels reduced seedlings length and weight.
Although camphor is tolerant to salinity and drought and is distributed in harsh environmental conditions; however, there is no report regarding the ability of camphor seeds to germinate under different salinity and drought stress

levels. So, this experiment was conducted to evaluate the germination of camphor seeds from three different habitats under various drought stress levels and temperatures.

MATERIALS AND METHODS

To conduct this experiment, camphor seeds were collected from three natural habitats in Iran:

Arak. 49^{o} 41' E, 34^{o} 05' N, 293 km west of Tehran, 222.2 mm average annual precipitation, 12.7^{o}C average annual temperature, 48.6% relative humidity.

Hamedan. 48^{o} 31' E, 34^{o} 48' N, 337 km southwest of Tehran, 334.7 mm average annual precipitation, 11^{o}C average annual temperature, 53% relative humidity.

Shahrekord. 50^{o} 51' E, 32^{o} 19' N, 543 km southwest of Tehran, 317.7 mm average annual precipitation, 11.8^{o}C average annual temperature, 46% relative humidity.

The experiment was conducted in factorial in the form of a completely randomized design with three replications. Treatments of the experiment included: three populations (Arak, Hamedan, and Shahrekord), three temperatures (10, 25 and 35^{o}C) and seven drought stress levels induced by PEG (0, -2, -4, -6, -8, -10 and -12 osmotic potential bars). The concentration of PEG required to provide the water potentials was measured by the following equation [6]:

$$\Psi_S = - (1.18 \times 10^{-2}) C - (1.18 \times 10^{-4}) C^2 + (2.67 \times 10^{-4}) CT + (8.39 \times l0^{-7}) C^2T$$

Where C is the concentration of PEG-6000 in g/l, T is the temperature in ^{o}C and Ψ_S is the water potential in bar.
The experiment was conducted in the three temperatures (± 2^{o}C), 16 h light and 8 h dark, and 25 seeds in each petri dish. Seeds were sterilized by 70% alcohol for 30 seconds, then, were placed in the sterilized petri dishes. After that, 10 ml of the required solutions was added to each petri dish. Petri dishes were packed by parafilm and were located in germinator. Traits were measured according to the instruction of the International Seed Testing Association [12, 14]. Petri dishes were monitored regularly and the germination speed was calculated by the following equation:

$$RS = \Sigma \frac{Si}{Di}$$

Where:
RS is the germination speed (seeds/day)
Si is the number of germinated seeds in each observation
Di is the number of days to the n measurement

Seed vigor was also measured by the following equation:

Seed vigor = (100/seedling length) × (germination percentage)

After 14 days, all germinated seeds were checked; radicle and plumule length was measured. Finally, data were first tested for their normality and some of them were normalized. Then, data were analyzed using SAS and means were compared by the Duncan's multiple range test.

RESULTS

Analysis of variance indicated the significant effect of habitat (population), temperature and PEG on germination percentage and speed, plumule and radicle length, radicle / plumule ratio and seed vigor index (Table 1). Moreover, the two-fold and three-fold interactions had also a significant effect on most of the measured traits.

Table 1. Analysis of the variance of the measured traits

SOV	df	Mean Squares (MS)						
		Germination percentage	Germination speed	Plumule length	Radicle length	Plumule / radicle ratio	Seed vigor index	Seed germination index
Habitat (A)	2	**	*	**	**	**	**	**
Temperature (B)	2	**	**	**	**	**	**	**
PEG (C)	6	**	**	**	**	**	**	**

AB	4	*	**	**	**	**	**	*
AC	12	ns	**	**	ns	ns	**	ns
BC	12	**	**	**	**	**	**	**
ABC	24	ns	*	*	*	ns	**	ns
Error	126	96.9	0.062	0.81	7.74	0.40	6.81	2.48
CV (%)	-	19.03	21.13	19.4	27.85	25.38	25.6	19.03

*ns, nonsignificant; *, significant at P≤0.05; **, significant at P≤0.01.*

Mean comparison of the three habitats (Table 2) showed that Shahrekord had the highest germination percentage (57.34%), germination speed (1.25 seeds / day), plumule length (5.22 mm), radicle length (13.53 mm) and seed vigor index (12.8). However, radicle / plumule ratio was the highest in Arak habitat (2.85).

