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M. Yasin Ashraf, Kalsoom Akhtar, G. Sarwar, M. Ashraf

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Research article

Role of the rooting system in salt tolerance potential of different guar accessions

M. Yasin ASHRAF[a]*, Kalsoom AKHTAR[b], G. SARWAR[a], M. ASHRAF[b]**

[a] Stress Physiology Lab., Salinity and Environmental Management Division, Nuclear Institute for Agriculture and Biology, PO Box 128, Jhang Road, Faisalabad, Pakistan
[b] Dept. of Botany, University of Agriculture, Faisalabad, Pakistan

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Abstract – To examine the role of the rooting system in salt tolerance of 15 guar (*Cyamopsis tetragonoloba* L.) accessions collected from arid and semi-arid regions of Pakistan, a pot-culture experiment was conducted under natural conditions in a net house. The experiment comprised three salinity treatments, i.e., 3, 9 and 15 dS m^{-1}, with three replications. The results showed that whole plant dry weight, root length, root dry weight and number of nodules decreased due to salinity in all the accessions; however, different guar accessions showed variation in root length, dry weight and number of nodules under normal and stressed conditions. The root morphology revealed that accessions with a longer root, greater root dry weight and higher number of nodules had higher seed yield. A positive relationship was found between the rooting system and seed yield under salt stress. It is concluded that accessions with better rooting systems produced higher seed yield and were more salt-tolerant than others.

guar / root morphology / nodulation / seed yield / guar and soil salinity

1. INTRODUCTION

Salinity adversely affects the growth of most agricultural crops, with serious injury in legumes. This is due to a combination of disturbance in the host metabolism per se and development of a root system devoid of root hair, a mucilaginous layer and infection thread formation, as these plants rely heavily on the nitrogen fixed through nodulation in the presence of rhizobia (Sprent and Sprent, 1990; Shereen et al.,1998).

Guar (*Cyamopsis tetragonoloba* L.) is an annual summer legume crop of Pakistan and India. It is grown over an area of about 242.6 thousand hectares with seed production of 220.7 thousand tons annually on an average yield of 909.7 kg ha^{-1} (Anonymous, 2003). It is drought-tolerant and is grown as a vegetable for human consumption, forage for cattle, green manure for crops, and as a grain crop (Hymowitz and Matlock, 1964). Its seed is a rich source of agro-based industry to obtain galactomannin gum, which is used in food processing, paper manufacturing, textile printing, and the pharmaceutical and cosmetics industries (Alexander et al., 1988). It is a fast-growing crop of short duration, hence it fits nicely in most of the prevailing summer cropping systems. The endemic germplasm of guar appears to be diverse in nature, and has good adaptability to a wide range of environmental conditions of the country, including some cooler parts, too.

Limitation to the growth of guar on saline soil may be due to a number of environmental and ecological factors that affect the root development system and nodulation which have not been extensively studied. It has not yet been resolved whether salinity exerts a greater effect on the root system and nodulation, and if so, on rhizobia survival and the infection process on nodule function. Studies were, therefore, conducted to study the effect of salinity on plant growth, the rooting system and nodulation to assess which accession of guar performs better with what type of rooting and nodulation.

2. MATERIALS AND METHODS

The experiment was conducted under natural conditions in a net house of the Department of Botany, University of Agriculture, Faisalabad, Pakistan in earthen pots (with dia 30 cm, length 45 cm) containing 10 kg of air-dried soil (60% river sand and 40% field soil). The pots were lined with plastic sheet for

* Corresponding author: niabmyashraf@hotmail.com; niabmyashraf@yahoo.co.uk
** ashrafm@fsd.paknet.com.pk

Table I. Guar germplasm collected from southwestern Pakistan.

