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Salt tolerance of Indian mustard (*Brassica juncea*) at germination and early seedling growth

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Abstract

Soil salinity is one of the most important constraints limiting crop production in arid and semi arid regions. Seed germination is a critical stage in the life history of individual plants and salt tolerance during germination is crucial for the establishment of plants growing in saline soils. The research was carried out in order to test the effect of salinity on germination traits and seedling growth in 25 Indian mustard (*Brassica juncea*) genotypes. The results revealed statistically significant effects of salinity (EC 12 dS m^{-1}) on germination traits as well as growth characteristics of seedlings. Genotypic responses were significant for germination percentage, speed of germination, germination index, and relative germination rate, which were all generally retarded by salt stress. However, the mean germination time increased under saline conditions. Decline in root/shoot ratio and dry matter of seedlings was observed under salinity. Six mustard genotypes were characterized by significantly higher tolerance index for root growth. Significant correlation existed between tolerance index and shoot length, dry matter and also salt tolerance efficiency. Based on the results, the genotypes RB-10 and PR-2004-2 were identified as highly tolerant and NDR-05-01, PBR300, RK-05-01, NPJ-93, PDR-1188 and RGN-145 as moderately tolerant to salt stress.

Key words: *Brassica juncea*, germination, Indian mustard. relative germination rate, salt tolerance efficiency, salinity.
Abbreviations: DAS, days after sowing; GI, germination index; GP, germination percentage; MGT, mean germination time; RGR, relative germination rate; STE, salt tolerance efficiency.

Introduction

Indian mustard [*Brassica juncea* (L.) Czen and Cross] is an important winter oilseed crop grown across the Northern Indian plains. The maximum distribution area is centered in the North-West agro-climatic zone, where the majority of ground water sources are highly saline and have medium to high sodicity problems. Pronounced spatial and temporal variability of both resources and abiotic factors create major environmental constraints. Salt and osmotic stresses are responsible for inhibition of and delayed seed germination and also seedling establishment (Almansouri et al. 2001). Germination failure on saline soils is often the result of high salt concentration in the seed planting zone caused by upward movement of soil solution and subsequent evaporation at the soil surface. These salts interfere with seed germination and crop establishment (Flower 1991). Salt stress on seed germination may be attributed to either osmotic effect and/or to specific ion toxicities to radicle emergence or seedling development.

Seedling establishment is a critical stage in crop production and considerably depends on biochemical and physiological structures of the seed. In order to obtain fast and good establishment of seedlings, seeds with high viguor are needed to provide essential nutrients for seedling establishment and to enable them to photosynthesize independently. Seed germination, seedling emergence and early survival are particularly sensitive to substrate salinity. Successful seedling establishment depends on the frequency and amount of precipitation, as well as on the ability of seed species to germinate and grow when soil moisture and osmotic potential are low (Ahmad, Jalal 2009). Salinity affects seed germination, seedling growth, and reduces root/shoot elongation and dry matter accumulation (Mishra, Anju1996). The magnitude of the effect of salinity varied with the plant species, type and level of salinity. There are interspecies, intraspecies and intercultivar variations, and even individual lines differ at different ontogenetic stages to salt tolerance, which provides scope for selection of genotypes for salt tolerance.

There is also a need to enhance crop production under saline conditions. Germination and seedling characteristics are the most viable criteria for selecting salt tolerance. Further, germination percentage, germination speed and seedling growth are important criteria for cultivar selection. Therefore, it becomes imperative to screen genotypes at the seedling stage under saline environments to identify tolerant genotypes for better germination and early seedling establishment, to obtain higher yields and manage salinity. Genotypic variation in Indian mustard has been reported earlier (Lallu, Dixit, 2001; Lallu et al. 2009). The information on the salt tolerance of recently developed mustard genotypes is lacking. Therefore, the present study was undertaken to evaluate the effect of salinity on seed germination and seedling growth in 25 genotypes of *B. juncea* and further to assess their genotypic variation.