Table 2. Effect of the three habitats on the measured traits

Habitats	Germination percentage	Germination speed (seeds / day)	Plumule length (mm)	Radicle length (mm)	Plumule / radicle ratio	Seed vigor index	Seed germination index
Shahrekord	57.34a	1.25a	5.22a	13.53a	2.4b	12.8a	9.18a
Hamedan	54.76a	1.17ab	4.57b	11.40b	2.24b	9.9b	8.76a
Arak	43.06b	1.12b	4.09c	11.6b	2.85a	7.89c	6.9b

Means in a column followed by the same letter are not significantly different at P≤0.01.

Studying the effect of temperature (Table 3) on camphor seed germination indicated that all the traits were the highest in 25°C and the lowest in 10°C. Germination percentage was 53.7% in 25°C and 37.7% in both 10°C and 35°C.

Table 3. Effect of the three temperatures on the measured traits

Temperatures	Germination percentage	Germination speed (seeds / day)	Plumule length (mm)	Radicle length (mm)	Plumule / radicle ratio	Seed vigor index	Seed germination index
10°C	37.7c	0.94c	1.94c	3.62c	1.94c	2.1c	6.04c
25°C	53.7a	1.35a	6.42a	18.61a	2.94a	15.99a	9.88a
35°C	37.7b	1.25b	5.52b	14.29b	2.64b	12.5b	8.92b

Means in a column followed by the same letter are not significantly different at P≤0.01.

Mean comparison of the PEG induced drought stress levels (Table 4) indicated that germination percentage was the highest (66.33%) in -2 bar and the lowest (30.74%) in -12 bar. Moreover, germination speed was the highest (1.35 seeds / day) in -6 bar and the lowest (0.98 seeds / day) in -10 bar.

Table 4. Effect of the seven PEG induced drought stress levels on the measured traits

PEG levels	Germination percentage	Germination speed (seeds / day)	Plumule length (mm)	Radicle length (mm)	Plumule / radicle ratio	Seed vigor index	Seed germination index
0 bar	62.25ab	1.28a	6.82a	13.92a	1.82d	14.65a	9.96ab
-2 bar	66.33a	1.28a	5.17b	14.47a	2.55c	14.4a	10.61a
-4 bar	59.48bc	128a	4.49c	13.84a	2.84bc	12.1b	9.52bc
-6 bar	54.18c	1.35a	4.36c	14.15a	3.07ab	11.2bc	8.67c
-8 bar	48.7d	1.21ab	4.27c	14.65a	3.21a	10.36c	7.8d
-10 bar	40.37e	0.98c	3.65d	7.74b	2.11d	5.07d	6.46e
-12 bar	30.74f	1.1bc	3.66d	6.98b	1.89d	3.57e	4.92f

Means in a column followed by the same letter are not significantly different at P≤0.01.

Mean comparison of the interaction of habitat × temperature (Table 5) indicated that the highest germination percentage, plumule length, radicle length, radicle / plumule ratio, seed vigor index and seed germination index were achieved in Shahrekord × 25°C. In the interaction of habitat × PEG (Table 6), the highest germination percentage belonged to Shahrekord × control, Shahrekord × -2 bar and Shahrekord × -4 bar. The highest germination speed was achieved in Shahrekord × 0 bar, Shahrekord × -6 bar and Hamedan × -6 bar. The interaction of temperature × PEG (Table 7) showed that the highest germination percentage belonged to 25°C × -2 bar, 25°C × -4 bar, 35°C × 0 bar, 35°C × -2 bar and 35°C × -4 bar. The highest plumule length (10.43 mm) was achieved in 35°C × 0 bar, and the highest radicle length (25 mm) was achieved in 25°C × -8 bar.

