Agronomy Research **15**(2), 501–514, 2017

Seed priming improves seedling emergence time, root characteristics and yield of canola in the conditions of late sowing

Sh. Nazari[1,*], M.A. Aboutalebian[1] and F. Golzardi[2]

[1]Department of Agronomy and Plant Breeding, Faculty of Agriculture, University of Bu-Ali Sina, Hamedan
[2]Seed and Plant Improvement Institute, Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran
[*]Correspondence: shahram_nazari1986@yahoo.com

Abstract. In central zones of Iran, late sowing of canola is the major reason of low yield. This yield reduction is principally due to poor crop establishment and root development dynamics because of low temperature prevailing. The present study was conducted to explore the possibility of improving late sown canola performance by seed priming techniques. A field experiment was conducted using five sowing dates (SD) at 10-day intervals from 5-September to 15-October during 2014–2015 and 2015–2016 seasons, three canola cultivars (Okpai, Zarfam and Talayeh) and seed priming strategies were: hydropriming and osmopriming with $ZnSO_4$ for 10 h. Results showed that minimum time to incipient emergence (T_0) and time to 50% emergence (T_{50}) was recorded from osmopriming of the optimal SD (5-Sep) by Okapi, Talayeh and Zarfam cultivars, respectively. The maximum root length (RL) was on the 5-Sep, so at that this date under the osmopriming and hydropriming, RL increased by 82 and 61 percent in Okapi, 47 and 43 percent in Zarfam and 58 and 44 percent in Talayeh in both growth seasons compared to control, respectively. Also, maximum root diameter (RD), root surface area density (RSAD) and grain yield (GY) was recorded in Okapi, Zarfam and Talayeh cultivars on the 5-Sep under hydropriming and osmopriming, respectively. Delay sowing significantly affected root dry weight (RDW) and root volume (RV). Maximums of RDW and RV at both seasons were recorded from osmopriming on 5-Sep in Okapi cultivar followed by hydropriming.

Key words: Hydropriming, Osmopriming, Root length.

INTRODUCTION

Canola is one of the world's four largest oil crops, and is the sixth largest crop in Iran with an annual planting area of 160,000 hectares (FAO, 2014). Canola yield is very low as compared to its production potential. Out of many constraints regarding low production of canola, low seedling establishment is of prime importance. Iran has arid or semiarid climates mostly characterized by low rainfall and high potential evapotranspiration. The annual precipitation varies from about 1,800 mm over the Western Caspian Sea coast and Western highlands to less than 50 mm over the uninhabitable Eastern deserts. The average annual precipitation over the country was estimated to be around 250 mm, occurring mostly from October to March (Eslamian et al., 2009). Additionally, the annual average temperatures for the entire time period ranged between 9 °C and 27 °C. In central zones of Iran, the optimum time of canola sowing date (SD) is the first week of September, but often sowing is late until mid-October because of late harvesting of the preceding crop. Only strong and vigorous canola seedlings can cope with cold and wet weather conditions, frequently observed in central zones of Iran. Well-developed shoot and root systems are key features for genotypic differences in cold tolerance (Lee et al., 2002; Hund et al., 2007). Low temperature at late sown is a major yield-limiting factor for canola grown in this zone. Low temperature reduces growth of shoots and roots and the mineral nutrition of plants (Cooper, 1973; Bowen, 1991). The root is an important organ that plays a significant role in the growth and development of plants. Seed priming techniques can be effectively used to improve the performance of late sown in crops (Rehman et al., 2015a). Seed priming improves the increasing growth of root and shoot under less than optimum field conditions (Lee & Kim, 2000; Kant et al., 2006).

Zinc (Zn) is one of the vital micronutrients for plants as it has many critical functions. Zn deficiency is common throughout the developed and developing world (Takkar &Walker, 1993) and lack of Zn can limit the growth and productivity of a wide range of crops (Khattak & Parveen, 1986). In most of the Iranian soils pH is high and they are also calcareous, in this type of soils solvability of micronutrient is less and cause decline uptake these elements and finally requirement of plants to this elements is increasing (Mousavi, 2011). Since this nutrients are significantly involved in reproduction process and their deficiency may occur simultaneously in calcareous soils of Iran (Ziaeyan & Rajaie, 2009). It acts as a co-factor for more than 300 enzymes and is also required for the production of tryptophan which is a precursor of auxin (Aravind & Prasad, 2003). Seed priming with Zn can improve crop emergence, stand establishment, and subsequent growth. For example, priming *Echinacea purpurea* (L.) seed with 0.05% $ZnSO_4$ solution increased root development (Babaeva et al., 1999). In barley (*Hordeum vulgare* L.), seed priming with Zn improved 50% reduced germination time (Ajouri et al., 2004). Priming seeds in Zn solution enhanced dry weight of root in rice (Prom-u-thai et al., 2012). The present study was designed to evaluate the potential of osmopriming agent in comparison with hydropriming technique on seedling development and root morphological characteristics of late sown three canola cultivars under the climatic conditions in central zones of Iran during two growing seasons.

MATERIALS AND METHODS

Site description

The present study was conducted during the two growing seasons of 2014–2015 and 2015–2016 under field at the experimental farm of Islamic Azad University, Karaj Branch, Iran. The site is located at latitude of 35°45′ N, longitude of 51°6′ E and 1,313 m above the sea level in a semi-arid climate experimental field (Fig. 1). The soil type was a silty clay (10.33% sand, 46.33% silt, 43.34% clay), with 0.98% organic matter and pH of 7.4. Daily rainfall and temperature were obtained from a meteorology station located 7 km away from the experimental field (Fig. 1).