Materials and methods

The experiment was conducted in the Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana, India during the winter season of 2006 – 2007. The study was performed with 25 Indian mustard genotypes grown in the greenhouse under two treatments: control EC 0 and saline 12 dS m^{-1}. Twenty seeds of each genotype were grown in earthen pots (25.4 cm in diameter and 20.3 cm in height). The actual salinity level achieved was 11.98 dS m^{-1}. Each pot contained 4 kg of sandy loam soil. The soil was saturated before sowing with distilled water (control) or saline solution comprising NaCl, $CaCl_2$, $MgSO_4$ and Na_2SO_4 in water to give a Cl:SO_4 ratio of 4:1 and Ca:Mg ratio of 1.3:1. A sodium adsorption ratio of 10 to 12 was maintained. Treatments were replicated three times with three pots per treatment. During the experimental period, the pots were weighed on alternate days and water loss was replaced by adding distilled water or saline water as needed. The experiment was conducted in the greenhouse under dark conditions for the first three days and at day/night temperature of 30/25 °C, followed by 12 h light period of photon flux density 325 µmol m^{-2} s^{-1} and relative humidity of 70% for the next 10 days. Temperature and relative humidity were measured and controlled automatically in the greenhouse. Seedling emergence was recorded daily after the first emergence in the control and counted for 13 days after sowing (DAS). Germination recorded was expressed on percent basis after 7 DAS as per ISTA (1996) and Sehirali (2002). Five seedlings were randomly taken after 13 DAS for recording shoot length, root length and dry weight of seedlings. Seedlings were oven-dried at 70 °C until constant weight was achieved.

Germination percentage, germination speed, germination index, and relative germination rate were determined by the following formula (Li 2008):

(1) Germination percentage ($G\%$) = $n / N \times 100$,

where n is the number of germinated seed at the seventh day; N is the number of total seeds;

(2) Germination speed (GS) = $\sum D \times n / \sum n$,

where n is the number of germinated seeds at each day; D is number of days after the start of the experiment;

(3) Germination Index (GI) = $\sum Gt / Dt$,

where Gt is the number of seeds germinated in t days; Dt is the number of corresponding germination days;

Relative germination rate (RGR) = d / e,

where d is germination percentage in saline conditions; e is germination percentage in corresponding control.

Mean germination time was calculated using the method of Younsheng and Sziklai (1985) as follows:

$$MGT = \sum ni \times di / n,$$

where n is the total number of seeds germinated during the 13–day experimental period; ni is the number of seeds germinated on day di; di represents the particular day during the germination period (between 0 and 13).

Salt tolerance indices were calculated for root and shoot length as well as for dry mass of seedlings by dividing respective data from saline-treated plants with those of the control. The data was subjected to statistical analysis by SAS programme.

Results

Germination traits

The results revealed a significant effect of salinity on germination traits of mustard genotypes (Table 1). In general, salt stress adversely affected germination of mustard cultivars. The mean germination of all tested genotypes was lower than the control by 22.1%. Germination percentage ranged from 8.3 [ORYJ (M)-15-2] to 88.3% (PR-2004-2) under control conditions and 6.7 [ORYJ (M)-15-2, RK-05-01] to 78.3% (NRCD-509) under salt stress conditions. Rate of germination in the control varied from 1.98 (RK-05-01) to 17.63 (SKM-450) and ranged from 1.08 (RK-05-01) to 16.6 (NRCD-509) with salt stress. Mustard genotypes ORYJ (M)-15-2 and RK-05-01 had low germination percentage and rate of germination in both control and saline conditions. Reduction in germination by salinity was very low in RB-10 (4.5%), RK-05-2 (4.3%), NDR-05-01 (6.1%), PBR-20 (2.8%), JKMS-2 (4.4%), JGM-03-02 (8.3%) and NRCDR-509 (7.9%). Speed of germination was reduced by salinity by less than 1% in RB-10 and PR-2004-2. Inhibition of these traits with salt stress was less than 10% in Varuna, RB-10, RK-05-02, PBR-300, and NRCDR-509.

