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Effects of salt Stress on Root Anatomy and Hydraulic Conductivity of Barley Cultivars

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ABSTRACT- A hydroponic experiment was carried out to compare root anatomy and hydraulic conductivity of four barley cultivars including Valfajr, Karoon, Afzal and Zarjo under salt stress conditions. The results showed that under salt stress, the minimum diameter of vessels was observed in the peripheral metaxylem of seminal roots of Valfajr cultivar and in adventitious roots; Karoon with 19±3 µm had maximum diameter of vessels. In all barely cultivars, salt stress affected the diameter of central and peripheral metaxylem vessels more negatively in comparison to the number of the vessels. The mature xylem vessels of the seminal roots of the Valfajr and Zarjo cultivars had the most lignified cell walls. When the plants were exposed to salt stress, the casparian bands could be detected more in the seminal roots as U-shape and not in the adventitious roots. The lowest lignification thickness of cell wall (0.78 µm) was observed in the central metaxylem vessels of adventitious roots of Afzal cultivar under salt stress. Also, Afzal cultivar with highest surface area and lowest thickness of lignified cell walls, had the highest seminal root hydraulic conductivity (5.84×10^{-9} m s^{-1} MPa^{-1}), whereas hydraulic conductivity was decreased to 3.21 and 3.17×10^{-9} m s^{-1} MPa^{-1} in Valfajr and Zarjo cultivars, respectively. Overall, Afzal and Karoon cultivars were found to perform better in water uptake at the early stages of growth due to less lignified cell walls of xylem in seminal and adventitious roots under salt stress conditions. Further research on hydraulic conductivity could be recommended.

INTRODUCTION

Roots are essential to plant growth and play an important role in determining crop yield. However, they are hidden from view, often deep in the soil, which makes them difficult to study and easy to ignore (Emam and Bijanzadeh, 2012). Roots are the primary sites of water uptake by plants and have a remarkable capacity to sense most of the physico-chemical parameters of the soil and to adjust their growth and water transport properties accordingly; these functions are tightly linked to shoot physiology (Vysotskaya, 2004; Maurel et al., 2010). The movement of water across the root is driven by water potential differences and limited by hydraulic resistance. Frensch and Steudle (1998) declared that in transpiring plants, water uptake is purely passive and mainly follows a hydrostatic pressure gradient between the root surface and the xylem.

Excessive soil salinity is an important external factor reducing root and shoot growth particularly in field crops. Although good management practices may give partial amelioration of damage by saline soil, an inherent tolerance of crop cultivars to salinity remains highly desirable (Flowers, 2004). Achieving this will require a better understanding of plant growth responses to salinity and of how some plant species and varieties achieve greater salt-resistance than others. Inhibitory effects of salinity on plant growth can be attributed to decreased availability of water imposed by an osmotic stress or to toxic effect of excessive Na^+ or Cl^- ions (Veselov, 2009).

The initial salinity response and its detrimental effects are generally believed to be induced mostly by water deficiency and independently of any effects of salt itself (Munns, 2006). Salt stress also, causes a rapid and potentially lasting reduction in the rate of root growth. A reduction of the velocity of root elongation results from a reduction in the number of elongating cells or a reduction in the rate of cell elongation or from both (Fricke and Peters, 2002; Knipfer and Fricke 2010b). From the biophysical point of view, a leaf or root cell of a NaCl-treated plant may expand at lower rates due to reduced uptake rates of water or osmolytes, hardened walls, or lowered turgor pressure in the roots (Cosgrove, 2000).

The hydraulic resistances, as they occur at the root and shoot level, can limit water flow through the plant, analogous to Ohm’s Law (Frensch, 1997).The physical characteristics of roots are related to their structure and there is no way to interpret root flow and hydraulic conductivity data without sufficient knowledge of their anatomy (Steudle and Peterson, 1998; Steudle, 2000). Also, for the movement of water in the soil, plant, and atmosphere, the root hydraulic conductivity is a key parameter contributing to the limitation of water flow rate (Steudle and Jeschke, 1983; Steudle, 2000). In addition to stomata, the water status of the shoot will be largely determined by hydraulic conductivity (Knipfer and Steudle, 2008). Root hydraulic properties could be changed with the magnitude of water flow induced across roots (Passioura and Munns, 1984; Maurel, 2010). The hydraulic conductivity of a root is a complex parameter due to complicated structure of the osmotic barrier made up of exodermis, cortex and endodermis (Kramer and Boyer, 1995).