Accession No.	Accession Name	Sites of collection/district	Altitude (m)
1	BR-90	Bahawalpur	-
2	83/5 (a)	Hathilangar/Baluchistan	-
3	83/5 (b)	Hathilangar/Baluchistan	-
4	290/3	Tank/Khuzdar	570
5	286/8	Katagiri/Baluchistan	-
6	281/3	Shadikaur/Guadar	1000
7	239/2	Dera Pandwa/Baluchistan	-
8	242/3	Dhobricast/Baluchistan	-
9	272/4	Tajaban/Baluchistan	440
10	274/6	Dasht-e-Khudan/Baluchistan	60
11	279/1	Chalani/Baluchistan	60
12	277/2	Naloot/Turbat	45
13	260/6	Naal/Khuzdar	1000
14	291/3	Guttay Duff/Khuzdar	585
15	279/2	Chalani/Turbat	-

examining the root system and nodulation. The experiment consisted of 15 guar accessions collected from different agro-climatic zones of Pakistan; details are in our earlier publication (Ashraf et al., 2002) (Tab. I). The experiment comprised 15 guar accessions, three salinity treatments and three replications. The soil samples were taken and analyzed for pH (7.49), (electrical conductivity) EC (3.0 dS m^{-1}), (sodium adsorption ratio) SAR (7.0), (exchangeable sodium percentage) ESP (8.3), saturation percentage (29.85), physical and chemical properties i.e., soil texture was determined by the hydrometer method (Dewis and Freitas, 1970), electrical conductivity of the saturation extract (by Conductivity meter LF 538, WTW, Germany), pH (pH meter 530, WTW, Germany), and HCO_3 and Ca+Mg were determined according to Jackson (1962). Sodium and potassium contents were estimated flame-photometrically. All the soil characteristics are summarized in Table Ib. The SAR and ESP of the 9 dS m^{-1} treatment at the time of harvest were 29.93 and 30.07, respectively. Similarly, the SAR and ESP of the 15 dS m^{-1} treatment were 55.16 and 44.87, respectively.

The salinity levels 3 (T_1), 9 (T_2) and 15 (T_3) dS m^{-1} were maintained with the addition of NaCl. Seeds of each accession of guar in each pot were sown and tap water with salt concentration of 1 dS m^{-1} was used for irrigation. Before maturity the plants were harvested. Fresh and dry weights of the root, root length, number of nodules and whole plant dry weight were recorded. The percent reduction over control was estimated by using the following formula:

$$\text{\% reduction over control for } (T_2)\ 9 \text{ dS m}^{-1} = [(T_1 - T_2/T_1) \times 100]$$

$$\text{\% reduction over control for } (T_3)\ 15 \text{ dS m}^{-1} = [(T_1 - T_3/T_1) \times 100].$$

Root morphology was also recorded by tracing an exact copy of the roots, holding the roots on a transparent piece of glass with drawing paper on the other side of the glass. With the help of electric light, the image of the root was traced with a fine black pencil. At maturity, seed yield per plant was recorded. All the data recorded were statistically analyzed and the (Duncan's Multiple Range Test) DMRT test was used to compare the treatment and accession means (Steel and Torre, 1980).

3. RESULTS AND DISCUSSION

The soil characteristics show that it is a normal type of soil with normal pH (7.49), sodium adsorption ratio SAR (7.00) and exchangeable sodium percentage ESP (8.30), which did not influence the root growth. However, the EC_e (electrical conductivity of saturated paste of soil) of the soil was slightly higher than that of normal soils, even though it was classified as normal because the lower limit of the saline soils starts from EC 4 dS m^{-1}.

The root length was significantly reduced by increasing salinity levels in all guar accessions (Tab. II). At 9 dS m^{-1}, accession 279/2 showed the minimum reduction over control in root length (5.35%), while the maximum was in 279/1 (62.89%). The performance of accessions 281/3 and 239/2 was also comparable under 9 dS m^{-1} as the percent reduction in their root lengths was 10.83 and 13.90, respectively. At the highest salinity level (15 dS m^{-1}) the minimum reduction in root length was recorded in accession 281/3, which was closely followed by accessions 239/2 and 291/2.

Number of nodules per plant decreased with the progressive increase in salinity. Under the first salinity level (9 dS m^{-1}) the maximum reduction over control in number of nodules was recorded in accession 83/5(b) (38.46%), while the minimum was in accession 272/4 (15.38%). Accessions 83/5(a), 242/3 and 272/4 had a similar reduction in number of nodules at 9 dS m^{-1} (Tab. III): 16.67, 16.67 and 15.38%, respectively, but these values were the minimum of those of all accessions. Under all salinity levels, accession 272/4 performed better than the other accessions by showing the minimum reduction in number of nodules. At the highest salinity level (15 dS m^{-1}), the minimum reduction was recorded in accession 272/4 (23.07%) and the maximum was in accessions 291/3 and 279/2 (60%).