Among the 25 mustard cultivars, the highest germination index (GI) values were recorded for NRCD 509 and Varuna under control consitions, and only minimal decline was recorded for both cultivars under salinity. Sensitive cultivars were SKM-425, JGM-03-02, CS-2100-5-6 and RH-0116. Mean GI values were 14.48 in control conditions and 5.96 under salt stress. Overall 58.8% decline in GI with salinity was recorded. Relative germination rate (RGR) was higher in the control than in saline treatment. Salinity reduced RGR in all cultivars, and 44.9% decline was recorded under salt stress, compared with the control. The lowest RGR was 0.42 in cultivar RH-0116 under saline conditions. The highest germination rate in the control was for genotypes 3.15 (NPJ-93), 2.95 (SKM-425) and 2.52 (RH-0116) whereas the highest values under salt stress were 1.10 (RGN-152), 1.05 (NDR-05-01) and 1.1 (RGN-152). Salinity also had considerable affect on germination time of mustard seeds, as evident from different germination time delay among the cultivars. CS-1900-1-4 and RL-2047 had the fastest germinating seeds: 1.16 and 1.18 days, respectively (Table 1). Germination

Table 1. Effect of salinity on germination traits in *Brassica juncea* genotypes. C, control; S, salinity treatment

No	Genotype	Germination (%)		Speed of germination		Germination index		Relative germination rate		Mean germination time (days)	
		C	S	C	S	C	S	C	S	C	S
1	Varuna	85.0	76.7	16.6	15.7	14.59	14.34	1.13	0.91	1.56	1.68
2	RB-10	70.0	65.7	14.32	14.3	12.78	12.52	1.31	0.84	1.58	1.79
3	SKM-450	73.3	70.0	17.63	13.0	13.37	11.08	1.51	0.98	1.7	2.58
4	RK-05-02	40.0	38.3	7.47	7.06	7.00	6.70	1.14	0.94	1.85	2.1
5	RGN-48	70.0	51.7	12.53	10.3	12.07	9.48	1.36	0.76	1.36	1.62
6	NPJ-92	66.7	63.7	12.97	12.1	11.67	11.44	1.09	0.98	1.5	1.63
7	NDR-05-01	65.0	51.7	10.65	8.83	11.0	8.3	1.55	1.05	1.51	1.80
8	PBR-300	68.3	60.0	11.78	11.6	10.56	9.89	1.15	0.89	1.47	1.52
9	RK-05-01	10.0	6.7	1.98	1.08	1.74	1.22	1.67	0.78	1.47	2.47
10	PR-2004-2	88.3	76.7	14.73	14.6	14.89	12.81	1.18	0.89	1.63	1.85
11	NPJ-93	73.3	42.5	13.77	9.03	12.34	7.63	3.15	0.76	1.88	4.23
12	SKM-425	71.7	32.5	12.4	8.9	12.70	6.18	2.95	0.48	1.91	4.68
13	PBR-1188	71.7	45.0	12.7	7.98	11.92	6.89	1.76	0.64	1.74	3.34
14	RGN-145	81.7	71.7	17.4	14.8	13.33	11.63	1.16	0.88	1.73	1.92
15	JKMS-2	76.7	73,3	14.5	12.7	13.15	12.63	1.16	1.01	1.70	1.78
16	JGM-03-02	60.0	38.3	11.5	6.77	10.59	6.44	2.19	0.68	1.62	3.59
17	ORYJ(M)-15 -2	8.3	6.7	2.3	2.0	2.07	1.30	1.11	0.83	1.63	3.71
18	RL-2047	73.3	48.3	13.9	9,19	11.93	8.18	0.94	0.71	1.18	1.67
19	CS-1900-1-4	86.7	58.3	15.4	10.6	14.73	10.3	0.94	0.72	1.16	1.66
20	NRCDR-2	70.0	61.7	15.5	11.9	11.74	11.19	1.18	0.87	1.61	1.74
21	RH-0116	83.3	35.0	16.3	6.73	14.48	5.96	2.52	0.42	1.54	3.45
22	RGN-152	73.3	71.7	14.4	10.0	12.70	12.59	1.31	1.10	1.63	1.77
23	NRCDR-509	85.0	78.3	17.3	16.6	14.81	14.67	1.01	1.0	1.53	1.62
24	CS-2100-5-6	65.0	30.0	12.2	5.65	11.19	5.81	1.50	0.56	1.65	4.92
25	CS-610-5-2-5P	83.3	71.7	16.4	13.3	14.11	12.15	1.17	0.86	1.54	1.92
	Mean	68	53.0	13.06	10.19	11.66	9.25	1.49	0.82	1.59	2.48
	C.D@5%	Gen. (G) = 1.36		Gen. (G) = 0.23		Gen. (G) = 0.296		Gen. (G) = 0.055		Gen. (G) = 0.0586	
		Saline (S) = 1.4		Saline (S) = 4.82		Saline (S) = 1.04		Saline (S) = 0.195		Saline (S) = 0.207	
		G × S = 1.16		G × S = 6.81		G × S = 1.12		G × S = 0.275		G × S = 0.293	