Considering the importance of barley in Iran, where barley is mainly growing in saline conditions (Emam, 2011), better understanding of the relationship between root anatomy and hydraulic conductivity for Iranian barley cultivars would be of great priority. With respect to differing salinity tolerance in barley cultivars (Steudle, 2000; Omidi, 2001; Hoseini, 2003), the root anatomy and water movement in different cultivars at early growth stages need to be explored more in detail. The objectives of present study were comparison of root surface area, root to shoot ratio, seminal and adventitious root dimensions and their hydraulic conductivity, at the third leaf stage of four barley cultivars, under salt stress conditions.

MATERIALS AND METHODS

To investigate the effect of salt stress on root anatomy and hydraulic conductivity of four barley cultivars including Valfajr, Karoon, Afzal and Zarjo, a hydroponic experiment was conducted at Agricultural College and Natural Resources of Darab, Shiraz University in 2012. Afzal, Valfajr and Karoon had higher tolerance to salt stress than Zarjo (Omidi, 2001; Hoseini, 2003). Twelve plants from each barley cultivar at two concentrations of NaCl (0 and 100 mMNaCl) in three replications were compared in a completely randomized design. The seeds were first bubbled in distilled water for one day and then put in CaSO4 solution in a 10-liter beaker and were aerated for three days. When seedlings had a root length of 20–30 mm, they were transferred to a hydroponic system, containing a modified half-strength Hoagland nutrient solution [KH_2PO_4 (1.5 mM), KNO_3 (2.0 mM), $CaCl_2$ (1.0 mM), $MgSO_4$ (1.0 mM), FeNa (18.0 μM), H_3BO_3 (8.1 μM), $MnCl_2$ (1.5 μM)] (Fricke et al., 1997). Four plants were kept in each 1-liter glass beaker and the nutrient solution was ventilated by a gas exchange pump at a flow rate of 400 mL min^{-1} in growth chamber. Plants were kept at a day/night photoperiod of 16/8 hours and temperature of 21/15°C. Relative humidity was 70% and photosynthetic active radiation at the level of the developing leaf 3 was 300–400 μmol m^{-2} s^{-1}. Plants were sampled at early growth stages (ZGS13; Zadoks et al., 1974) before the root system became complex and difficult to handle (tangled lateral roots), which makes likely damages to roots and causes electrolyte leakage (hydraulic, solute; 23). Root anatomy, root surface area, hydraulic conductivity, growth rate, and water loss in 14- to 18- day-old plants were measured according to the following procedures:

Root anatomical structures and surface area

Root anatomy was investigated on free-hand cross-sections that were made from 5-10 mm root tips (Steudle, 2000). Sections were stained with 0.5% toluidine blue for 1 minute and viewed under bright light for the detection of central and peripheral metaxylem (Knipfer and Fricke, 2010b).

For detection of casparian bands and lignified cell walls (bright signal), sections were then stained for 30 minutes with 0.1% berberinehemisulfate and counterstained for 1–3 minutes with 0.5% toluidine blue (Hachez et al., 2006). Then, sections were observed with a Canon microscope (HL 1891, Japan) under fluorescence light by a UV/violet filter with an excitation wavelength of 390–420 nm and images were captured with a digital camera.

Surface area of the roots was determined by measuring the length and the radius of the main axis of seminal and adventitious roots and the number, length, and diameter of the lateral roots of the 18-day-old plants. Surface area was calculated by treating roots as cylinders (Knipfer and Fricke, 2010b).

Total root area (A_r) was calculated as:

$$A_r= 2\pi\ r_1L_1+ 2\pi\ r_2L_2+2\pi\ r_3L_3+2\pi\ r_4L_4$$

Where, r_1= Main root radius ≈ 250 μm; L_1=≈Main root length; r_2= Lateral root (I) radius ≈

125 μm; L_2= Lateral root (I) length; r_3= Lateral root (II) radius ≈ 62.5 μm; L_3= Lateral root (II) length; r_4= Lateral root (III) radius ≈31.25 μm, L_4= Lateral root (III) length.

