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Seed Germination and Early Root Growth of Three Barley Cultivars as Affected by Temperature and Water Stress

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Abstract: Effects of temperature (9, 15, 21, 27 and 33°C) and water stress (water potentials of 0, -0.3, -0.6 and -0.9 MPa) on germination and early rooting of three barley (*Hordeum vulgare* L.) cultivars were studied. High temperatures (27, 33°C) reduced germination rate and percentage, but these effects were more pronounced under high stress conditions. Main axis and total root lengths were highest at temperatures 21 and 27°C regardless of water stress level, while the highest number of seminal roots was obtained at temperatures between 15 and 27°C. Water stress caused significant reductions of both germination and rooting characters. The cultivar Rehani -3 had the highest germination percentage and rate among studied cultivars, while SLB-6 cultivar had generally the highest main axis and total root lengths regardless of temperature and water stress level, which may indicate that roots of this cultivar could elongate rapidly which ensuring better water supply under arid and semiarid conditions.

Key words: Germination · *Hordeum vulgare* · root elongation · arid region · water potential

INRODUCTION

Barley (*Hordeum vulgare* L.) is one of the most widely grown crops in arid and semiarid regions of the world. It is grown mainly as feed grain or it can be grazed before heading in dry years. Seeding at the optimum date (usually in fall) or even earlier is important in barley production in Mediterranean arid regions. High evaporation rates due to high temperatures may occur during the common sowing time of barley, resulting in a rapid drying of surface soils after being wetted and causing a marked decrease in soil water potential [1, 2]. The seeds of barley show a delayed or reduced germination when the water potential of surrounding medium decreases [1, 3, 4]. Also the sensitivity to water stress differs greatly in relation to genetic and environmental factors [5-7].

The effect of unfavorable weather is probably more critical during germination and early seedling development stages than at any other stage of vegetative growth. Successful germination of the seeds under a wide range of environmental conditions (e.g., temperature and moisture) is important for early seedling establishment [8-11]. The rate and final percentage of germination of cereals are affected by moisture stress and temperature [1, 12]. The results of early studies on the effects of temperature on different plant species showed that there was a broad optimum temperature for the growth of seedlings [9, 10, 13]. However, seedling establishment may be hindered by a rapid drying of surface soils after being wetted [1, 14]. Therefore, plants grown in these environments should have the ability to develop a root system rapidly once seed germination has occurred, in order to ensure a continuous water supply for transpiration and growth. Sometimes, the plant's need for water can be met by a rapidly elongating main axis [9], while in other situations many long laterals are needed to exploit the water found in a thin layer of wetted surface soil.

Little information was found in the literature about the combined effects of temperature and water stress on germination and early root growth of different barley cultivars. The objectives of this study were to test the hypothesis that seed germination and early root growth of barley cultivars are affected by temperature and water stress and to determine if genetic variability exists

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between barley cultivars in response to these stress factors.

MATERIALS AND METHODS

Seed lots of the barley cultivars Rehani-3, SLB-6 and Rum were used in this study. Seeds of all cultivars had similar initial moisture contents of 8-10%. Thirty seeds from each cultivar were germinated on two layers of Whatman filter paper, in 9-cm petri dishes containing different potentials of osmotic solution created by adding polyethylene glycol 8000 (PEG) at 0, 16.0, 19.5 and 22.5% in solution (W/W) (equivalent to approximately 0, -0.3, -0.6 and -0.9 MPa, respectively). The petri dishes were placed in an incubator at the appropriate temperature (9, 15, 21, 27 or 33°C) in the dark. The treatments were placed in a factorial arrangement in a completely randomized design with four replications. Distilled water was added to each petri dish to replace the evaporated water.

Seeds were considered germinated when they exhibited radicle extension of >3 mm. Counts of germinated seeds were made daily during the course of the experiment to determine both final germination percentage and germination rate index. Final germination percentages were calculated from total number of seeds germinated divided by total number of seeds used. The germination rate index was determined by using the procedure described by Al-Karaki [1]: Germination rate index = $\Sigma G_n/D_n$

Where, G_n are germination percentages at different days (D_n) after initiation of germination.