time dramatically increased with salt stress. However, considerable germination time differences for genotypes PBR300, JKMS-2, NRCD-509 were not observed between control seeds and those germinated at salinity of 12 dS m^{-1}. CS-2100-5-6 was found to have the longest germination time (4.92) under saline conditions, followed by 4.68 in SKM-425.

Seedling growth characteristics

Significant differences were observed for root, shoot and hypocotyle length between different mustard genotypes and these traits were inhibited by salt stress (Table 2). Overall decline due to germination in saline conditions for root length was 42.7%, hypocotyle length 22.4% and shoot length 32.4% in comparison to the control. Minimum reduction in root length was observed for RB-10 (4.9%), in shoot length for RL-2047 (1.6%), JKMS-2 (2.2%), RK-05-02 (3.1), NPJ-92 (3.5%), RGN-145 (4.6%) and PBR-300 (4.7%). No differences in hypocotyl length were observed for RGN 145 due to salt stress. Impact of salinity on root/shoot ratio and dry matter of seedling was significant (Table 2). Overall, 27.1% decline in root/shoot ratio and 57.5% in dry mass of seedlings were recorded under salinity. Minimum reduction of DM was evident for genotype RB-10 (9.6%). Significant genotypic variation was recorded with saline treatment. High variability existed for dry matter accumulation in the seedlings. Coefficient of variation ranged from 37.9 to 39.2 % for the germination traits indicating variability in response to salinity amongst the cultivars. In contrast, root, shoot and hypocotyl length did not show much variation.

Interaction effects between genotypes and salinity showed significant variation among the genotypes with respect to germination and seedling growth parameters. It was observed that among the 25 genotypes, RB-10 showed better performance in almost all the parameters studied.

Table 2. Effect of salinity on on growth and seedling characteristics in *Brassica juncea* genotypes. C, control; S, salinity treatment