Table 5. Effect of habitat × temperature on the measured traits

Habitat × temperature	Germination percentage	Germination speed (seeds / day)	Plumule length (mm)	Radicle length (mm)	Plumule / radicle ratio	Seed vigor index	Seed germination index
A_1B_1	40.52f	8.1f	1.14b	2.26d	3.49ef	1.6c	2.39e
A_1B_2	70.05a	14.0a	1.36a	7.68a	22.025a	2.94ab	21.33a

A_1B_3	61.48b	12.3b	1.22ab	5.74c	15.04cd	2.67ab	14.68b
A_2B_1	44.9ef	8.98ef	0.98a	1.84d	2.52f	1.4c	1.99e
A_2B_2	62.14b	12.43b	1.26ab	6.44b	18.09b	2.77ab	15.41cd
A_2B_3	57.24bc	11.45bc	1.27ab	5.42c	13.55d	2.57b	12.29c
A_3B_1	27.76g	5.56g	0.7d	1.71d	4.85e	2.8ab	1.9e
A_3B_2	52.95cd	10.6cd	1.39a	5.14c	15.7c	3.09a	11.22cd
A_3B_3	48.48de	9.7de	1.26ab	5.41c	14.27cd	2.66ab	10.52d

Means in a column followed by the same letter are not significantly different at P≤0.01.
A_1, Shahrekord; A_2, Hamedan; A_3, Arak.
B_1, 10°C; B_2, 25°C; B_3, 35°C.

Table 6. Effect of habitat × PEG on the measured traits

Habitat × PEG	Germination percentage	Germination speed (seeds / day)	Plumule length (mm)	Radicle length (mm)	Plumule / radicle ratio	Seed vigor index
A_1C_1	73.33a	1.38abc	7.98a	15.35abc	1.73efg	19.93a
A_1C_2	74.11a	1.33bcd	5.16bcd	16.3ab	2.76cd	18.16a
A_1C_3	64.66abc	1.13cdefg	4.86bcdef	14.92abc	2.78cd	14.23b
A_1C_4	56.11cd	1.46ab	5.11bcd	15.6abc	2.9bcd	13.3bcd
A_1C_5	54.5cde	1.27bcd	4.92bcdef	16.39a	3.02bcd	13.26bcd
A_1C_6	45.1efg	0.92fgh	4.2defgh	8.47e	1.99efg	6.45gh
A_1C_7	33.5h	1.23bcde	4.34cdefgh	68.7e	1.65g	4.29hi
A_2C_1	62.7bc	1.28bcd	7.19a	13.21cd	1.66g	14.39b
A_2C_2	69.6ab	1.2bcdef	4.97bcde	13.82cd	2.52cde	13.78bc
A_2C_3	62.33bc	1.13cdefg	4.46bcde	12.89cd	2.57cde	11.99bcde
A_2C_4	57.89cd	1.61a	3.97fgh	12.85cd	2.83bcd	10.7de
A_2C_5	49.4def	1.16cdefg	4.25defgh	14.39abcd	2.87bcd	9.98ef
A_2C_6	43.78fg	0.84h	3.38hi	6.01e	1.59g	9.38hi
A_2C_7	37.44gh	0.96efgh	3.78ghi	6.55e	1.68g	4.1hi
A_3C_1	50.67def	1.17cdef	5.28bc	11.61d	2.06efg	9.65ef
A_3C_2	55.22cde	1.35bcd	5.35b	13.29abcd	2.38def	11.3cde
A_3C_3	51.44def	0.9gh	4.12efgh	13.7abcd	3.2abc	10.11ef
A_3C_4	48.55def	0.97efgh	3.98fgh	14.01abcd	3.47ab	9.29ef
A_3C_5	42.11fgh	1.2bcdef	3.64ghi	13.19cd	3.74a	7.85fg
A_3C_6	32.22h	1.18cdef	3.39hi	8.75e	2.75cd	4.38hi
A_3C_7	21.22i	109defgh	2.88i	6.7e	2.35def	2.3i

Means in a column followed by the same letter are not significantly different at P≤0.01.
A_1, Shahrekord; A_2, Hamedan; A_3, Arak.
C_1, 0; C_2, -2; C_3, -4; C_4, -6, C_5, -8; C_6, -10; C_7, -12.