Root dry weight was also decreased significantly due to salinity in all guar accessions (Tab. IV). At salinity level 9 dS m^{-1}, the maximum reduction in root dry weight was recorded in accession 83/5(a) (77.78%), and the minimum in accession 279/1 (1.39%). The performance of accessions 277/2 and 274/6 is also quite comparable, because both accessions also showed lower reduction (6.89 and 9.62%, respectively) than the other accessions. Under the 15 dS m^{-1} salinity level, the minimum reduction in root dry weight was recorded in accession 281/3 (28.09%), while the highest was in accession 83/5(a) (82.40%) (Tab. IV).

The root morphology (Fig. 1) showed that all the accessions performed differently under varying salinity levels. The accessions which produced higher whole plant and root biomass also had longer roots than the others. Accession 281/3 showed a higher degree of salt tolerance due to its higher root dry weight and root length than the others.

Table II. Effect of different levels of NaCl salinity on root length of different guar accessions.

Accession No.	Salinity levels – dS m^{-1}					
	3.0	9.0	15.0	9.0	15.0	Mean
	Root length (cm)			% reduction over control		
BR-90	16.63	10.30	5.90	38.06	64.52	10.94 b
83/5 (a)	18.67	9.70	5.10	48.05	72.68	11.16 c
83/5 (b)	14.37	9.13	6.43	36.46	55.25	9.98 e
290/3	23.10	10.17	5.50	56.00	76.19	12.92 r
268/8	9.40	6.47	4.53	31.17	51.80	6.80 n
281/3	14.93	10.83	9.90	**10.83**	**33.69**	11.88 c
239/2	10.50	9.07	6.90	**13.90**	**34.29**	8.82 i
242/3	30.14	10.70	7.73	64.50	74.35	16.19 a
272/4	8.50	4.80	1.47	43.52	82.70	4.92 q
274/6	9.40	7.47	5.40	20.53	42.55	7.42 k
279/1	11.67	4.33	63.60	62.89	69.15	6.53 n
277/2	11.90	7.33	6.33	38.40	46.80	8.52 h
260/6	9.00	7.37	5.30	18.11	41.11	7.22 i
291/3	10.87	7.50	6.93	31.00	**36.32**	8.43 h
279/2	7.47	7.07	4.20	**5.35**	43.77	6.24 o
Mean	13.77 a	8.10 b	5.73 c			
Percent decrease		41.17	58.38			

Means sharing same letters do not differ significantly at the 5% level of significance according to DMRT.

Table III. Effect of different levels of NaCl salinity on number of nodules per plant of different guar accessions.

Accession No.	Salinity levels – dS m^{-1}					
	3.0	9.0	15.0	9.0	15.0	Mean
				% reduction over control		
BR-90	9.67	7.33	4.33	24.19	55.22	7.11 hi
83/5 (a)	12.00	10.00	7.00	**16.67**	41.66	9.67 e
83/5 (b)	13.00	8.00	5.33	38.46	59.23	8.78 f
290/3	15.33	12.33	9.67	19.57	**36.93**	12.44 a
268/8	13.00	10.00	7.00	23.08	46.15	10.00 d
281/3	15.00	12.00	10.67	20.00	**28.86**	12.55 a
239/2	11.00	7.00	5.00	36.36	54.54	7.67 g
242/3	12.00	10.00	6.33	**16.67**	47.25	9.44 e
272/4	13.00	11.00	10.00	**15.38**	**23.07**	11.33 b
274/6	14.00	9.00	6.00	35.71	57.12	9.67 e
279/1	13.00	10.00	6.00	23.08	53.84	9.67 e
277/2	10.00	7.00	5.00	30.00	50.00	7.33 h
260/6	8.67	6.67	4.00	23.07	53.86	6.44 j
291/3	10.00	8.00	4.00	20.00	60.00	7.33 h
279/2	10.00	7.00	4.00	30.00	60.00	7.00 i
Mean	11.98 a	9.02 b	6.28 c			
Percent decrease		24.70	47.57			

Means sharing same letters do not differ significantly at the 5% level of significance according to DMRT.