No	Genotype	Root length (cm)		Hypocotyl length (cm)		Shoot length (cm)		Root:shoot ratio		Dry matter of seedling (g)	
		C	S	C	S	C	S	C	S	C	S
1	Varuna	2.25	1.61	1.83	1.50	5.08	4.93	0.442	0.326	6.08	2.96
2	RB-10	2.05	1.94	1.85	1.54	4.99	4.34	0.410	0.447	5.40	4.88
3	SKM-450	2.08	1.83	1.78	1.10	6.69	4.59	0.273	0.453	10.5	6.85
4	RK-05-02	1.61	1.59	1.19	0.95	4.59	4.29	0.352	0.370	9.24	1.72
5	RGN-48	1.92	1.54	3.12	1.19	6.25	4.57	0.301	0.336	3.50	2.35
6	NPJ-92	2.27	1.79	1.67	1.45	5.70	5.65	0.399	0.316	8.74	3.48
7	NDR-05-01	3.88	2.03	2.37	1.77	5.38	4.87	0.721	0.416	6.60	3.61
8	PBR-300	2.69	1.65	1.51	1.45	5.71	5.43	0.710	0.303	6.23	3.40
9	RK-05-01	2.75	0.69	1.08	0.37	6.00	3.08	0.458	0.224	7.90	4.07
10	PR-2004-2	4.17	1.87	1.56	1.40	6.07	4.45	0.687	0.419	7.55	6.36
11	NPJ-93	3.89	1.93	1.30	0.96	5.75	4.45	0.677	0.434	9.86	5.51
12	SKM-425	3.68	2.09	1.65	1.36	6.92	3.29	0.532	0.634	13.4	4.03
13	PBR-1188	3.41	1.00	1.72	1.57	4.62	3.75	0.739	0.266	11.9	6.16
14	RGN-145	2.83	1.51	2.09	2.09	5.03	4.65	0.562	0.322	12.0	6.67
15	JKMS-2	3.14	2.03	1.80	1.25	6.01	5.64	0.522	0.359	9.71	6.68
16	JGM-03-02	2.34	1.59	2.37	1.65	6.33	4.21	0.370	0.379	10.2	2.50
17	ORYJ(M)-15-2	2.66	1.10	1.97	1.47	5.54	3.10	0.480	0.355	7.84	1.56
18	RL-2047	2.33	1.65	1.87	1.44	4.83	4.50	0.41	0.567	13.6	3.43
19	CS-1900-1-4	3.77	1.63	2.16	1.65	6.91	5.87	0.546	0.278	10.8	4.94
20	NRCDR-2	3.33	1.57	1.57	1.45	6.67	4.77	0.499	0.329	9.90	2.13
21	RH-0116	2.74	2.03	1.88	1.72	6.06	5.49	0.520	0.337	8.30	2.22
22	RGN-152	2.85	1.97	2.07	1.83	6.73	5.33	0.423	0.369	14.0	2.19
23	NRCDR-509	2.96	1.65	1.93	1.89	7.77	4.27	0.381	0.386	5.96	0.75
24	CS-2100-5-6	4.15	1.73	2.03	1.17	6.81	4.07	0.610	0.426	5.44	1.92
25	CS-610-5-2-5P	2.65	1.42	1.38	1.26	7.83	5.25	0.338	0.270	4.76	2.88
	Mean	2.9	1.66	1.83	1.42	6.01	4.06	0.487	0.364	8.77	3.73
	C.D@5%	Gen. (G) = 0.224		Gen. (G) = 0.057		Gen. (G) = 0.144		Gen. (G) = 0.038		Gen. (G) = 0.155	
		Saline (S) = 0.792		Saline (S) =).22		Saline (S) = 0.509		Saline (S) = 0.136		Saline (S) = 0.531	
		G × S = 1.12		G × S = 0.286		G × S = 0.720		G × S = 0.192		G × S = 0.752	

Salt tolerance indices

Six genotypes (RB-10, SKM-450, RK-05-02, JGM-03-02. RL-2047 and NRCD-509) had higher tolerance index for root growth than that of shoot growth, indicating that shoots of these genotypes were more sensitive to salt stress than roots. However, for the rest of the genotypes, root growth was more adversely affected by salinity than shoot growth (Table 3). Salt tolerance index for dry matter was highest for RB-10 (0.92), followed by PR-2004-2 (0.84), but four genotypes had dry matter tolerance index > 0.6 and six genotypes > 0.5.

Correlations

Correlation studies indicated a highly positive correlation between germination percentage with all germination traits viz. speed of germination (SP), germination index (GI), mean germination time (MGT) and relative germination rate (RGR) both in control and saline treatment (Table 4). Similar trends occurredfor speed of germination, germination index and mean germination rate. Under saline condition, root/shoot ratio showed high positive correlation with G% (r = 0.798), SP (r = 0.777), GI (r = 0.854), mean germination time (0.815) and relative germination rate (r = 0.830). Root length showed highly negative correlation (r = –0.761) with salt tolerance index for root length under control but positive correlation (r = 0.576) with saline treatment. A similar trend was observed for shoot length and tolerance index for shoot length. Dry matter of the seedlings had positive correlation (r = 0.692) with tolerance index for dry weight under saline condition. Strong positive linear relationship was recorded between root: shoot ratio and root length (r = 0.6891) in the control (Fig. 1). Salinity of 12 dS m^{-1} weakened this relationship as indicated by a lower coefficient of determination (r = 0.4764)

Table 3. Salt tolerance indices in genotypes of *Brassica juncea*. *, highly tolerant; **, tolerant; ***, moderately tolerant. RTI and STI ≥ 3.0 – 4.5 (*); ≥ 2.0 – 3.0 (**); ≥ 1.5 – 1.9 (***). DMTI ≥ 0.8 – 1.0 (*); ≥ 0.6 – 0.7 (**); ≥ 0.5 – 0.59 (***). STE (%) ≥ 80 (*); ≥60 (**); ≥ 50 (***)