Table 7. Effect of temperature × PEG on the measured traits

Temperature × PEG	Germination percentage	Germination speed (seeds / day)	Plumule length (mm)	Radicle length (mm)	Plumule / radicle ratio	Seed vigor index
B_1C_1	39.89gh	0.87gh	2.38i	3.04g	1.27i	2.18h
B_1C_2	47.67fg	1.01h	2.32i	3.74g	1.55ghi	2.73h
B_1C_3	40.11gh	0.8fgh	2.02ij	3.64g	1.94efgh	2.33h
B_1C_4	36.89h	1.03fgh	1.78ij	4.32g	2.32def	2.1h
B_1C_5	34.55h	0.93fgh	1.82ij	4.47g	2.53cde	2.03h
B_1C_6	33.44h	1.0fgh	1.33j	2.72g	2.11efg	1.42h
B_1C_7	31.55h	0.97fgh	1.92ij	2.84g	1.8fghi	1.85h
B_2C_1	68.11bc	1.59ab	7.6b	16.64cd	2.23efg	16.88cd
B_2C_2	74.89ab	1.42abcd	6.84bc	20.46b	2.97bcd	20.93b
B_2C_3	69.11abc	1.2cdef	6.53c	20.36b	3.13bc	18.82bc
B_2C_4	64.44c	1.63a	6.62c	21.97b	3.42ab	18.72bc
B_2C_5	60.55cde	1.4abcd	6.45c	25.0a	3.9a	19.37bc
B_2C_6	54.44def	0.84gh	5.56de	13.21e	2.45def	10.14f
B_2C_7	40.44gh	13.34bcde	5.3ef	12.67e	2.46def	7.05g
B_3C_1	78.78a	1.38abcd	10.43a	20.49b	1.97efgh	24.89a
B_3C_2	74.44ab	1.45abc	6.33cd	19.2bc	3.15bc	19.56bc
B_3C_3	69.22abc	1.16def	4.9efg	16.98cd	3.47ab	15.16de
B_3C_4	61.22cd	1.38abcd	4.66efgh	16.18d	3.46ab	12.75e
B_3C_5	51.0ef	1.31cde	4.53fgh	14.49de	3.19b	9.67f
B_3C_6	33.22h	1.1efg	4.06gh	7.3f	14.78fghi	3.64h
B_3C_7	20.22i	0.98fgh	3.76h	5.39fg	1.43hi	1.78h

Means in a column followed by the same letter are not significantly different at P≤0.01.
B_1, 10°C; B_2, 25°C; B_3, 35°C.
C_1, 0; C_2, -2; C_3, -4; C_4, -6, C_5, -8; C_6, -10; C_7, -12.

Mean comparison of the three-fold interaction of habitat × temperature × drought stress level (Table 8) indicated that the highest germination percentage was achieved in Shahrekord × 25°C × 0 bar, Shahrekord × 25°C × -2 bar, Shahrekord × 35°C × 0 bar, Shahrekord × 35°C × -2 bar, Hamedan × 35°C × 0 bar and Hamedan × 35°C × -2 bar. The highest plumule length was achieved in Shahrekord × 35°C × 0 bar (12 mm) and Hamedan × 35°C × 0 bar (11.5

mm). The highest radicle length was also achieved in Shahrekord × 25°C × -8 bar (29.7 mm) and Hamedan × 25°C × -8 bar (26.8 mm).