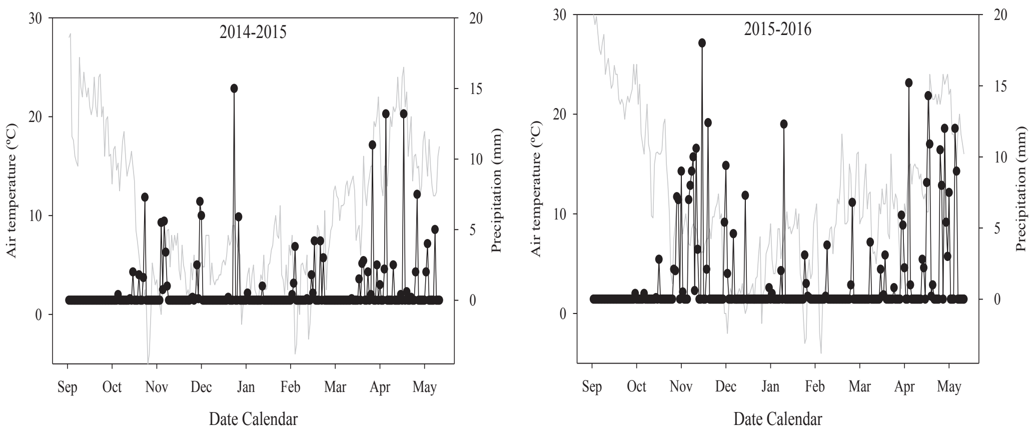

Figure 1. Daily mean temperatures (solid line) and daily total precipitation (●) during the experimental years.

Experimental details

To prepare the field, it was irrigated before conducting the experiment and after the field got wet enough, it was a 30-cm deeply by moldboard plowing in a few days before sowing in August, followed by a disking to slice plant residue and incorporate fertilizers into the soil. Canola seeds were obtained from Seed and Plant Improvement Institute (SPII), Karaj, Iran. NPK fertilizers were applied at rates of 150:80:80 kg ha^{-1}, respectively. P, K and 1/3 of N were applied before sowing and incorporated. Other portions of N were used at the end of rosette stage and beginning of the flowering. Each experimental plot included 6 sowing rows with 6 m in length and 30 cm in width. Average density was 80 plants m^{-2}. The fields were irrigated five times in two growing seasons. The experimental field was visited daily to record stand establishment of canola cultivars. In each plot, two quadrats (1 × 1 m) were randomly marked and the number of emerged seedlings counted daily until the constant count (Association of Official Seed Analysts 1990). The day when the first seedling emerged was recorded as the time to incipient emergence (T_0). Time to 50% emergence (T_{50}) was calculated as described by Farooq et al. (2005). Field experiments were conducted to determine the relationship between root parameters up to the four-leaf stage. Root characteristics were measured at rosette stage using mean data of ten plants in each experimental at a depth of 20 cm of soil. Root length (RL) were measured manually unit with a ruler and dry weights of root (RDW) were determined after drying at 80 °C for 24 h. Roots volume (RV) was evaluated according to the method of Musick et al. (1965) by immersion in a graduate test tube and measure of the displaced water volume. Then root diameter (RD) was determined using the equation 1 (Hajabbasi, 2001) and then root surface area density (RSAD) was calculated using the equation 2 (Schenk & Barber, 1979): RFW is root fresh weight (g).

$$RD = \left(\frac{4 \times RFW}{RL \times 3.14} \right)^{0.5} \quad (1)$$

$$RSAD = \left(RL \times RD \times 3.14 \right) \quad (2)$$

Grain yield (GY) samples were harvested on 5 dates between 5 May and 20 May in 2014–2015, and 15 May and 30 May in 2015–2016. GY was assessed by harvesting plants from adjacent 50-cm lengths of 4 inner rows (6 m^2) in each plot.

Statistical analysis

The experiment was laid out in a randomized complete block design as split plot factorial with three replications. Main factor was including five sowing dates (SD) (5, 15 and 25 September, 5 and 15 October in both crop years) and three canola cultivars (Okapi, Zarfam and Talayeh) and priming treatments (including priming with water, priming with $ZnSO_4$ and control) as factorial in sub-plots. Seed priming was done by soaking in water and 35 ppm $ZnSO_4$ solution for 10 h at 20 °C. Zinc sulfate with 22% Zn manufactured by the Eksir Farayand Espadana Corporation of Iran. Concentration of zinc sulfate solution and duration of priming seeds already determined in a preliminary experiment inspired by research conducted by Harris et al. (2008). Primed seeds dried in the shade to become closer to their original weight at 28 ± 2 °C (Basra et al., 2005). Analysis of variance was done using the PROC GLM procedure of the SAS package 9.1 (SAS Institute, Cary, NC, USA) and test the significance of variance sources, while LSD test (P = 0.05) was used to compare the differences among treatment means.

RESULTS AND DISCUSSION

Results showed that the time to incipient emergence (T_0) and time to 50% emergence (T_{50}) of canola was significantly (P = 0.01) affected by year × sowing date × cultivars × priming interaction (Table 1). The results indicated in both growth seasons that hydropriming and osmopriming compared with non-primed reduced T_0 and T_{50} in all of canola cultivars.

Table 1. Significance levels of analysis of variance combined over 2014–2015 and 2015–2016

Source of variation	d.f	T_0	T_{50}	RL	RD	RSAD	RV	RDW	GY
Year (Y)	1	***	***	n.s.	***	***	***	***	***
Block (Y)	4								
Sowing date (SD)	4	***	***	***	***	***	***	***	***
Y × SD	4	***	***	***	***	***	***	*	***
Block × SD (Y)	16								
Cultivars (C)	2	***	***	***	***	***	***	***	***
Priming (P)	2	***	***	***	***	***	***	***	***
Y × C	2	***	***	n.s.	n.s.	n.s.	**	n.s.	***
Y × P	2	***	***	***	n.s.	***	**	n.s.	***
SD × C	8	***	***	***	***	n.s.	***	***	***
SD × P	8	***	***	***	***	***	***	***	*
C × P	4	***	***	***	***	*	***	***	**
Y × SD × C	8	***	***	n.s.	n.s.	n.s.	n.s.	n.s.	**
Y × SD × P	8	*	***	***	n.s.	*	n.s.	n.s.	***
Y × C × P	4	**	***	n.s.	n.s.	n.s.	*	*	**
SD × C × P	16	***	***	**	***	n.s.	***	***	**
Y × SD × C × P	16	***	***	n.s.	n.s.	n.s.	**	*	**
Block × C × P (SD ×	160								

* Significance at 0.05 probability level; ** Significance at 0.01 probability level; *** Significance at 0.001 probability level. T_0 = time to incipient emergence; T_{50} = and time to 50% emergence; RL = root length; RD = root diameter; RSAD = root surface area density; RDW = root dry weight; RV = root volume; GY = grain yield.