No	Genotype	Root tolerance index (RTI)	Shoot tolerance index (STI)	Dry matter tolerance index (DMTI)	Salt tolerance efficiency (STE%)
1	Varuna	2.15 **	2.95 **	0.49	49.2
2	RB-10	3.00 *	2.63 **	0.92 *	91.8 *
3	SKM-450	3.55 *	2.06 **	0.65 **	65.0 **
4	RK-05-02	3.17 *	2.81 **	0.19	18.9
5	RGN-48	2.85 **	4.10 *	0.68 **	68.1 **
6	NPJ-92	2.34 **	3.01 *	0.40	40.0
7	NDR-05-01	1.61 ***	2.74 **	0.55 ***	55.0 ***
8	PBR-300	1.83 ***	3.17 *	0.55 ***	54.6 ***
9	RK-05-01	0.77	1.57 ***	0.53 ***	53.1 ***
10	PR-2004-2	1.41	2.20 **	0.84 *	83.2 *
11	NPJ-93	1.55 ***	2.32 **	0.52 ***	52.3 ***
12	SKM-425	1.65 ***	1.43	0.30	30.0
13	PBR-1188	1.13	2.44 **	0.52 ***	51.9 ***
14	RGN-145	1.70 ***	2.82 **	0.56 ***	55.9 ***
15	JKMS-2	1.95 ***	2.81 **	0.66 **	65.7 **
16	JGM-03-02	2.31**	2.00 **	0.25	24.5
17	ORYJ(M)-15-2	1.29	1.68 ***	0.20	20.1
18	RL-2047	4.38 *	3.24 *	0.25	25.2
19	CS-1900-1-4	1.39	2.58 **	0.46	46.0
20	NRCDR-2	1.48	2.14 **	0.22	21.8
21	RH-0116	2.23 **	3.30 *	0.27	27.0
22	RGN-152	2.23 **	2.37 **	0.16	15.7
23	NRCDR-509	1.89 ***	1.65 ***	0.15	15.4
24	CS-2100-5-6	1.40	1.79 ***	0.35	35.2
25	CS-610-5-2-5P	1.68 ***	2.01 **	0.61 **	60.6 **
	C.D@5%	0.679	0.824	0.450	11.7

Discussion

Seed germination and establishment are the two critical steps in the life cycle of a crop. The loss of plants leads to reduction in the yield by decrease in plant density. Thus, screening of genotypes at the early stages may be an important criterion for selecting salt tolerant genotypes, thus saving considerable time. However, salt tolerance at early growth stages is not always correlated with that in the following growth stages (Mass, Grieve 1994; Zeng et al. 2002; Ferdose et al. 2009). In the present investigation, we focused on evaluation of the potential tolerance of mustard genotypes to salt stress at early stages of growth.

Seed germination begins with water intake. Salinity prevents water imbibition, thereby inhibiting the initial process of seed germination (Othman 2005). Salinity imposes osmotic stress by accumulation of Na and Cl ions. Previous studies have shown that increase in salinity delays the initiation of germination leading to reduction in germination percentage. In the present study, seed germination traits were significantly inhibited by salt stress in all the mustard genotypes. Our results are similar to the findings reported by Karagiizel (2003) and later by Li (2008). Germination index was high under salt stress and comparable with the control in Varuna, RB-10, NPJ-92, NRCDR-2, RGN-152 and NRCD509. Shanon and Grieve (1999) reported that salinity slowed germination rate at low concentration; the only effect was on germination rate and not on the total percentage of germinating seeds. In further studies with *Brassica* species (Jamil et al. 2005) and some tomato cultivars (Al-Hirbi et al. 2008) it was demonstrated that germination rates were considerably lower in high salt concentration with respect to the control. Germination time in mustard seeds was considerably affected by salinity. According to Karagiizel (2003), germination time in different plant species considerably increases with an increase in salt concentration. Salinity influenced germination time more dramatically than the germination percentage (Ozcoban, Demir 2006). This means that increase in salt concentration results in prolongation of germination time. However, salinity caused different germination time delay amongst the cultivars studied. Delayed germination has also been

Table 4. Correlation between germination and seedling growth traits and salt tolerance indices in *Brassica juncea* genotypes. **, significant at 5%; *, significant at 1 % level. Numbers in parentheses indicate saline treatment. SP, speed of germination; GI, germination index; MGT, mean germination time; RGR, relative germination rate; RL, root length; HL, hyopcotyl length; SL, shoot length; R:S, root:shoot ratio; DM, dry matter; RLT, root length tolerance; SLT, shoot length tolerance; DMT, dry matter tolerance.