Table 8. Effect of the three-fold interaction of habitat × temperature × drought stress levels on the measured traits

Habitat × Temperature × PEG	Germination percentage	Germination speed (seeds / day)	Plumule length (mm)	Radicle length (mm)	Plumule / radicle ratio	Seed vigor index
$A_1B_1C_1$	43.33L-v	1.1c-g	2.8p-u	3.0s	1.07u	2.51qr
$A_1B_1C_2$	46.67i-t	1.2b-f	2.4r-w	3.1s	1.29r-u	2.57qr
$A_1B_1C_3$	45.66L-u	1.1c-g	2.2s-w	1.63s	1.65m-u	2.69qr
$A_1B_1C_4$	38.0p-y	1.4b-e	2.0t-w	3.86s	1.93k-u	2.27qr
$A_1B_1C_5$	37.67m-x	1.1c-g	2.13s-w	4.46s	2.12h-u	2.51qr
$A_1B_1C_6$	36.67p-x	1.0d-h	1.8t-w	3.53s	1.97k-u	2.03r
$A_1B_1C_7$	35.67r-w	1.1c-g	2.5q-w	2.83s	1.21su	2.15r
$A_1B_2C_1$	83.0abc	1.7ab	9.17b	19.07d-k	2.14g-u	23.54cd
$A_1B_2C_2$	88.33ab	1.3b-f	7.5c-f	26.0a-c	3.47a-f	29.67ab
$A_1B_2C_3$	74.67b-f	1.2b-f	7.4c-f	23.53b-e	3.18a-k	23.22cd
$A_1B_2C_4$	71.66b-g	1.9a	8.63b-c	25.8a-c	3.12a-l	24.67c
$A_1B_2C_5$	70.0b-g	1.4b-e	7.93b-d	29.7a	3.76a-d	26.32bc
$A_1B_2C_6$	62.0e-m	0.6g-j	6.6d-j	15.2h-o	2.44e-t	13.37h-l
$A_1B_2C_7$	40.67n-x	1.6a-c	6.53d-j	15.1h-o	2.46e-s	8.5L-p
$A_1B_3C_1$	93.67a	1.37b-e	12.0a	24.0b-d	2.0j-u	33.72a
$A_1B_3C_2$	87.33ab	1.5a-d	5.6g-n	19.8d-i	3.53a-f	22.24cd
$A_1B_3C_3$	73.67b-f	1.1c-g	5.0j-o	17.6f-l	3.52a-f	16.76e-h
$A_1B_3C_4$	58.67d-o	1.1c-g	4.7k-o	17.13f-m	3.64a-e	12.95h-m
$A_1B_3C_5$	56.0f-p	1.3b-f	4.7k-o	15.0h-o	3.19a-k	10.93i-n
$A_1B_3C_6$	36.67p-y	1.17c-f	4.2m-q	6.67p-s	1.59n-u	3.95p-r
$A_1B_3C_7$	24.33v-z	1.0d-h	4.0n-r	5.1r-s	1.28r-u	2.21qr
$A_2B_1C_1$	44.0m-v	0.97e-h	2.2s-w	2.6s	1.18s-u	2.11r
$A_2B_1C_2$	60.33d-n	0.93e-i	2.0t-w	2.7s	1.35q-u	2.83q-r
$A_2B_1C_3$	44.33k-u	0.9e-i	1.8t-w	2.4s	1.33q-u	1.83r
$A_2B_1C_4$	43.33L-v	1.23b-f	1.4u-w	2.37s	1.69m-u	1.61r
$A_2B_1C_5$	42.33n-x	1.1c-g	1.7u-w	2.27s	1.4p-u	1.65r
$A_2B_1C_6$	40.67n-x	0.9e-i	1.3u-w	1.5s	1.15tu	1.13r
$A_2B_1C_7$	39.33o-x	0.83f-j	2.57p-v	3.87s	1.68m-u	2.78q-r
$A_2B_2C_1$	65.67c-i	1.57a-c	7.57b-d	15.57h-o	1.94k-u	15.31e-h