Primed seeds have a better ability to complete the process of germination in a short time and cope with environmental stresses including low temperature (Kant et al., 2006). Osmopriming with $ZnSO_4$ reduced the time to start emergence and T_{50} of canola. Hydropriming also complete the process of emergence in a short time, but to a lesser extent. Rehman et al. (2015b) reported that hormonal priming with 0.5 M $ZnSO_4$ and 0.1 M $ZnCl_2$ were more effective than hydropriming for earlier and synchronized germination and emergence in wheat. Results showed that T_0 and T_{50} decreased significantly in all treatments were observed in 2014–2015 compared with 2015–2016 season. In 2014–2015 and 2015–2016 mean temperature during the 30 days after sowing on the 15-Oct was 5 and 10 °C, respectively (Fig. 1). Low temperatures causes reduce seedling emergence, particularly in those crops such canola which require optimal temperatures between 20 and 25 °C for germination (Zheng et al., 2015). However osmopriming was better during both years (Table 2). T_0 and T_{50} increased significantly as SD was delayed from 5-Sep to 15-Oct in canola cultivars under hydropriming and osmopriming (Table 2). The minimum T_0 and T_{50} was on the 5-Sep under the osmopriming by 2.81 and 3.01 days in the Okapi, 3.61 and 5.04 days in Zarfam and 3.18 and 4.51 days in both growth seasons, respectively.

Increased knowledge of root architecture and root development dynamics could help improve crop productivity in agroecosystems. Better understanding of root architecture and growth dynamics of annual crops may lead to a more efficient use of applied nutrients and water (Fageria, 2011). The study of plant roots is one of the most promising research area, but has a small portion of plant growth research (Box & Ramseur, 1993; Zobel, 2005). Root length (RL) and root diameter (RD) of canola was significantly affected by sowing date × cultivars × priming interaction (Table 1). Among the five SD, the highest RL was obtained on the 5-Sep, while late in SD could cause decreased rapidly from 5-Sep in all the primed seed and control (Table 3).

The maximum RL was on the 5-Sep, so much that this date under the osmopriming and hydropriming increased by 82 and 61 percent in the Okapi, 47 and 43 percent in Zarfam and 58 and 44 percent in Talayeh in both growth seasons compared to control, respectively (Table 3). Results showed remarkable reduction in RD associated with late sowing as compared with the early sowing. Also seed priming with water (hydropriming) and zinc sulfate solution (osmopriming) increased the RD compared with control in three cultivars under all SD. However, the maximums of RD were recorded in Okapi (0.86 and 1.04), Zarfam (0.92 and 0.98) and Talayeh (1.04 and 0.91) cultivars on the 5-Sep under hydropriming and osmopriming, respectively (Table 3). Root surface area density (RSAD) were significantly affected by year × sowing date × priming interaction (Table 1). Results showed that RSAD increased significantly by 48% in 2015–2016 compared with 2014–2015 season (Table 4). Experimental evidence of the higher of RSAD were recorded in the osmopriming agent as compared to hydropriming. Among the five SD, the highest RSAD was obtained on the 5-Sep, while late in SD could cause decreased rapidly from 5-Sep in all the primed seed and control. The lowest RSAD were observed in non-primed treatments (Table 4).

Table 2. Time to incipient emergence and Time to 50% emergence of Okapi, Zarfam and Talayeh cultivars among different sowing dates under seed priming treatments