Traits	SP	GI	MGT	RGR	RL	HL	SL	R:S	DM	RLT	SLT	DMT
G (%)	0.952**	0.931**	0.997**	0.986**	0.216	0.173	0.271	0.661*	0.156	0.151	0.182	0.178
	(0.920)**	(0.934)**	(0.996)**	(0.983)**	(0.390)	(0.426)	(0.614)*	(0.798)**	(0.207)	(0.226)	(0.371)	(0.333)
SP		0.921**	0.967**	0.979**	0.058	0.272	0.258	0.588	0.087	0.262	0.244	0.192
		(0.897)**	(0.943)**	(0.963)**	(0.400)	(0.390)	(0.436)	(0.772)**	(0.279)	(0.226)	(0.234)	(0.377)
GI			0.950**	0.967**	0.189	0.152	0.307	0.742**	0.025	0.099	0.103	0.229
			(0.953)**	(0.968)**	(0.461)	(0.406)	(0.631)*	(0.854)**	(0.177)	(0.311)	(0.395)	(0.298)
MGT				0.995**	0.193	0.187	0.277	0.669*	0.132	0.163	0.184	0.188
				(0.994)**	(0.407)	(0.425)	(0.602)	(0.815)**	(0.216)	(0.241)	(0.362)	(0.340)
RGR					0.162	0.203	0.283	0.674	0.101	0.176	0.184	0.200
					(0.425)	(0.421)	(0.581)	(0.830)	(0.226)	(0.259)	(0.346)	(0.345)
RL						–0.096	0.392	0.255	0.051	–0.761**	–0.408	0.072
						(0.094)	(0.405)	(0.493)	(0.127)	(0.576)*	(0.275)	(0.025)
HL							–0.138	–0.501	–0.108	0.288	0.398	–0.07
							(0.236)	(–0.095)	(0.088)	(–0.187)	(0.094)	(–0.070)
SL								0.346	–0.021	–0.346	–0.675*	0.202
								(0.595)	(–0.005)	(0.298)	(0.769)**	(0.170)
R:S									0.008	–0.124	–0.115	0.334
									(0.171)	(0.497)	(0.438)	(0.364)
DM										0.133	–0.151	–0.384
										(–0.059)	(0.044)	(0.692)*
RLT											0.480	–0.028
											(0.481)	(–0.028)
SLT												0.237
												(0.237)

reported by Zapata et al. (2003) on *Lactuca sativa* and Chartzoulokis and Klapaki (2000) on pepper. Fooled and Lin (1999) reported that germination under salt stress can be used as a criterion for salt tolerance. Non-significant differences were recorded in mean germination time for cultivar JKMS-2. Furthermore, the rapid germination may contribute to salt tolerance to some extent.

The seeds of different genotypes of crops may germinate adequately under salt stress. Nevertheless, the seedling may not be fully established for further growth. Differential inhibition in the root length, shoot length as well as hypocotyl was observed in the present investigation. This phenomenon has been also reported in triticale (Abdul Karim et al. 1992) and wheat (Raiaj-Ahmed et al. 2001; Kaya et al. 2008; El-Hendaway et al. 2011). These authors suggested that seedling parameters are the most important criterion for screening genotypes for salt tolerance at the early growth stages. The present study clearly showed that salinity had greater inhibitory effects on seedling growth than on germination, and there was substantial genotypic variation in salt tolerance among the mustard genotypes. The significant reduction in seedling growth by salinity may be attributed to the toxic effect of sodium chloride and unbalanced nutrient uptake by seedlings. These deleterious effects of salinity may result in a significant decrease in photosynthesis and increase in respiration rate leading to a shortage of assimilate to the developing organs, thus slowing down growth or stopping it entirely (El-Hendaway et al. 2005b). As salinity enhances osmotic pressure leading to reduction in water absorbance, cell division and differentiation are inhibited, which adversely affects metabolic and physiological processes. This causes more delay in initiation of germination followed by prolonged seed germination duration (Kang, Saltvett 2002) and ultimately reducing plumule and radical length (Keshavarzi 2012). Similar results have been reported by Etesami and Galeshi (2008) for barley, Massai et al. (2004) for *Prunus* and El-Hendawy et al. (2011) for wheat.