The experiment was terminated by harvesting seedlings three days after no more germination occurred. After the Main Axis Root Length (MARL) was measured by a ruler and Seminal Root Number (SRN) was counted for each seedling, the seedlings were separated into shoots and roots. The total root root mass was weighed to determine Root Fresh Weight (RFW). Ttotal Root Length (TRL) were measured according to the procedure described by Al-Karaki [1].

Data were statistically analyzed using analyses of variance in the MSTATC PROGRAM (Michigan State Univ., East Lansing, MI). Probabilities of significance were used to indicate significance among treatments and interaction effects. LSD ($p<0.05$) was used to make comparisons among means.

RESULTS

The temperature (T) and water potential (WP) treatments and the T×WP interactions provided numerous significant responses for most of the studied plant traits (Table 1). Cultivars (C) had significant differences for all germination and rooting traits except for root fresh weight. Other significant interaction effects were T×C and WP×C for final germination percentage and rate index and T×WP×C for germination rate index.

In all cultivars, the final germination percentage was highest at 15°C and started to decrease as the temperature increased with the lowest at 33°C, regardless of water potential (Table 2). Final germination percentage at 9°C was significantly lower than at 15°C only for the cultivars Rum and Rehani-3. As water potential in the medium decreased (0 to-0.9 MPa), the final germination percentage was decreased in all cultivars. The genotypic differences in response to temperature and water potential for final germination were highly significant. The cultivar Rehani-3 had higher final germination percentage than the other two cultivars regardless of temperature or water potential (Table 2). However, the cultivar Rum generally had the lowest final germination percentage regardless of temperature or water potential.

The germination rate index decreased (more time needed for germination) as water potential of medium decreased (more stress) in all cultivars (Table 3). Highest germination rate of the seeds of all cultivars occurred at 15 and 21°C and decreased thereafter with increasing temperature regardless of water potential. The cultivar Rehani-3 had higher germination rate than the other two cultivars regardless of temperature or water potential. The

Table 1: Probabilities of significance for different traits of barley as affected by Temperature (T), Water Potential (WP) and Cultivar (C)

Trait	T	WP	C	T×WP	T×C	WP×C	T×WP×C
Final germination	**	**	**	**	**	**	ns
Germination rate	**	**	**	**	**	*	*
Main axis root length	**	**	*	**	ns	ns	ns
Total root length	**	**	*	**	ns	ns	ns
Seminal root number	**	**	*	ns	ns	ns	ns
Root fresh weight	**	**	ns	**	ns	ns	ns

** and * are significant at $p<0.01$ and $p<0.05$, respectively. ns: not significant

Table 2: Effects of temperature and Water Potential (WP) on final germination (%) of three barley cultivars

		Temperature (°C)				
WP (-MPa)	Cultivar	9	15	21	27	33
0	Rum	80 b-g[¶]	87 a-d	70 d-j	52 k-o	30 r-u
	Rehani-3	91 ab	98 a	91 ab	67 f-k	62 h-m
	SLB-6	90 a-c	91 ab	91 ab	50 l-p	35 p-s
0.3	Rum	74 d-I	84 a-e	54 j-n	29 r-v	27 r-v
	Rehani-3	91 ab	98 a	84 a-e	59 i-m	58 i-m
	SLB-6	84 a-e	89 a-c	85 a-e	49 m-q	24 r-v
0.6	Rum	67 f-k	83 a-f	54 j-n	28 r-v	20 t-v
	Rehani-3	89 a-c	98 a	81 b-j	57 j-m	40 n-r
	SLB-6	82 a-g	83 a-f	69 e-d	33 q-s	23 s-v
0.9	Rum	66 g-l	76 c-h	36 o-s	13 v	14 u-v
	Rehani-3	78 b-h	87 a-d	78 b-h	34 p-s	32 r-t
	SLB-6	78 b-h	80 b-j	59 i-m	20 s-v	16 t-v

Values followed by the same letter(s) are not significantly different (p = 0.05) according to LSD

Table 3: Effects of temperature and Water Potential (WP) on germination rate index of three barley cultivars