	Control			HP			OP			
	Okapi	Zarfam	Talayeh	Okapi	Zarfam	Talayeh	Okapi	Zarfam	Talayeh	Mean
Time to incipient emergence (days)										
2014–2015										
5-Sep	4.01 f	4.7 d	4.15 f	3.11 h	3.99 f	3.36 g	2.85 h	3.76 f	3.29 g	3.69 E
15-Sep	4.33 e	4.98 d	4.54 e	3.3 g	4.14 f	4.1 f	3.13 h	3.98 f	4.03 f	4.05 D
25-Sep	4.58 e	5.26 c	5.43 c	4.13 f	4.48 e	4.45 e	4.00 f	4.23 f	4.26 f	4.53 C
5-Oct	5.26 d	5.63 c	6.07 b	4.35 e	5.16 d	4.91 d	4.15 f	4.89 d	4.51 e	4.99 B
15-Oct	6.15 b	6.36 a	6.21 b	4.7 d	5.59 c	5.04 d	4.38 e	5.2 d	4.87 d	5.38 A
2015-2016										
5-Sep	3.29 g	4.00 f	3.69 g	2.89 h	3.52 g	3.27 g	2.77 h	3.46 g	3.08 h	3.33 F
15-Sep	3.87 f	4.36 e	4.05 f	3.15 h	3.93 f	3.53 g	2.98 h	3.69 f	3.17 h	3.64 E
25-Sep	4.15 f	4.87 d	4.43 e	3.58 g	4.25 f	3.87 f	3.23 h	3.98 f	3.46 g	3.98 D
5-Oct	4.77 d	5.26 c	4.97 d	4.09 f	4.59 e	4.33 e	3.92 f	4.16 f	4.05 f	4.46 C
15-Oct	5.49 c	6.00 b	5.73 b	4.43 e	5.09 d	5.29 c	4.13 f	4.93 d	4.24 f	5.04 B
Mean	4.59 C	5.14 A	4.93 B	3.77 E	4.47 C	4.21 D	3.55 F	4.22 D	3.89 E	
$LSD_{0.05} = 0.09$										
Time to 50% emergence (days)										
2014–2015										
5-Sep	5.35 g	5.91 f	5.67 f	4.51 i	5.36 g	5.09 h	4.05 j	5.14 h	4.61 i	5.08 H
15-Sep	5.88 f	6.31 d	6.13 e	4.84 h	5.87 f	5.47 g	4.43 i	5.64 g	5.21 h	5.53 F
25-Sep	6.3 d	6.81 c	6.52 d	5.16 h	6.2 f	5.98 f	5.00 h	6.06 f	5.83 f	5.98 D
5-Oct	6.76 c	7.28 c	7.03 c	5.74 f	6.45 d	6.31 d	5.45 g	6.31 d	6.05 f	6.37 A
15-Oct	6.97 c	7.8 a	7.57 b	6.12 f	7.16 c	6.77 c	5.87 f	6.68 d	6.26 f	6.8 B
2015–2016										
5-Sep	5.04 h	5.72 f	5.37 b	4.25 j	5.09 h	4.66 i	3.97 j	4.95 h	4.41 i	4.83 I
15-Sep	5.24 h	5.93 f	5.77 a	4.57 i	5.46 g	4.95 h	4.21 j	5.28 h	4.83 h	5.14 G
25-Sep	5.42 g	6.38 d	6.13 f	4.95 h	5.82 f	5.44 g	4.47 i	5.69 f	5.29 g	5.51 F
5-Oct	6.00 f	6.87 c	6.43 d	5.13 h	6.06 f	5.88 f	4.89 h	5.96 f	5.69 g	5.88 E
15-Oct	6.34 d	7.11 c	7.02 c	5.69 f	6.46 d	6.22 f	5.25 h	6.11 f	5.97 f	6.24 C
Mean	5.93 D	6.61 A	6.36 B	5.09 G	5.99 C	5.66 E	4.76 H	4.78 H	5.41 F	
$LSD_{0.05} = 0.031$										

T_0 = time to incipient emergence; T_{50} = and time to 50% emergence; HP = hydropriming; OP = osmopriming.

Table 3. Root length and root diameter of Okapi, Zarfam and Talayeh cultivars among different sowing dates under seed priming treatments

	Control			HP			OP			
	Okapi	Zarfam	Talayeh	Okapi	Zarfam	Talayeh	Okapi	Zarfam	Talayeh	Mean
RL (cm)										
5-Sep	7.56 h	7.45 h	7.44 h	12.22 b	10.41 cd	10.76 cd	13.77 a	10.97 cd	11.78 b	10.26 A
15-Sep	7.01 hi	6.62 ij	6.78 hi	10.39 de	8.67 g	9.31 f	11.62 bc	9.37 f	10.19 ef	8.89 B
25-Sep	6.15 jk	5.19 lm	5.66 kl	7.44 h	6.49 ij	7.42 h	8.35 g	7.17 hi	7.66 h	6.84 C
5-Oct	5.11 lm	4.13 no	4.59 mn	6.31 ij	5.39 kl	5.36 kl	6.88 hi	5.72 jk	5.98 jk	5.47 D
15-Oct	3.25 pq	2.54 q	2.98 pq	3.71 no	3.04 pq	3.31 op	4.00 no	3.29 op	3.31 pq	3.27 E
Mean	5.82 D	5.19 D	5.49 D	8.01 B	6.8 C	7.23 BC	8.89 A	7.31 B	7.78 C	
$LSD_{0.05}$ = 0.81										
RD (cm)										
5-Sep	0.37 fg	0.66 cd	0.4 fg	0.86 ab	0.92 ab	1.04 a	1.04 a	0.98 a	0.91 ab	0.79 A
15-Sep	0.54 ef	0.39 fg	0.42 fg	0.8 bc	0.86 ab	0.84 bc	0.96 a	0.71 cd	0.71 cd	0.69 A
25-Sep	0.39 fg	0.3 gh	0.37 fg	0.42 fg	0.83 bc	0.55 e	0.77 bc	0.64 d	0.69 cd	0.55 B
5-Oct	0.34 gh	0.37 fg	0.36 fg	0.38 fg	0.82 bc	0.42 fg	0.76 bc	0.56 de	0.39 fg	0.49 B
15-Oct	0.23 h	0.3 gh	0.22 h	0.27 gh	0.31 gh	0.28 gh	0.43 fg	0.29 gh	0.22 h	0.28 C
Mean	0.37 D	0.4 D	0.35 D	0.55 C	0.75 AB	0.63 BC	0.79 A	0.64 BC	0.58 C	
$LSD_{0.05}$ = 0.13										

RL = root length, RD = root diameter; HP = hydropriming; OP = osmopriming.

Table 4. Root surface area density of different sowing dates under seed priming treatments over two studied years

RSAD (m^2 m^{-3})	Control	HP	OP	Mean
2014–2015				
5-Sep	8.81 hi	23.54 d	29.12 c	20.49 B
15-Sep	7.72 hij	17.66 f	22.09 de	15.82 C
25-Sep	5.58 jkl	10.17 h	12.97 g	9.57 D
5-Oct	3.14 mn	4.04 lmn	9.59 h	5.59 E
15-Oct	2.75 n	2.94 n	3.56 mn	3.08 E
2015–2016				
5-Sep	13.17 g	36.67 b	47.73 a	32.52 A
15-Sep	9.59 h	21.68 de	27.93 c	19.73 B
25-Sep	8.53 hi	15.04 g	19.92 ef	14.49 C
5-Oct	5.94 jkl	7.39 ijk	14.34 g	9.22 D
15-Oct	3.69 lmn	4.52 klm	6.27 jkl	4.82 C
Mean	6.89 C	14.36 A	19.35 B	
$LSD_{0.05}$ = 0.68				

RSAD; root surface area density; HP = hydropriming; OP = osmopriming.