Determination of root hydraulic conductivity using root exudation method

An individual root was attached with the excised root base to a glass capillary (diameter 0.5 mm). The rise of the xylem sap in the capillary was measured in 5 minutes intervals for one hour. Exudate volume (V_e) was used to determine the hydraulic properties of the roots. V_e and the hydraulic conductivity of the root (Lpr) were determined as below (Knipfer and Fricke, 2010b):

$$Lpr= V_e\ .(1/\Delta t).(1/\Delta p).(1/A_r)$$

$$Ve= \pi r^2 h$$

$$\Delta p= Pe\text{-}Pm$$

where, r= Radial of glass capillary (250 μm); h= Height of the root exudates in glass capillary, t= Time of going up the root exudates in the glass capillary, Pe= osmotic potential of the root exudates, and Pm= osmotic potential of the medium. The osmolality of root exudates (Pe) and medium (Pm) was determined by Picolitre Osmometry (Model P302, UK). Samples were either analyzed or stored under a of liquid paraffin layer (to minimize evaporation) in 0.2-ml centrifuge tubes at 4°C for up to 3 days (Fricke and Peters, 2002)

Measurement of the growth rate and water loss

Growth rate of third leaf was measured with a ruler from the base of leaf every 12 hour and averaged to exclude possible temporal effects, daily (Fricke and Peters, 2002; Fricke et al., 2010). The water loss of entire plants was determined gravimetrically in the growth chamber. Single barley plants were placed in a measuring cylinder, which was filled with Hoagland nutrient solution and placed on a balance and water loss was measured daily compared to control (i.e. cylinder with Hoagland nutrient solution without plant) in 14- to 18-day-oldseedlings (Steudle and Peterson, 1998). Finally, dry matter of the roots and the shoots of the 18-day-old seedlings, were measured after being dried in at 75°C for 72 hours. Analysis of the variance was performed using SAS software and the mean comparisons were performed using LSD test at 5% probability level.

RESULTS AND DISCUUSION

Anatomical structures and xylem dimensions of barley roots

The seminal roots were the first major roots appeared, after radicle formation (Fig. 1). Adventitious roots appeared when seedlings were 10-14 days old, differing in anatomy from seminal roots. The thicker (in diameter) adventitious roots had more cortical cell layers and contained more central metaxylem vessels of larger diameter than the seminal roots (Fig. 2). When plants were 14- to 18-day-old (the developmental stage at which they were analyzed), there were three to six seminal roots and two to four stem-borne adventitious roots per plant. Under normal conditions (0 mMNaCl), the mean length of seminal and adventitious roots ranged from 71±3 to 62±1 mm and 31±2 to 26±3 at 18 days old plants, respectively. In contrast, under salt stress conditions (100 mMNaCl), the length of seminal and adventitious roots of barley cultivars decreased significantly and ranged from 51±2 to 37±5 mm and 20±3 to 17±4, respectively (data not shown).

Seminal roots had a mean diameter of 521±33 µm, between four and five cortical cell layers, and typically one large central metaxylem, and 5 to 7 smaller and circularly arranged peripheral metaxylem vessels (Fig. 2). According to Knipfer and Fricke (2010b), the peripheral metaxylem vessels are early metaxylem, being fully functional during the early stages of development of a root segment in barley, whereas the central vessel is late metaxylem, being the last of the xylem elements to become fully functional. The adventitious roots were much thicker compared to seminal roots, having 5-8 cortical cell layers, with 2 to 3 central metaxylem and 7 to 9 peripheral metaxylem vessels (Fig. 2). Zhao et al. (2004) also found that in wheat, the diameter of the adventitious root was 1.7 to 2.5 fold thicker than the seminal root at the 3 to 6 leaf stage plants. Emam and Bijanzadeh (2012) reported that in wheat, stellar cells were less lignified in adventitious roots, as compared with seminal roots, and mature xylem vessels of seminal roots of Shiraz and Yavaros cultivars had more lignified walls compared to other cultivars of 18 days old plants.

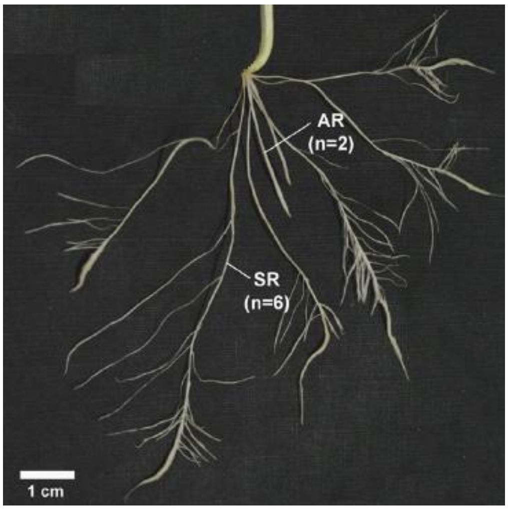

Fig. 1. Root development in 14-day-old barley plant (cv. Karoon); typical root system showing six seminal roots (SR) and two adventitious roots (AR).