		Temperature (°C)				
WP (-MPa)	Cultivar	9	15	21	27	33
0	Rum	16.2 n-w[¶]	24.6 f-m	22.5 g-p	19.2 k-r	8.2 w-y
	Rehani-3	22.7 f-p	43.1 ab	48.5 a	36.0 b-e	33.5 c-e
	SLB-6	19.6 i-r	30.9 d-f	33.9 c-e	17.8 l-t	9.9 t-y
0.3	Rum	15.5 o-w	25.7 e-l	24.1 f-n	14.5 p-w	11.7 r-x
	Rehani-3	21.3 h-q	29.8 d-j	40.7 a-c	28.9 d-h	26.7 e-k
	SLB-6	17.2 m-v	27.9 d-i	39.4 bc	27.6 e-j	13.3 q-x
0.6	Rum	15.1 o-w	23.0 f-o	24.6 f-m	5.7 xy	9.0 u-y
	Rehani-3	19.5 j-r	28.4 d-h	42.7 ab	22.4 g-p	17.3 m-u
	SLB-6	18.3 l-s	27.6 e-j	25.0 f-m	13.1 q-x	8.9 v-y
0.9	Rum	13.1 q-x	22.7 f-p	10.1 s-y	2.5 y	2.0 y
	Rehani-3	18.1 l-t	23.5 f-o	30.4 d-j	13.2 q-x	9.8 t-y
	SLB-6	19.1 k-r	24.1 f-n	22.4 g-p	5.9 xy	2.7 y

Values followed by the same letter are not significantly different (p = 0.05) according to LSD

Table 4: Effects of temperature and Water Potential (WP) on main axis root length (cm/seedling) of three barley cultivars

		Temperature (°C)				
WP (-MPa)	Cultivar	9	15	21	27	33
0	Rum	1.9 q-t[¶]	5.8 f-l	9.2 a-d	10.2 ab	6.9 d-I
	Rehani-3	1.8 r-t	5.8 f-l	7.2 c-h	9.9 ab	6.4 e-j
	SLB-6	2.5 o-t	6.4 e-j	10.0 ab	10.5 a	7.3 c-h
0.3	Rum	1.9 q-t	6.0 e-k	5.0 h-n	7.4 c-g	5.1 g-n
	Rehani-3	1.8 r-t	4.3 j-p	7.0 c-i	8.0 b-f	7.0 c-i
	SLB-6	2.1 p-t	5.8 f-l	8.2 a-e	9.3 a-c	6.1 e-k
0.6	Rum	1.3 st	4.5 j-o	4.2 j-q	7.1 c-h	3.8 k-r
	Rehani-3	1.8 r-t	4.7 i-o	6.0 e-k	6.0 e-k	5.2 g-n
	SLB-6	2.1 p-t	6.0 e-k	7.2 c-h	7.2 c-h	5.1 g-n
0.9	Rum	1.4 st	3.2 m-t	3.1 n-t	4.2 j-q	3.6 l-s
	Rehani-3	1.2 t	3.8 k-r	3.9 k-r	6.5 e-j	4.3 j-p
	SLB-6	2.1 p-t	5.5 g-m	4.7 i-o	4.7 i-o	5.0 h-n

Values followed by the same letter(s) are not significantly different (p = 0.05) according to LSD

Table 5: Effects of temperature and Water Potential (WP) on total root length (cm/seedling) of three barley cultivars

		Temperature (°C)				
WP (-MPa)	Cultivar	9	15	21	27	33
0	Rum	6.5 r-y[¶]	18.0 g-m	27.9 a-c	30.0 ab	19.0 f-l
	Rehani-3	4.6 w-y	16.6 n-q	25.5 a-f	24.6 a-g	20.2 d-j
	SLB-6	7.6 r-y	19.4 f-k	26.3 a-e	31.3 a	26.7 a-d
0.3	Rum	4.8 w-y	16.9 h-p	16.2 h-q	19.7 e-k	15.6 h-q
	Rehani-3	4.7 w-y	12.1 m-u	18.8 f-m	21.3 c-h	17.5 h-n
	SLB-6	5.5 u-y	16.7 h-q	24.4 b-g	29.5 ab	19.3 f-k
0.6	Rum	5.1 w-y	14.4 i-r	15.4 h-q	16.7 h-q	12.4 l-t
	Rehani-3	3.7 wy	11.1 n-w	19.5 e-k	16.1 h-q	15.2 h-q
	SLB-6	5.6 t-y	14.8 h-q	20.7 d-i	19.9 d-k	17.3 h-o
0.9	Rum	3.5 y	10.1 p-y	10.5 o-x	13.3 k-s	13.8 j-r
	Rehani-3	3.7 wy	10.0 q-y	10.6 o-w	15.6 h-q	13.4 j-r
	SLB-6	5.0 w-y	15.7 h-q	13.9 i-r	15.7 h-q	16.6 h-q