The interaction between year × sowing date × cultivars × priming on root dry weight (RDW), root volume (RV) and grain yield (GY) was significant (Table 1). The mean RDW, RV and GY of canola in response to seed priming with hydropriming, osmopriming and control is shown in Table 5. Seed priming treatments significantly affected RDW, RV and GY in late sown canola. Osmopriming with the greater impact than hydropriming in all of SD and cultivars, improved RDW, RV and GY at both seasons. Delay sowing negatively affected RDW, RV and GY. Maximum RDW, RV and GY at both seasons was recorded from osmopriming on 5-Sep in Okapi cultivar followed by hydropriming. Mean increase in GY by 25, 32, 37, 46 and 47% by Okapi cultivar under priming with $ZnSO_4$ solution was observed in plots with 5-Sep, 15-Sep, 25-Sep, 5-Oct and 15-Oct SD respectively, in comparison with their controls in both years. Low temperatures after sowing caused considerably longer emergence duration at the four delayed SD (15 and 25-Sep; 5 and 15-Oct), and canola exposed to sub-optimal temperatures for this parameters. Decreased this parameters due to low temperature in late-sown has been reported by many researchers (Finch-Savage et al., 2004; Kant et al., 2006; Guan et al., 2009; Rehman et al., 2015a).

Table 5. Root dry weight, root volume and grain yield of Okapi, Zarfam and Talayeh cultivars among different sowing dates under seed priming treatments over two growing seasons

	Control			HP			OP			
	Okapi	Zarfam	Talayeh	Okapi	Zarfam	Talayeh	Okapi	Zarfam	Talayeh	Mean
RDW (g plant^{-1})										
2014–2015										
5-Sep	0.19 r	0.4 p	0.17 r	1.56 g	1.67 e	2.00 c	2.12 b	1.46 g	1.41 h	1.22 B
15-Sep	0.32 q	0.16 r	0.16 r	1.19 j	1.34 i	1.27 i	1.51 g	0.77 l	0.85 k	0.84 C
25-Sep	0.34 q	0.06 s	0.1 s	0.13 s	0.83 l	0.33 q	0.72 m	0.21 r	0.56 n	0.36 E
5-Oct	0.08 s	0.04 s	0.09 s	0.13 s	0. 58 n	0.18 r	0.56 n	0.11 s	0.12 s	0.21 F
15-Oct	0.06 s	0.02 s	0.02 s	0.02 s	0.03 s	0.03 s	0.02 s	0.02 s	0.03 s	0.028 G
2015–2016										
5-Sep	0.28 q	0.69 m	0.2 r	1.57 f	1.73 e	2.17 a	2.15 b	1.62 f	1.47 g	1.32 A
15-Sep	0.34 q	0.2 r	0.23 r	1.16 j	1.45 h	1.45 h	1.75 d	0.82 l	0.88 k	0.92 C
25-Sep	0.45 o	0.15 s	0.2 r	0.26 q	0.9 k	0.47 o	0.84 l	0.3 q	0.69 m	0.47 D
5-Oct	0.13 s	0.18 r	0.16 r	0.22 r	0.75 m	0.23 r	0.67 m	0.16 r	0.14 s	0.29 EF
15-Oct	0.16 r	0.04 s	0.07 s	0.07 s	0.07 s	0.06 s	0.05 s	0.06 s	0.04 s	0.07 G
Mean	0.23 E	0.19 E	0.14 E	0.63 D	0.93 B	0.82 C	1.04 A	0.55 D	0.62 D	
$LSD_{0.05}$ = 0.09										
RV (cm^3 plant^{-1})										
2014–2015										
5-Sep	3.91 l	2.8 m	1.24 op	10.78 e	10.48 f	9.83 f	14.67 b	10.01 f	10.7 e	8.26 B
15-Sep	2.24 n	1.48 no	1.85 n	7.56 h	4.73 k	7.77 h	10.42 f	5.35 k	8.92 g	5.59 D
25-Sep	2.16 n	0.27 pq	0.72 op	2.95 m	1.46 no	1.92 n	3.27 m	1.7 n	5.89 j	2.26 F
5-Oct	0.56 pq	0.2 pq	0.33 pq	0.89 op	0.49 pq	0.75 op	0.92 op	0.64 pq	0.85 op	0.62 GH
15-Oct	0.06 q	0.03 q	0.04 q	0.11 q	0.08 q	0.09 q	0.21 pq	0.1 q	0.1 q	0.09 H

Table 5 (continued)