Under salt stress, the mean diameter of the central and peripheral metaxylem vessels of seminal roots were 31±4 and16±3 µm at the tip region of the root, respectively (Fig. 2 and Table 1). Steudle (2000) reported that the diameter of the central metaxylem of the seminal roots varied from 52 to 200 µm at the early growth stages of wheat and barley. In all cultivars, the diameter of central metaxylem was more than peripheral metaxylem in seminal and adventitious roots (Fig. 2 and Table 1). Afzal and Karoon cultivars had thicker central metaxylem compared to Valfajr and Zarjo. Also, in seminal and adventitious roots, the number of central metaxylem of vessels was not affected by salt stress (Fig. 2 and Table 1). Under salt stress conditions, in the peripheral metaxylem of seminal roots, the minimum diameter of vessels was observed in Valfajr cultivar and in adventitious roots, Karoon and Valfajr with 19±3 and 8±1 µm had the maximum and minimum diameter of vessels, respectively. Generally, in all barely cultivars, salt stress more negatively affected the diameter of central and peripheral metaxylem vessels in comparison to the number of the vessels (Table 1). The stellar cells in all cultivars were less lignified in adventitious, as compared to the seminal roots and the mature xylem vessels of the seminal roots of Valfajr and Zarjo had the most lignified walls, compared to other cultivars in both normal and salt stress conditions (bright color, Fig. 2-A, B, M, and N). Knipfer and Fricke (2010a, 2010b) also reported that the amount of lignification area in the xylems of seminal and adventitious roots had an important role in decreasing hydraulic conductivity and water uptake of barley.