Induced salinity significantly reduced the whole plant dry matter in all the guar accessions (Tab. VI). At 9 dS m^{-1} the maximum reduction in dry matter (38.82%) was observed in accession 83/5(a) and less than 20% was in accessions 268/8 (11.46%), 242/3 (15.23), 281/3 (15.99) and 277/2 (17.91). While under the highest salinity level (15 dS m^{-1}), only accession

Table IV. Effect of different levels of NaCl salinity on root dry weight of different guar accessions.

Accession No.	Salinity levels – dS m^{-1}					
	3.0	9.0	15.0	9.0	15.0	Mean
	Dry weight (g)			% reduction over control		
BR-90	0.53	0.25	0.11	52.83	79.24	0.30 i
83/5 (a)	1.08	0.24	0.19	77.78	82.40	0.50 de
83/5 (b)	0.45	0.24	0.18	46.66	60.00	0.29 i
290/3	0.84	0.53	0.13	36.90	84.52	0.50 de
268/8	0.79	0.51	0.41	35.44	48.10	0.38 gh
281/3	1.21	0.89	0.87	26.45	**28.09**	0.97 a
239/2	1.09	0.66	0.50	39.45	54.12	0.62 b
242/3	1.06	0.38	0.22	64.15	79.24	0.55 cd
272/4	0.66	0.33	0.12	50.00	81.81	0.37 h
274/6	0.52	0.47	0.22	**9.62**	57.69	0.40 fgh
279/1	0.73	0.72	0.21	**1.39**	71.23	0.57 bc
277/2	0.29	0.27	0.11	**6.89**	62.07	0.22 j
260/6	0.82	0.24	0.34	70.73	58.53	0.46 ef
291/3	0.19	0.16	0.06	15.79	68.42	0.13 k
279/2	0.70	0.39	0.21	44.29	70.00	0.44 fg
Mean	0.73 a	0.39 b	0.42 c			
Percent decrease		46.57	67.12			

Means sharing same letters do not differ significantly at the 5% level of significance according to DMRT

Table V. Effect of different levels of NaCl salinity on seed yield per plant of different guar accessions.

Accession No.	Salinity levels – dS m^{-1}					Mean
	3.0	9.0	15.0	9.0	15.0	
		Seed yield (g $plant^{-1}$)			% reduction over control	
BR-90	2.56	2.50	1.22	2.34	52.34	2.09 hi
83/5 (a)	2.65	2.03	1.83	23.40	30.94	2.17 gh
83/5 (b)	2.68	2.49	1.97	**7.08**	**26.49**	2.38 f
290/3	2.85	2.72	2.11	**4.56**	**25.96**	2.56 eg
268/8	2.02	1.98	1.63	**1.98**	39.00	1.87 k
281/3	3.71	3.18	2.82	14.29	**23.98**	3.23 a
239/2	3.33	2.93	2.32	12.01	30.33	2.86 d
242/3	3.18	2.98	1.85	**6.28**	41.82	3.00 c
272/4	2.98	2.82	1.92	**5.37**	35.57	2.57 e
274/6	3.39	3.06	1.87	9.73	44.83	2.77 de
279/1	3.04	2.68	1.93	11.84	36.51	2.55 e
277/2	2.88	2.34	1.90	18.75	34.02	2.37 f
260/6	2.84	1.96	1.26	30.98	55.63	2.02 ij
291/3	2.96	2.10	1.56	29.05	62.83	2.21 g
279/2	2.79	1.81	1.22	35.13	56.27	1.94 jk
Mean	2.94 a	2.43 b	1.82 c			
Percent decrease		16.89	37.75			

Means sharing same letters do not differ significantly at the 5% level of significance according to DMRT.

281/3 was successful at maintaining the minimum reduction (27.19%) in whole plant dry matter, while the reduction was maximum in accessions 291/3 (64.52%) and 83/5 (a) (64.14%).