2015–2016										
5-Sep	5.04 k	3.15 m	2.67 m	11.82 d	11.23 e	11.03 e	16.15 a	12.09 d	13.4 c	9.62 A
15-Sep	3.07 m	1.95 n	2.34 n	8.71 g	5.56 jk	8.04 h	12.33 d	6.67 i	9.77 f	6.49 C
25-Sep	2.66 m	1.09 op	1.95 n	4.26 l	1.8 n	3.4 m	6.00 j	3.24 m	4.29 l	3.19 E
5-Oct	1.17 op	0.45 pq	0.97 op	2.09 n	0.81 op	1.4 op	2.51 n	0.99 op	1.75 n	1.34 G
15-Oct	0.28 pq	0.13 q	0.13 q	0.64 op	0.28 pq	0.36 pq	0.89 op	0.38 pq	0.47 pq	0.39 H
Mean	2.11 E	1.55 EF	1.22 F	4.98 BC	3.69 D	4.46 CD	6.74 A	4.11 D	5.61 B	
$LSD_{0.05}$ = 0.36										
GY (kg ha^{-1})										
2014–2015										
5-Sep	2,841 j	2,266 o	2,539 m	3,106 g	2,773 j	3,068 g	3,576 c	2,924 i	3,378 e	2,941.22 C
15-Sep	2,468 m	2,030 r	2,425 n	2,788 j	2,376 n	2,677 k	3,044 h	2,425 n	2,954 h	2,576.33 D
25-Sep	1,963 r	1,797 t	1,944 s	2,255 o	2,156 p	2,257 o	2,520 m	2,276 o	2,397 n	2,173.89 F
5-Oct	1,714 u	1,395 x	1,643 v	2,070 q	1,725 u	1,991 r	2,249 p	1,840 t	2,126 q	1,861.44 H
15-Oct	1,395 x	1,215 z	1,384 x	1,725 u	1,530 w	1,711 u	1,840 t	1,703 u	1,886 s	1,598.78 I
2015–2016										
5-Sep	3,063 g	2,453 m	2,766 j	3,497 d	3,152 g	3,345 f	3,851 a	3,466 d	3,766 b	3,262.11 A
15-Sep	2,476 m	2,041 r	2,155 p	3,110 g	2,540 m	2,870 i	3,490 d	3,049 h	3,389 e	3,124.44 B
25-Sep	2,064 q	1,683 u	1,814 t	2,672 k	2,406 n	2,525 m	3,023 h	2,785 j	2,874 i	2,427.33 E
5-Oct	1,763 t	1,437 x	1,543 w	2,361 n	2,090 q	2,164 p	2,854 i	2,515 m	2,663 k	2,154.44 F
15-Oct	1,576 v	1,330 y	1,445 x	2,140 q	1,916 s	2,036 r	2,582 l	2,253 p	2,440 n	1,968.67 G
Mean	2,132.3 F	1,764.7 H	1,965.8 G	2,572.4 C	2,266.4 E	2,464.4 D	2,902.9 A	2,823.6 AB	2,787.3 B	
$LSD_{0.05}$ = 100.1										

RDW = root dry weight; RV = root volume; GY = grain yield; HP = hydropriming; OP = osmopriming.

Micronutrients, such as Zn is important co-factors of various enzymes involved in the detoxification of AOS, such as superoxide dismutases (SODs), (Cakmak & Marschner, 1988a; Cakmak & Marschner, 1988b; Cakmak, 2000). Zinc has functions in direct membrane stabilization, in biosynthesis of auxins (Salami & Kenefick, 1970) involved in plant growth regulation and in protein synthesis in general. Therefore, limited supply of these micronutrients under conditions of low root zone temperature (Engels, 1994) may increase oxidative damage of root cells and induce disturbances in plant growth, which may be alleviated by supplementation via micronutrient seed priming. This result indicated that hydropriming and osmopriming compared with non-primed improved the root system in canola (Tables 3–5). Increased emergence rate due to seed priming may be due to increased rate of cell division in the root tips of seedlings from primed seeds as reported in tomato (Farooq et al., 2005). Seed priming triggers the emergence metabolism (e.g. the activity of hydrolytic enzymes) (Bam et al., 2006; Farooq et al., 2006a), stimulates protein synthesis and structural repair (Bray et al., 1989) and helps early and uniform stand establishment (Kaur et al., 2005; Farooq et al., 2006b). Osmopriming with $ZnSO_4$ was more effective than hydropriming in improving the RL, RD, RSAD, RDW and RV (Tables 3–5). Improving root growth at seedling stage could be also important for a positive feedback with early establishment of the root system and thus for better acquisition of nutrients including soil Zn (Prom-u-thai et al., 2012). Ozturk et al. (2006) reported that priming with Zn improved emergence and seedling growth, possibly due to the involvement of Zn in the early stages of coleoptile and radicle development. Seed priming with Zn increased the seedling RWD due to uniform and early germination, which improved the seedling growth as affirmed by strong correlations of mean emergence time, seedling shoot and RL with RWD (Rehman et al., 2015c). Zinc priming significantly enhanced RL and RDW in seedling rice (Prom-u-thai et al. 2012). Farooq et al. (2012) reported that seed hydropriming and osmopriming with ascoibic acid (AsA) improved RL in wheat. Also Jalilian et al. (2014) reported that seed priming improved RL, RDW and RV in barley.

The results obtained from the present study indicate in both growth seasons that seed priming with water and $ZnSO_4$ compared with non-primed improved GY in canola cultivars. In seven trials, mean GY of wheat was significantly increased from 2.28 to 2.42 t ha^{-1} (6%) by priming with water alone and to 2.61 t ha^{-1}(14%) by priming with 0.3% Zn (Harris et al., 2008). Harris et al. (2008) showed that enhancing Zn seed content by priming seeds with solutions of $ZnSO_4$ was highly cost effective in increasing maize yield in North West Frontier Province (NWFP). Seed priming with $ZnSO_4$ and hydropriming were effective enough to improve the GY in late sown canola. Sowing on 15-Oct primed with water and $ZnSO_4$ solution, increased GY by 29 and 27% in the Okapi, 34 and 40% in Zarfam and 31 and 45% in Talayeh compared to control (Table 5). Probably the reasons of the increased GY during late sowing under priming, as has been seen were the increasing root morphological characteristics. There was a significant increase in GY with increasing root length and dry weight in all of canola cultivars (Fig. 2). Authors found that root length as well as root weight has positive association with grain yield in crops (Barraclough, 1984; Thangaraj et al., 1990; Leon & Schwang, 1992; Fageria, 2011; Fageria & Moreira, 2011; Koscielny & Gulden, 2012).

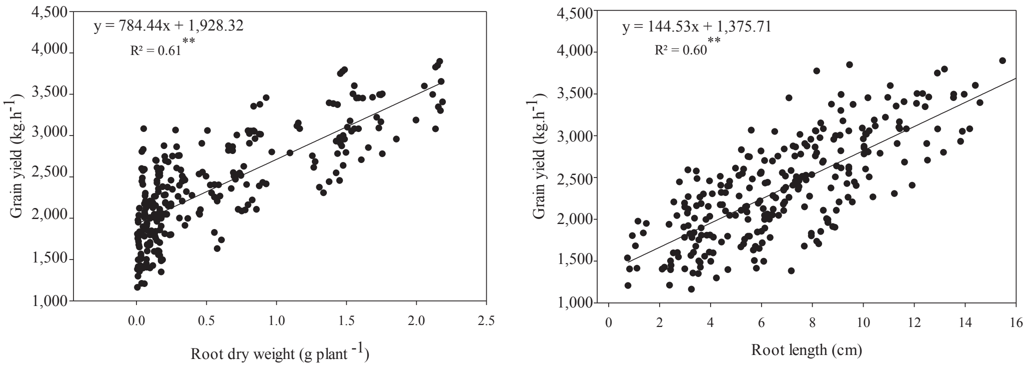

Figure 2. The relationship between root dry weight and root length with grain yield.