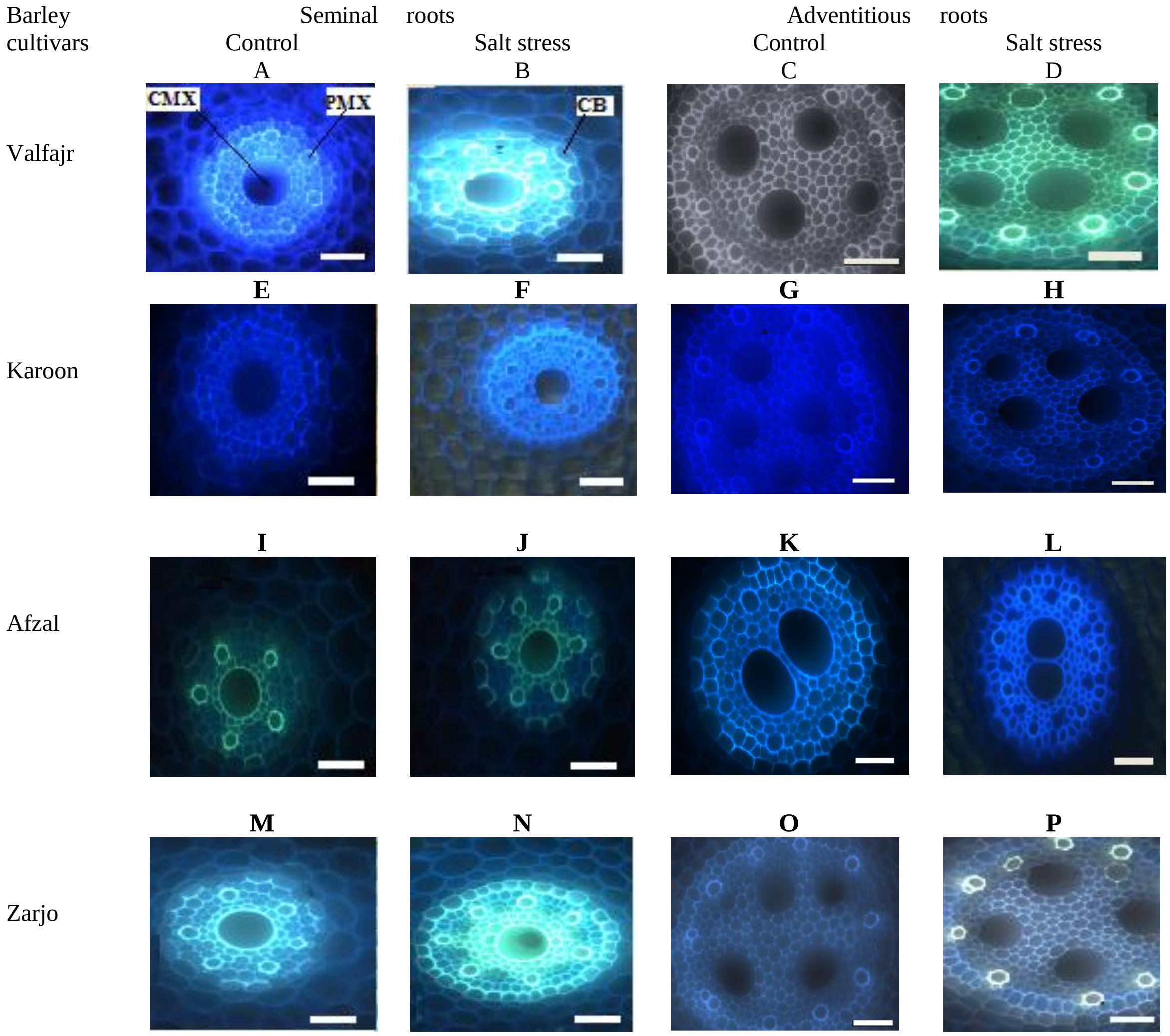

Fig. 2. Anatomic structure of xylem in the seminal and adventitious roots of four barley cultivars including Valfajr (A-D), Karoon (E-H), Afzal (I-L), and Zarjo (M-P) of the 18-dayold plants. Hand cross-sections of seminal roots taken at 5–10 mm from seminal and adventitious root tip and stained with berberinehemisulfate and counterstained with toluidine blue and viewed under fluorescence light (390–420 nm) to visualize casparian bands and xylem development. CMX: central metaxylem; PMX: peripheral metaxylem, CB: Casparian bands. Scale bar is 50 µm.

Table 1. Mean number and dimensions of mature xylem vessels at 14- to 17-day-old barley plants. Results are means ±SD.

Barley cultivar	Root type	Central metaxylem				Peripheral metaxylem			
		Number of vessels		Diameter of vessels (µm)		Number of vessels		Diameter of vessels (µm)	
		Control	Salt stress (100 mM)	Control	Salt stress (100 mM)	Control	Salt stress (100 mM)	Control	Salt stress (100 mM)
Valfajr	Seminal	1±0	1±0	31±2	21±2	6±1	5±1	13±2	10±1
	Adventitious	4±1	4±1	51±6	23±2	9±1	7±2	16±3	8±1
Karoon	Seminal	1±0	1±0	37±10	30±7	7±1	7±2	20±1	18±2
	Adventitious	3±1	3±1	46±2	36±1	9±1	7±1	22±7	19±3
Afzal	Seminal	1±0	1±0	30±7	27±1	6±1	5±2	24±4	18±2
	Adventitious	2±1	2±1	58±12	48±2	10±2	9±1	14±1	10±2
Zarjo	Seminal	1±0	1±0	32±6	18±2	8±2	7±2	23±3	19±1
	Adventitious	4±1	4±1	53±6	28±4	10±1	9±1	20±4	17±2

Under normal and salt stress conditions, in all cultivars, the central metaxylem vessels of the seminal roots were less lignified compared to the peripheral metaxylems (Fig. 2 and Table 2). Indeed, they could be classified as immature, compared to the peripheral metaxylem vessels, which had highly lignified walls especially under salt stress conditions. Similar to seminal roots, higher lignification thickness of cell wall of central and peripheral metaxylems vessels was observed in adventitious roots of Valfajr and Zarjo cultivars under salt stress (Table 2).

The casparian bands could be detected more in the seminal roots as U-shape [Fig. 2-B; (28)], but not in the adventitious roots when the plant exposed to salt stress, (Fig. 2). Casparian bands appeared during the root development prior to the formation of additional wall depositions in the endodermis (2010b). In the adventitious roots, the lowest lignification thickness of cell wall (0.78 µm) was observed in the central metaxylem vessels of Afzal cultivar under salt stress (Table 2 and Fig. 2). Emam and Bijanzadeh (2012) showed that, increasing the lignification of cell walls in the casparian bands and peripheral and central metaxylem vessels decreased the hydraulic conductivity and water uptake of wheat cultivars. In contrast, Peterson et al. (1993) reported that in young maize roots, the formation of a casparian band in the exodermis did not affect hydraulic conductivity. Overall, in all cultivars, under salt stress, central and peripheral metaxylem vessels had more lignified cell walls compared to non stress conditions (Table 2). Similarly, Steudle (2000) found that suberization of roots increases with age and during stress (drought, high salinity, nutrient deprivation, anoxia, etc.).