Seed yield per plant was significantly reduced due to salinity (Tab. V). Under 9 dS m^{-1} the maximum yield reduction (35.13%) was recorded in accession 279/2, while the lowest

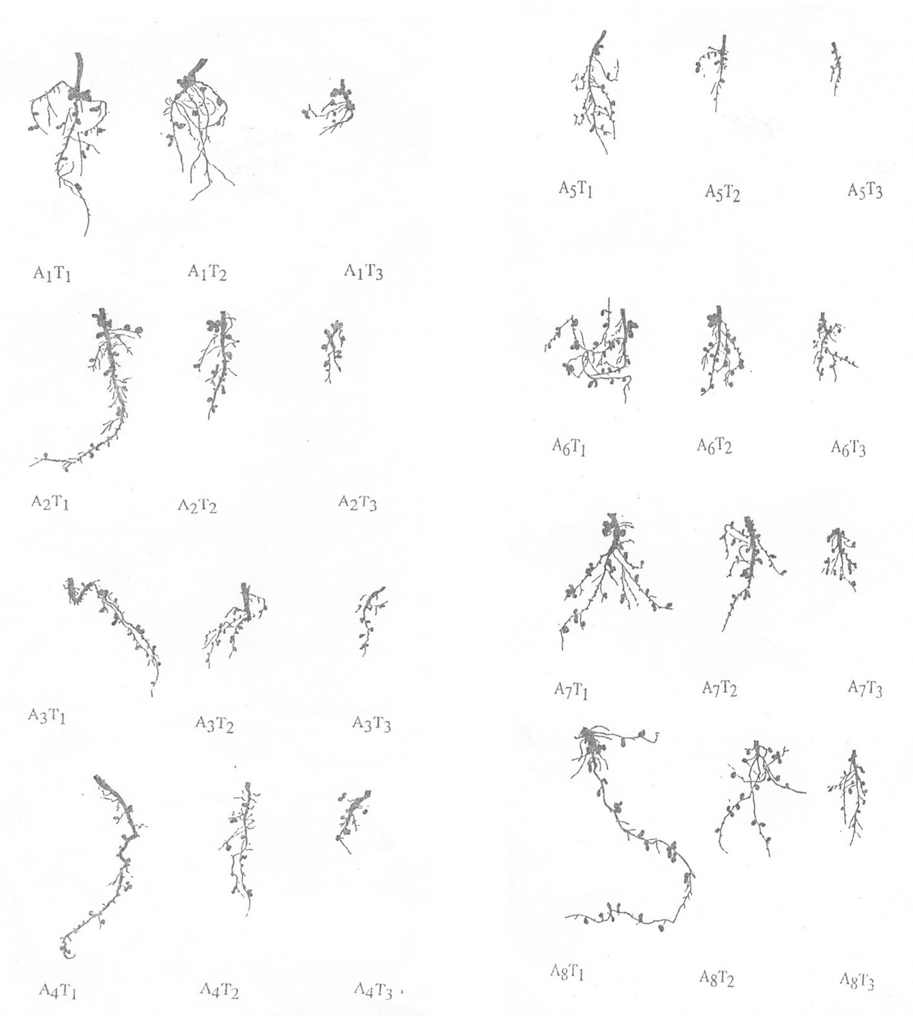

Figure 1. Effect of different levels of NaCl salinity on root morphology of different guar accessions. Note: A_1 = Accession No. 1, T_1 = 3 dS m^{-1}, T_2 = 9 dS m^{-1}, T_3 = 15 dS m^{-1}, A_1T_1 = Accession 1 under 3 dS m^{-1}, A_1T_2 = Accession 1 under 9 dS m^{-1}, A_1T_3 = Accession 1 under 9 dS m^{-1}. Same for other accessions.

reduction (1.98%) was observed in 268/8 followed by accessions 290/3 (4.56%), 272/4 (5.37%) and 83/5(b) (7.08%). Under the highest salinity level, the best performing accession was 281/3 (23.98%) followed by 290/3 (25.96%) and 83/5 (b) (26.49%). Accession 291/3 showed poor performance, because the maximum reduction in seed yield was shown by this accession.