Conclusion

Canola seed osmopriming with zinc sulfate have an important impact in reducing the seedling emergence time and improving the root system characteristics. This treatment is important because the delay in sowing of canola can lead to a sharp reduction in seedling emergence percent and weakening of the root system and in case of delay in sowing of canola, zinc sulfate solution can be used as seed osmopriming agent to reduce above mentioned limitations. In this study also seed hydropriming treatment showed a good performance in second place after seed osmopriming by $ZnSO_4$ solution.

REFERENCES

Ajouri, A., Asgedom, H. & Becker, M. 2004. Seed priming enhances germination and seedling growth of barley under conditions of P and Zn deficiency. *Journal* of *Plant Nutrition* and *Soil Science* **167**, 630–636.

Aravind, P. & Prasad, M.N.V. 2003. Zinc alleviates cadmium induced oxidative stress in *Ceratophyllum demersum* L. A free floating fresh water macrophyte. *Plant Physiology and Biochemistry* **41**, 391–397.

Association of Official Seed Analysts (AOSA). 1990. Rules for testing seeds. *Seed Science and Technology* **12**, 1–112.

Babaeva, E.Y., Volobueva, V.F., Yagodin, B.A. & Klimakhin, G.I. 1999 Sowing quality and productivity of *Echinacea purpurea* in relation to soaking the seed in manganese and zinc solutions. *Izvestiya Timiryazevskoi Sel'skokhozyaistvennoi Akademii* **4**, 73–80.

Bam, R.K., Kumaga, F.K., Ori, K. & Asiedu, E.A. 2006. Germination, vigor and dehydrogenase activity of naturally aged rice (*Oryza sativa* L.) seeds soaked in potassium and phosphorus. *Asian Journal* of Plant Science **5**, 948–955.

Barraclough, P.B. 1984. The growth and activity of winter wheat roots in the field, Root growth of high yielding crops in relation to shoot growth. *Journal of Agricultural Science* **103**, 439–442.

Basra, S.M.A., Farooq, M. & Tabassum, R. 2005. Physiological and biochemical aspects of seed vigor enhancement treatments in fine rice (*Oryza sativa* L.). *Seed Science and Technology* **33**, 623–628.

Bowen, G.D. 1991. Soil temperature, root growth and plant function. In. Plant Roots-the Hidden Half, eds., Waisel, Y. Eshel, A. & Kafkafi, U. pp. 309–330. New York, Marcel Dekker.

Box, J.E. & Ramseur, E.L. 1993. Minirhizotron wheat root data, Comparisons to soil core root data. *Agronomy Journal* **85**, 1058–1060.

Bray, C.M., Davison, P.A., Ashraf, M. & Taylor, R.M. 1989. Biochemical events during osmopriming of leek seed. *Annals of Applied Biology* **102**, 185–193.
Cakmak, I. 2000. Possible roles of zinc in protecting plant cells from damage by reactive oxygen species. *New Phytologist* **146**, 185–205.
Cakmak, I. & Marschner, H. 1988a. Increase in membrane permeability and exudation in roots of zinc deficient plants. *Journal of Plant Physiology* **132**, 356–361.
Cakmak, I. & Marschner, H. 1988b. Enhanced superoxide radical production in roots of zinc deficient plants. *Journal of Experimental Botany* **39**, 1449– 1460.
Chen, C., Jackson, G., Neill, K., Wichman, D., Johnson, G. & Johnson, D. 2005. Determining the feasibility of early seeding canola in the Northern Great Plains. *Agronomy Journal* **97**, 1252–1262.
Cooper, A.J. 1973. Root temperature and plant growth-A review. In. Research Review No 4 Commonwealth Bureau of Horticulture and Plantation Crops. Wallingford, U.K., Commonwealth Agricultural Bureaux.
Engels, C. 1994. Nutrient acquisition by plants and its limitations by low temperatures in maize. In, Dörffling, K., European Commission (Eds.), Crop Adaptation to Cool Climates. COST 814 Workshop. ECSP-EEC-EAEC, Brussels.
Eslamian, S.S. Abedi–Koupai, J., Amiri, M.J. & Gohari, S.A. 2009. Estimation of daily reference evapotranspiration using support vector machines and artificial neural networks in greenhouse. *Research Journal of Environmental* Sciences **3**, 439–447.
Fageria, N.K. 2011. The Role of Plant in Crop Production. CRC Press.
Fageria, N.K. & Moreir, A.A. 2011. The role of mineral nutrition on root growth of crop plants. *Advances in Agronomy* **110**, 251–331.
FAO, 2014. http,//faostat3.fao.org/download/Q/QC/E.
Farooq, M., Basra, S.M.A., Hafeez, K. & Ahmad, N. 2005. Thermal hardening, a new seed vigor enhancement tool in rice. *Journal of Integrative Plant Biology* **47**, 187–193.
Farooq, M., Basra, S.M.A. & Wahid, A. 2006a. Priming of field-sown rice seed enhances germination, seedling establishment, allometry and yield. *Plant Growth Regulation* **49**, 285–294.
Farooq, M., Barsa, S.M.A. & Ur-Rahman, H. 2006b. Seed priming enhances emergence, yield, and quality of direct seeded rice. *Crop Management and Physiology* **12**, 42–47.
Farooq, M., Irfan, M., Aziz, T., Ahmad, I. & Cheem, S.A. 2012. Seed priming with ascorbic acid improves drought resistance of wheat. *Journal of* Agronomy *and* Crop Science **199**, 1–11.
Guan, Y., Hu, X., Wang, X. & Shao, C. 2009. Seed priming with chitosan improves maize germination and seedling growth in relation to physiological changes under low temperature stress. *Journal of Zhejiang University Science* **10**, 427–433.
Finch-Savage, W.E., Dent, K.C. & Clark, L.J. 2004. Soak conditions and temperature following sowing influence the response of maize (*Zea mays* L.) seeds to on-farm priming (pre-sowing seed soak). *Field Crops Research* **90**, 361–374.
Hajabbasi, M.A. 2001. Tillage effects on soil compactness and wheat root morphology. *Journal* of Agricultural *Science and Technology* **3**, 67–77.
Harris, D., Rashid, A., Miraj, G., Arif, M. & Yunas, M. 2008. On-farm seed priming with zinc in chickpea and wheat in Pakistan. *Plant Soil* **306**, 3–10.
Hund, A., Richner, W., Soldati, A., Fracheboud, Y. & Stamp, P. 2007. Root morphology and photosynthetic performance of maize inbred lines at low temperature. *The European Journal of Agronomy* **27**, 52–61.
Jalilian, J., Khalilzadeh, R. & Khanpaye, E. 2014. Imroving of barley seedling growth by seed priming under water deficit stress. *The Journal of Stress Physiology and Biochemistry* **10**, 125–134.
Kant, S., Pahuja, S.S. & Pannu, R.K. 2006. Effect of seed priming on growth and phenology of wheat under late-sown conditions. *Tropical Science* **44**, 9–15.