Table 2. The lignified thickness of cell walls in central and peripheral metaxylem vessels of the seminal and adventitious roots of barley cultivars.

Barley cultivars	Lignified thickness				of cell walls (µm)			
	Seminal root				Adventitious root			
	Central metaxylem		Peripheral metaxylem		Central metaxylem		Peripheral metaxylem	
	Control	Salt stress (100mM)	Control	Salt stress (100mM)	Control	Salt stress (100mM)	Control	Salt stress (100mM)
Valfajr	1.71	2.28	2.01	2.71	0.88	1.36	2.13	2.86
Karoon	0.68	1.01	1.11	1.92	0.73	1.01	1.67	1.93
Afzal	0.73	0.86	0.77	1.08	0.52	0.78	1.32	1.78
Zarjo	1.82	2.33	2.11	2.97	0.97	1.29	2.11	2.97
LSD(0.05)	0.22	0.18	0.54	0.43	0.39	0.27	0.65	0.31

Root surface area and hydraulic conductivity

Under normal conditions, Valfajr cultivar had the maximum root surface area (2.78×10^{-3} m^2) of the seminal roots, while had maximum reduction (48%) root surface area under salt stress conditions at 18-day-old (Table 3). The surface area of seminal root differed among the cultivars from 1.86 in Afzal to 1.02×10^{-3} m^2 in Zarjo under salt stress conditions. Also, Afzal cultivar, with the highest surface area (Table 3) and lowest thickness of lignified cell walls (Table 2), had the highest seminal root hydraulic conductivity (5.84×10^{-9} m s^{-1} MPa^{-1}) whereas in Valfajr and Zarjo cultivars, hydraulic conductivity was as low as 3.21 and 3.17×10^{-9} m s^{-1} MPa^{-1}, respectively (Table 3). Zhao et al.(2005) reported that in wheat (cv. Xiaoyan6), from 3 to 6 leaf stage, the hydraulic conductivity was 15 to 36×10^{-9} m s^{-1} MPa^{-1} and increased with increasing chromosome ploidy during evolution. In contrast to our results, Gallardo et al. (1996) showed that in wheat (cv. Kulin), the hydraulic conductivity of the seminal roots ranged from 12.3 to 15.2 $\times10^{-8}$ m s^{-1} MPa^{-1} at the early growth stages. Fricke et al. (2013) declared that salt stress caused a general reduction (40– 80%) in hydraulic conductivity of wheat roots, irrespective of whether individual seminal and adventitious roots, entire root systems or intact, transpiring plants were analysed.

Reductions of similar magnitude have been reported for hydraulic conductivity of individual roots and root systems of maize (Azaizeh et al., 1992), barley (Katsuhara and Shibasaka, 2007) and *Arabidopsis thaliana* L. (Martinez Ballesta et al., 2003) plants after longer-term exposure to salt stress.

Under normal conditions, no significant difference was observed among the surface area of adventitious roots of barley cultivars; however, surface area in Valfajr and Zarjo significantly decreased under salt stress compared to Karoon and Afzal, (Table 3).With respect to root surface area of seminal and adventitious roots, Afzal and Karoon with 2.18 and 2.03×10^{-10} m s^{-1} MPa^{-1} had the highest hydraulic conductivity under salt stress, respectively. In barley and wheat, changes in the root hydraulic conductivity might be related to the difference in surface area, the amount of lignified zone, osmotic driving force and distribution of the seminal and adventitious roots, nutrients concentration and the temperature of the medium (Knipfer and Fricke, 2010a; Knipfer and Fricke, 2010b; Emam and Bijanzadeh, 2012). It was showed that in barley, increasing the lignification of cell walls of the peripheral and central metaxylem vessels decreased the hydraulic conductivity and water uptake of Gulf cultivar. Overall, under salt stress, the hydraulic conductivities of the seminal and the adventitious roots of Afzal and Karoonwere significantly greater than those of Valfajr and Zarjo cultivars (Table 3).

Table 3. Root surface area, and hydraulic conductivity of seminal and adventitious roots of grown barley cultivars under control (a) and salt stress (b) conditions.