$A_2B_2C_2$	71.67b-g	1.37b-e	6.93c-g	19.1d-k	2.74b-o	18.65d-g
$A_2B_2C_3$	70.33b-h	1.27b-f	7.0c-f	20.33e-h	2.9a-m	19.24df
$A_2B_2C_4$	65.33c-j	1.7ab	6.23d-k	22.33b-f	3.58a-f	18.68d-g
$A_2B_2C_5$	59.67d-n	1.2b-f	6.8d-i	26.8a-b	3.92a-c	19.75de
$A_2B_2C_6$	55.33i-r	0.6g-j	5.03j-o	11.5n-p	2.3h-u	8.88k-o
$A_2B_2C_7$	47.0i-t	0.13c-f	5.23h-o	11.0n-q	2.01i-u	7.35n-q
$A_2B_3C_1$	78.67a-d	1.3b-f	11.5a	21.46c-g	1.87L-u	25.72bc
$A_2B_3C_2$	77.0a-e	1.3b-f	6.0f-l	19.67e-g	3.45a-f	19.83de
$A_2B_3C_3$	72.33c-f	1.23b-f	4.6k-o	15.93g-n	3.46a-f	14.86e-i
$A_2B_3C_4$	65.0c-j	1.9a	4.3L-o	13.87k-o	3.22a-k	7.8h-n
$A_2B_3C_5$	46.33i-t	1.2b-f	4.3L-o	14.1i-o	3.28a-j	8.52l-p
$A_2B_3C_6$	35.33s-x	1.03d-g	3.8n-s	5.03r-s	1.32q-u	3.09q-r
$A_2B_3C_7$	26.0uz	0.93e-i	3.5o-t	4.8s	1.37q-u	2.15r
$A_3B_1C_1$	32.33s-y	0.53h-i	2.15s-w	3.53s	1.54o-u	1.92r
$A_3B_1C_2$	36.0s-y	0.9e-i	2.57p-v	5.43r-s	2.01j-u	2.79r
$A_3B_1C_3$	30.33u-y	0.4j	2.06s-w	6.46p-s	2.85a-n	2.48qr
$A_3B_1C_4$	29.33u-y	0.47i-j	1.93t-w	6.73p-s	3.35a-h	2.44qr
$A_3B_1C_5$	23.67w-z	0.6g-j	1.67u-w	6.7p-s	4.08a	1.94r
$A_3B_1C_6$	23.0xyz	1.1c-g	0.9vw	3.13s	3.22a-k	1.08r
$A_3B_1C_7$	19.67yz	0.97e-h	0.7w	1.93s	2.53d-r	0.62r
$A_3B_2C_1$	55.67i-q	1.5a-d	5.9f-m	15.3h-o	2.59d-q	11.8h-n
$A_3B_2C_2$	64.67c-j	1.6a-c	6.1f-k	16.3g-n	2.67c-p	14.48f-j
$A_3B_2C_3$	62.33e-l	1.13c-f	5.2i-o	17.23f-m	3.31a-i	13.99g-j
$A_3B_2C_4$	56.33g-p	1.3b-f	5.0j-o	17.77f-l	3.55a-f	12.8h-m
$A_3B_2C_5$	52.0h-s	1.6a-c	4.63k-o	18.5e-l	4.03a-b	12.03h-n
$A_3B_2C_6$	46.0L-t	1.33b-f	8.07i-o	12.93L-o	2.59d-q	8.17m-p
$A_3B_2C_7$	33.67s-y	1.3b-f	4.13m-q	11.9m-o	2.9a-m	5.31o-r
$A_3B_3C_1$	64.0c-j	1.5a-d	7.8b-e	16.0g-n	2.05i-u	15.23e-i
$A_3B_3C_2$	65.0c-j	1.57a-c	7.4c-f	18.13f-l	2.45e-s	16.6e-h
$A_3B_3C_3$	61.67d-m	1.16c-f	5.1i-o	17.4f-l	3.41a-g	13.85g-k
$A_3B_3C_4$	60.0d-n	1.13c-f	5.0j-o	17.53f-l	3.5a-f	13.5h-l
$A_3B_3C_5$	50.67i-s	1.4b-e	4.6k-o	14.37i-o	3.12a-l	9.57j-o
$A_3B_3C_6$	27.67t-z	1.1c-g	4.2m-q	10.2o-r	2.42e-t	3.88p-r
$A_3B_3C_7$	10.33z	1.0d-h	3.8n-s	6.26q-s	1.65m-u	0.99r