Six genotypes had higher root tolerance index than shoot tolerance index indicating that shoots of these seedlings were more sensitive to salt stress than roots. Consequently, measurements derived from shoots are generally more effective screening criteria than those from roots, which may be due to osmotic adjustment occurring in roots more rapidly, and loss of turgour more slowly than shoots (Studer et al. 2007; Ferdose et al. 2009). These results

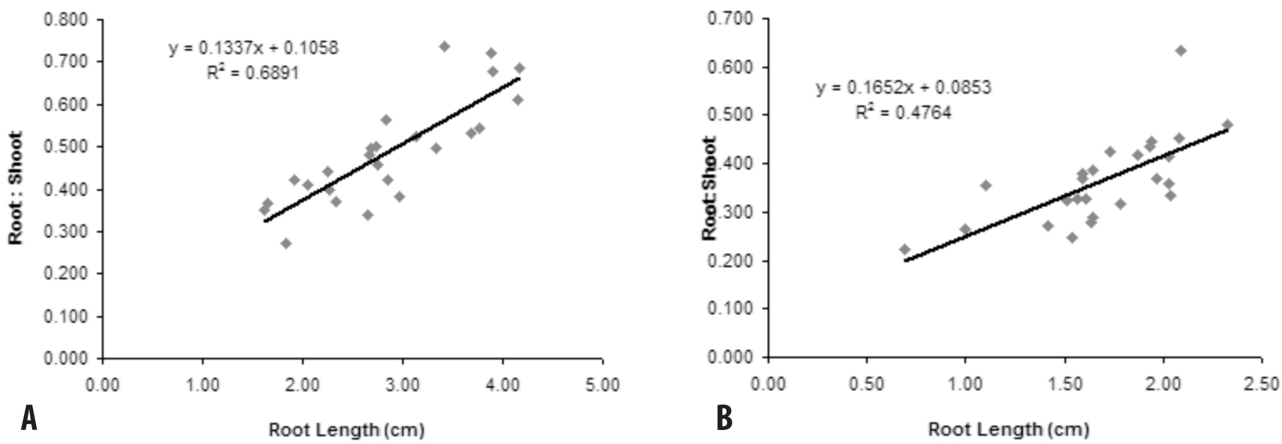

Fig. 1. Relationship between root length and root/shoot ratio under control (A) and saline (B) conditions in *Brassica juncea* genotypes.

were similar to the findings of Keiffer and Ungar (1997), Kaya et al. (2008) and Moud and Maghsoudo (2008), who showed that shoots of seedlings were more sensitive to salt stress than roots. In contrast, for other genotypes, root growth was more adversely affected by salinity than shoot growth, as indicated by higher shoot tolerance index than root tolerance index. These results are in accordance with findings from other studies (Rahman et al. 2001; Jamil et al. 2006; Ogawa et al. 2006; Rahim et al. 2012). Salt tolerance based on shoot length positively correlated with the dry matter tolerance index as well as salt tolerance efficiency.

Overall, it may be concluded that substantial variation in salt tolerance existed among the mustard genotypes at the seedling stage. Positive significant correlations were found between tolerance index for shoot length ($r = 0.769$), root length ($r = 0.576$) and dry matter ($r = 0.692$). Based on the results, genotypes RB-10 and PR-2004-2 (STE ≥ 83%) were identified as highly tolerant, RGN-48, JKMS-2 , SKM -450 and CS-610-5-25P (STE ≥ 60%) were characterized as tolerant and NDR-05-01, PBR 300, RK-05-01, NPJ-93, PDR -1188 and RGN-145 (STE ≥ 50%) as moderately tolerant genotypes to salinity. The other 13 genotypes were susceptible to salt stress. However, further study is necessary to assess whether these genotypes characterized as tolerant based on their responses to salt stress in initial growth stages, maintain their degree of salt tolerance till crop maturity.

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