	Seminal root				Adventitious root			
Barley cultivars	Root surface area [(m^2) × 10^{-3}]		Hydraulic conductivity [(m/s/MPa) ×10^{-9}]		Root surface area [(m^2) × 10^{-3}]		Hydraulic conductivity [(m/s/MPa) ×10^{-10}]	
	Control	Salt stress (100mM)	Control	Salt stress (100mM)	Control	Salt stress (100mM)	Control	Salt stress (100mM)
Valfajr	2.78	1.41	5.33	3.21	0.68	0.31	2.61	1.53
Karoon	2.01	1.82	6.68	5.37	0.73	0.59	2.79	2.03
Afzal	1.92	1.86	6.91	5.84	0.82	0.61	2.66	2.18
Zarjo	1.43	1.02	5.83	3.17	0.78	0.36	2.17	1.41
LSD (0.05)	0.36	0.23	0.63	0.17	0.28	0.18	0.66	0.47

Growth rate, water loss and root/shoot ratio

Under normal conditions, Karoon and Zarjo cultivars had the maximum growth rate of the third leaf at 17 days after germination (DAG) (Fig. 3a). Under salt stress, Karoon and Afzal cultivars with 2.43 and 2.08 mm h^{-1} had the highest growth rate, respectively at 17 DAG (Fig. 3b). Fricke and Peters (2002) declared that barley cultivars with higher growth rate and better establishment at the early growth stage grow faster and produce greater yield under salt stress conditions.

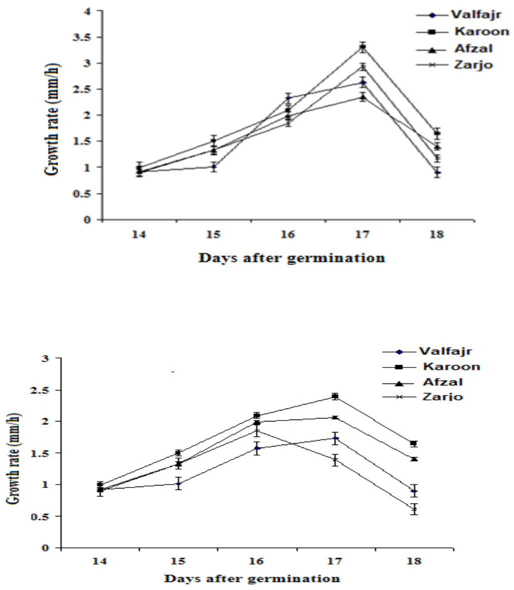

Fig. 3. Growth rate (mm/h) of the third leaf of barley cultivars from 14 to 18 days after germination under control (a) and salt stress (b) conditions. Results are means ±SD.

As plant biomass increased from 14 to 18 DAG, water loss enhanced in all cultivars, especially in Valfajr and Karoon cultivars under normal conditions (Fig. 4a). At 18 DAG, under salt stress, Zarjo and Valfajr with 0.23 and 0.21 g plant^{-1} h^{-1} had the highest water loss rate while Afzal, as a salt tolerant cultivar, under both normal and salt stress conditions, had the lowest water loss (Fig. 4a). Similarly, Fricke et al. (2010) reported that water loss in salinized barley plants remained lower than normal conditions due to stomata closure under salt stress. Likewise, Vysotskaya et al. (2010) reported that salt treatment (75 mM) inhibited water loss in tolerated cultivars more than sensitive barley cultivars.

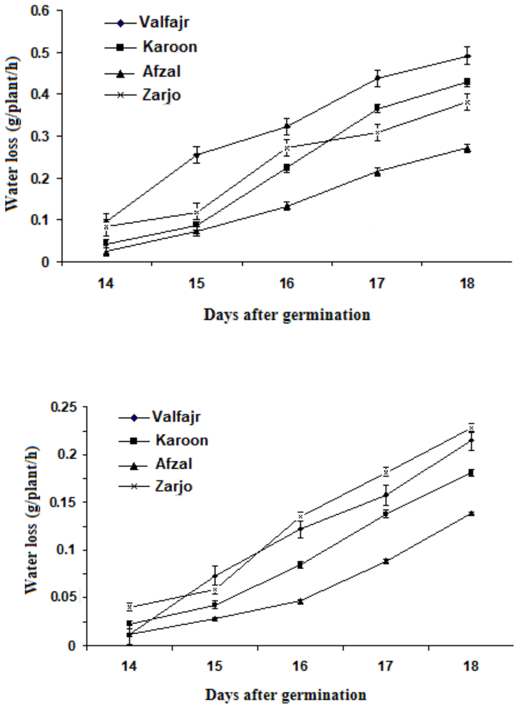

Fig. 4. Water loss (g/plant/h) of third leaf of barley cultivars from 14 to 18 days after germination under control (a) and salt stress (b) conditions. Results are means ±SD.