Means in a column followed by the same letter are not significantly different at P≤0.01.
A_1, Shahrekord; A_2, Hamedan; A_3, Arak.
B_1, 10°C; B_2, 25°C; B_3, 35°C.
C_1, 0; C_2, -2; C_3, -4; C_4, -6, C_5, -8; C_6, -10; C_7, -12.

Studying the correlation of the traits indicated that germination percentage was significantly correlated to all other measured traits (Table 9).

Table 9. Correlation of the measure traits

	Germination percentage	Germination speed	Plumule length	Radicle length	Plumule / radicle ratio	Seed vigor index
Germination percentage	1					
Germination speed	0.42**	1				
Plumule length	0.68**	0.45**	1			
Radicle length	0.69**	0.48**	0.83**	1		
Plumule / radicle ratio	0.28*	0.23*	0.22*	0.66**	1	
Seed vigor index	0.87**	0.47**	0.87**	0.92**	0.47**	1

*ns, nonsignificant; *, significant at P≤0.05; **, significant at P≤0.01.*

DISCUSSION

Results of this experiment indicated that the evaluated seeds were affected by the environmental conditions of their parent plant habitat, in the way that the seeds from Shahrekord habitat, which had grown in non-saline soil and high precipitation rate, had higher germination percentage and speed, and had longer plumule and radicle. These seeds had also a higher seed vigor index. Radicle / plumule ratio was higher in Arak seeds; indicating that plants from Arak habitat have inherited the ability to tolerate harsh conditions by increasing their root growth. It should be noted that plumule and radicle length was lower in Arak seeds than in the two other habitats; however, radicle / plumule ratio was the highest.

Seeds germinated better in 25^{o}C than in two other temperatures; all the measured traits were the highest in 25^{o}C. Because camphor is a C_4 plant, it was expected that the seeds germinate better in 35^{o}C; however, germination was the highest in 25^{o}C. This is probably because high temperature along with drought stress inhibits germination. Of course, these results are obtained in laboratory and different results may be obtained under the natural conditions of habitat.

Under stressed condition, traits were the highest in the control and the low osmotic pressure (-2 bar). Results indicated that root length increased up to -8 bar and decreased at higher drought stress level; indicating that plants try to cope with the harsh environmental conditions by increasing their root growth; when the stress level exceeds a certain level, all features including root length decreases.

Study of the effect of temperature × habitat showed that the best results were achieved in Shahrekord × 25^{o}C. In the interaction of temperature × PEG (Table 6), the highest germination percentage was achieved in 10^{o}C × 0, -2 and -4 bar. This proves that under drought conditions, seeds germinate better in lower temperatures, maybe because of lower evaporation. The highest germination speed was observed in -6 bar × Shahrekord and -4 bar × Hamedan which indicates that seeds of plants grown in more suitable conditions are more tolerant. Enhancement of plumule length in lower concentrations of PEG, and enhancement of radicle / plumule ratio in different PEG concentrations indicates that adaptation is important in addition to the growth condition of parent plants. That is why seeds of Arak habitat had longer radicles under stressed conditions. Results of this experiment were in agreement with those of Ghani et al. [1]; Kazerooni Monfared et al. [3] and Fallahi et al. [9].

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