Values followed by the same letter(s) are not significantly different ($p = 0.05$) according to LSD

Table 6: Effects of temperature and water potential (WP) on seminal root number of three barley cultivars

		Temperature (°C)				
WP (-MPa)	Cultivar	9	15	21	27	33
0	Rum	2.1 g-l[¶]	3.4 a-e	3.8 a	3.6 a-c	3.2 a-g
	Rehani-3	1.8 j-l	3.1 a-h	3.2 a-g	2.5 c-l	2.3 e-l
	SLB-6	2.4 d-l	3.5 a-d	3.8 a	3.7 ab	3.2 a-g
0.3	Rum	2.0 h-l	3.1 a-h	2.9 a-j	2.4 d-l	2.6 b-k
	Rehani-3	1.9 i-l	2.8 a-j	2.8 a-j	2.4 d-l	2.3 e-l
	SLB-6	2.2 f-l	3.5 a-d	3.4 a-e	3.5 a-d	3.0 a-i
0.6	Rum	1.8 j-l	3.3 a-f	2.6 b-k	2.2 f-l	2.2 f-l
	Rehani-3	1.4 l	2.4 d-l	2.6 b-k	2.3 e-l	2.0 h-l
	SLB-6	2.1 g-l	3.5 a-d	3.1 a-h	2.8 a-j	2.7 a-k
0.9	Rum	1.6 kl	2.8 a-j	2.5 c-l	2.3 e-l	1.8 j-l
	Rehani-3	1.6 kl	2.4 d-l	2.2 f-l	2.1 g-l	1.8 j-l
	SLB-6	1.9 i-l	3.3 a-f	2.3 e-l	2.4 d-l	2.2 f-l

Values followed by the same letter(s) are not significantly different ($p = 0.05$) according to LSD

Table 7: Effects of temperature and Water Potential (WP) on root fresh weight (mg/seedling) of three barley cultivars

		Temperature (°C)				
WP (-MPa)	Cultivar	9	15	21	27	33
0	Rum	3.8 t-x[¶]	19.6 d-m	24.1 d-h	39.0 ab	18.7 d-n
	Rehani-3	4.4 s-x	15.1 g-s	21.7 d-k	36.0-c	27.7 cd
	SLB-6	7.1 o-x	22.5 d-j	22.9 d-h	44.4 a	27.3 c-e
0.3	Rum	3.4 u-x	11.4 j-x	15.7 f-r	22.7 d-i	19.3 d-n
	Rehani-3	3.7 t-x	15.9 f-q	20.7 d-l	26.6 c-f	21.8 d-k
	SLB-6	4.9 p-x	14.8 g-t	25.6 c-g	29.4 b-d	16.3 e-o
0.6	Rum	2.9 wx	13.9 h-w	14.3 h-u	16.0 f-p	6.7 o-x
	Rehani-3	4.0 s-x	11.7 i-x	15.7 f-r	19.7 d-m	18.6 d-n
	SLB-6	4.7 r-x	14.8 g-t	19.7 d-m	22.9 d-h	10.2 l-x
0.9	Rum	2.7 x	6.3 o-x	9.1 m-x	4.7 r-x	4.8 q-x
	Rehani-3	3.5 u-x	7.2 o-x	13.0 h-x	7.4 o-x	5.8 o-x
	SLB-6	4.8 q-x	8.2 n-x	10.3 l-x	10.9 k-x	4.9 p-x

Values followed by the same letter(s) are not significantly different ($p = 0.05$) according to LSD cultivars Rum and SLB-6 showed the lowest germination rate at 33°C, while the effect of this temperature on the cultivar Rehani-3 was pronounced only at low water potential levels (-0.6 and-0.9 MPa) (Table 3). The cultivar Rehani-3 had higher germination rate index than the other two cultivars regardless of temperature or water potential.