Results showed that salt stress affected the root/shoot ratio of Valfajr and Zarjoo negatively, while in Afzal and Karoon cultivars, salt stress increased the root/shoot ratio (Fig. 5). Caird et al. (2007) reported that root/shoot ratio was an important index in predicting water loss, water uptake, and the hydraulic conductivity in the C3 plants. The lower root/shoot ratio in Valfajr and Zarjo cultivar (Fig. 5) might be related to the higher water loss [Fig. 4b, (Steudle, 2000)] and more lignified cell walls in the seminal and adventitious roots (Fig. 2) at the third leaf stage, under salt stress.

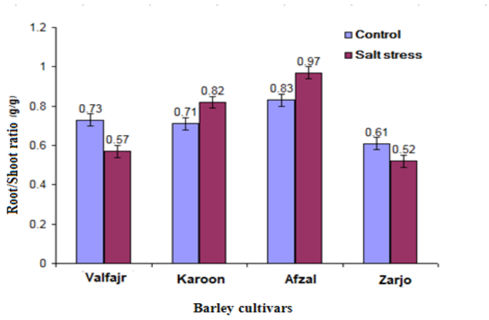

Fig. 5. Root to shoot ratio of barley cultivars at 18 days after germination under control (a) and salt stress (b) conditions. Results are means ±SD.

CONCLUSIONS

It could be concluded that at early growth stages of the barley cultivars (3rd leaf stage), root anatomy with less lignified cell walls in seminal and adventitious roots, cultivars. Indeed, in present study Afzal and Karoon greater hydraulic conductivity and root/shoot ratio might be of great help in screening salt tolerant cultivars, which had less lignified cell walls of central and peripheral metaxylem zones of the roots, performed better in water uptake compared to Valfajr and Zarjo cultivars. Afzal and Karoon cultivars could be recommended for water or soil salinity conditions. Further research to investigate the effect of salt stress on the variation of root anatomy, hydraulic conductivity, and water uptake of Iranian barley cultivars could shed more light on better understanding of salt tolerant cultivars.

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تاثیر تنش شوری روی آناتومی و هدایت هیدرولیک ریشه ارقام جو

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چکیده- آناتومی و هدایت هیدرولیک ریشه چهار رقم جو والفجر، کارون، افضل و زرجو در یک پژوهش هیدروپونیک در شرایط شوری مورد بررسی قرار گرفت. نتایج نشان داد در شرایط شوری، کمترین قطر آوند چوبی جانبی ریشه‌های بذری، در رقم والفجر مشاهده شد و در ریشه های نابجا، رقم کارون با ۳±۱۹ میکرو متر بیشترین قطر آوند چوبی جانبی را داشت. در همه ارقام جو، تأثیر منفی تنش شوری بر قطر آوند های چوبی مرکزی و جانبی بیش از تعداد آنها بود. دیواره سلولی آوندهای چوبی ریشه های بذری والفجر و زرجو بیشتر از سایر ارقام چوبی شده بودند. در شرایط تنش شوری، نوار کاسپاری به صورت یو شکل در ریشه های بذری بود که در ریشه های نابجا وجود نداشت. کمترین ضخامت لایه چوبی شده دیواره سلولی (۰/۷۸ میکرو متر) در آوند های چوبی مرکزی ریشه های نابجای رقم افضل در تنش شوری مشاهده گردید. همچنین رقم افضل با بیشترین سطح ریشه و کمترین ضخامت لایه چوبی شده دارای بیشترین هدایت هیدرولیک ریشه های بذری ($۵/۸۴\times۱۰^{-۹}$ متر بر ثانیه بر مگا پاسکال) بود در حالیکه در والفجر و زرجو هدایت هیدرولیک به ترتیب به $۳/۲۱\times۱۰^{-۹}$ و $۳/۱۷\times۱۰^{-۹}$ متر بر ثانیه بر مگا پاسکال کاهش یافت. به طور کلی، جو افضل و کارون به دلیل ضخامت کمتر لایه چوبی در سلول های آوندی در ریشه بذری و نابجا و بدنبال آن هدایت هیدرولیک و نسبت ریشه به ساقه بیشتر، کارکرد بهتری در جذب آب در مراحل اولیه رشد داشتند. پژوهش های تکمیلی در این راستا قابل توصیه است.

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