Kaur, S., Gupta, A.K. & Kaur, N. 2005. Seed priming increases crop yield possibly by modulating enzymes of sucrose metabolism in chickpea. *Journal of Agronomy and Crop Science* **191**, 81–87.

Khattak, J.K. & Parveen, S. 1986. Micronutrient status of Pakistan soils and their role in crop production. Bull. Soil Sci. No. 3. NWFP Agricultural University, Peshawar.

Koscielny, C.B. & Gulden, R.H. 2012. Seedling root length in *Brassica napus* L. is indicative of seed yield. *Canadian Journal* of *Agricultural Science* **92**, 1229–1237.

Lee, S.S. & Kim, J.H. 2000. Total sugars α-amylase activity and germination after priming of normal and aged rice seeds. *The Korean Journal of Crop Science* **45**, 108–111.

Lee, E.A., Staebler, M.A. & Tollenaar, M. 2002. Genetic variation in physiological discriminators for cold tolerance – early autotrophic phase of maize development. *Crop Science* **42**, 1919–1929.

Leon, J. & Schwang, K.U. 1992. Description and application of a screening method to determine root morphology traits of cereals cultivars. *Z. Acker- Pflanzenbau* **169**, 128–134.

Mousavi, S.R. 2011. Zinc in crop production and interaction with phosphorus. *Australian Journal of Basic and Applied Sciences* **5**, 1503–1509.

Musick, G.J., Fairchild, M.L., Ferguson, V. & Zuber, M.S. 1965. A method of measuring root volume in corn (*Zea mays* L.). *Crop Science* **5**, 601–602.

Ozturk, L., Yazici, M.A., Yucel, C., Torun, A., Cekic, C., Bagci, A., Ozkan, H., Braun, H., Sayers, Z. & Cakmak, I. 2006. Concentration and localization of zinc during seed development and germination in wheat. *Acta Physiologiae Plantarum* **128**, 144–152.

Prom-u-thai, C., Rerkasem, B., Yazici, A. & Cakmak, I. 2012. Zinc priming promotes seed germination and seedling vigor of rice. *Journal of Plant Nutrition and Soil Science* **175**, 482–488.

Rehman, H.U., Iqbal, H., Basra, S.M.A., Afzal, I., Farooq, M., Wakeel, A. & Ning, W. 2015a. Seed priming improves early seedling vigor, growth and productivity of spring maize. *Journal of Integrative Agriculture* **14**, 1–11.

Rehman, A., Farooq, M., Ahmad, R. & Basra, S.MA. 2015b. Seed priming with zinc improves the germination and early seedling growth of wheat. *Seed Science and Technology* **43**, 262–268.

Rehman, H.U., Kamran, M., Basra, S.M.A., Afzal, I. & Farooq, M. 2015c. Influence of seed priming on performance and water productivity of direct seeded rice in alternating wetting and drying. *Rice Science* **22**, 189–196.

Salami, A.U. & Kenefick, D.G. 1970. Stimulation of growth in zinc-deficient corn seedlings by the addition of tryptophan. *Crop Science* **10**, 291–294.

Schenk, M.K. & Barber, S.A. 1979. Root Characteristics of Corn Genotypes as Related to P Uptake. *Agronomy Journal* **71**, 921–927.

Takkar, P.N. & Walker, C.D. 1993. The distribution and correction of zinc deficiency. In, Robson AD (ed) Zinc in soils and plants. *Kluwer, Dordrecht*. 151–165.

Thangaraj, M., O'Tolle, J.C. & De-Datta, S.K. 1990. Root response to water stress in rainfed lowland rice. *Experimental Agriculture* **26**, 287–296.

Ziaeyan, A.H. & Rajaie, M. 2009. Combined effect of Zinc and Boron on yield and nutrients accumulation in corn. *International Journal of Plant Production* **3**, 35–44.

Zheng, J., Jian, F., Yang, P. & Hu, L. 2015. Responses of canola (*Brassica napus* L.) cultivars under contrasting temperature regimes during early seedling growth stage as revealed by multiple physiological criteria. *Acta Physiologica* **37**, 1–10.

Zobel, R.W. 2005. Tertiary root systems. In 'Roots and Soil Management, Interactions between Roots and the Soil' (R.W. Zobel & S.F. Wright, Eds.), pp. 35–56. ASA, CSSA, and SSSA, Madison, WI.