All cultivars had longest main axis root (MARL) and total root length (TRL) at temperatures 21 and 27°C at all water potentials except the highest level (-0.9 Mpa) (Table 4 and 5). Water stress reduced MARL and TRL of the three cultivars significantly at temperatures 21°C and above (Table 4 and 5). The cultivar SLB-6 had generally higher MARL and TRL than the other two cultivars at all temperatures even though these differences were only significant between SLB-6 and Rum at 21°C for MARL and TRL at-0.3 and for MARL at-0.6 MPa (Table 4). Higher number of seminal roots (SRN) was obtained at temperatures of 15°C and above for all cultivars (Table 6). Water stress had less effect on SRN in the three cultivars at temperatures of 21°C and above. Significant differences for SRN between cultivars were noted only at temperature 27°C for seeds placed in solutions of-0.3 MPa when the cultivar SLB-6 had higher SRN than the other two cultivars.

Root Fresh Weight (RFW) of all cultivars was higher at 27°C in comparison to other temperatures at water potentials 0 to-0.6 MPa (Table 7). Water stress significantly reduced root fresh weight at all temperatures except at 9°C for all cultivars. No significant differences between cultivars were noted for root fresh weight regardless of temperature or water potential.

DISCUSSION

Early high germination across a large range in temperatures may be beneficial for rapid establishments of plants in arid and semiarid regions where soil moisture in the upper soil surface is available for only a short period [9]. The results of this study showed a significant effect of temperature on final germination percentage and rate of germination for the three barley cultivars tested. However, it seems that cultivar Rehani-3 is more tolerant to high temperatures and water stress conditions when compared to the other cultivars tested in respect to germination percentage and rate. Sharma [15] found that germination rate was positively affected by increasing temperature, whereas final germination percentage increased up to a certain limit with increasing temperature.

Temperature and water stress affected the ability of seedlings to develop a root system rapidly after germination, which is critical for successful plant establishment [11]. They found that the optimum temperature range for germination of several Vicia species was lower than that for root growth.

In this study, the optimum temperature was 15°C for final germination percentage and 15 and 21°C for germination rate. The optimum temperatures for early root growth were 21 and 27°C regardless of water stress level. Lowest root growth was noted at 9°C. Lower rates of root growth of wheat (*Triticum aestivum* L.) were obtained at low temperatures of 3 to 10°C [12]. However, water stress had a depressing effect on all studied characters especially at optimum temperatures for growth. These results are in agreement to Soltani *et al.* [16] and Al-Karaki [1] who reported that water stress adversely affected germination. Neverthless, Lafond and Fowler [13] indicated that the effect of temperature on germination was much larger than moisture potential.

Brar *et al.* [9] indicated that since temperature had a strong influence on germination, seeding time should be selected to match expected temperatures required for successful germination at a particular location. They added that early high germination across a large range in temperatures might be beneficial for rapid establishment of the crop in semi-arid warm regions where soil moisture in the upper soil surface is available for only a short period. If seed germination and subsequent root development occurs rapidly, the survival of established seedlings is improved mainly due to the possibility of moisture uptake from greater soil depths [17].

The cultivar Rehani-3 attained the highest final germination percentage and rate than the other two cultivars regardless of temperature or water stress. However, the cultivar SLB-6 had generally higher main axis root and total root lengths than other cultivars regardless of temperature or water potential level. Initial root elongation was found to vary among different genotypes of legume species [9, 11].

In conclusion, seed germination of barley under suboptimal conditions, simulated by different temperatures or water potential in this study, is strongly influenced by cultivar. The cultivar Rehani-3 tended to germinate faster but had slower rooting growth than the cultivar SLB-6 regardless of temperature or water potential level. The cultivar SLB-6 may have better seedling establishment and increased survival ability than the other two cultivars in arid and semiarid regions since its roots could elongate rapidly, thus, ensuring a continuing water supply to the plant. However, additional work is needed to evaluate germination and early seedling growth of these barley cultivars under field conditions.

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