The growth of roots varies widely due to soil conditions because the status of all nutrients in plants is maintained from the soil with the help of roots. The root growth rate (root dry weight + root length) is severely affected by saline soils and reduction may even be recorded in salt-tolerant plants (Ashraf and Khan, 1993; Zaiter and Mahfouz, 1993; Ashraf et al., 1999a; Qureshi et al., 2000). However, the reduction in growth was more pronounced in the salt-sensitive cultivars of rice, wheat and guar (Ashraf and Ali, 1998; Ashraf et al., 1999a,b; Ashraf et al., 2002). The results of the present study (Tab. VI) confirm this statement. Accession 281/3 performed better than the others in growth and maintained the highest root length and root dry weight at the highest salinity level. Number of nodules per plant was more severely affected by salinity than the root growth of the plants. Number of nodules, dry weight of root, root length and yield decreased significantly with an increase in the salinity level. Salinity has generally been reported to inhibit the process of nodulation and nitrogen fixation, the effects vary with types and levels of salinity, stage of growth and development, and crop species (Rommi et al., 1994; Ashraf and Naqvi, 1996). In the present study, a smaller number of nodules, a shorter root, and less root dry weight could have been a consequence of poor plant growth. A very strong positive correlation was found between root length, root dry weight and yield per plant. The accessions with higher root fresh and dry weights and longer roots produced higher seed yield. However, information on root adaptability to saline conditions in the literature is scant.

The present work on root morphology provides strong evidence that the accessions with higher biomass have a longer and

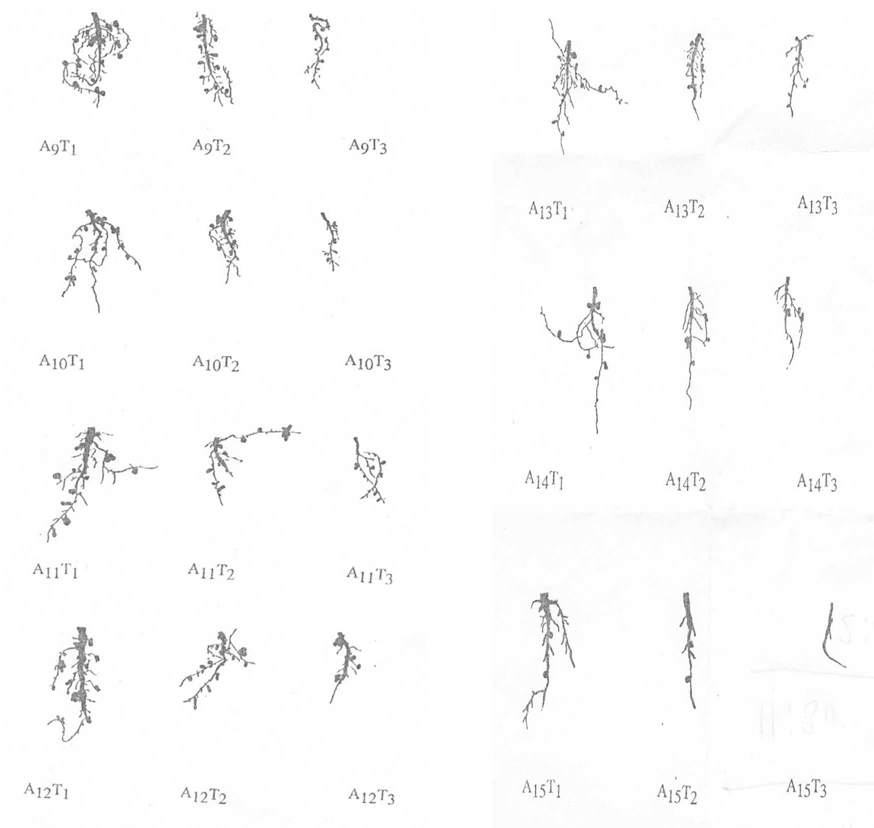

Figure 2. Effect of different levels of NaCl salinity on root morphology of different guar accessions. Note: A_1 = Accession No. 1, T_1 = 3 dS m^{-1}, T_2 = 9 dS m^{-1}, T_3 = 15 dS m^{-1}, A_1T_1 = Accession 1 under 3 dS m^{-1}, A_1T_2 = Accession 1 under 9 dS m^{-1}, A_1T_3 = Accession 1 under 9 dS m^{-1}. Same for other accessions.

Table VI. Effect of different levels of NaCl salinity on whole plant dry weight of different guar accessions.

Accession No.	Salinity levels – dS m^{-1}					Mean
	3.0	9.0	15.0	9.0	15.0	
	Plant dry weight (g $plant^{-1}$)			% reduction over control		
BR-90	6.45	4.49	3.62	30.39	43.88	4.85 d
83/5 (a)	4.74	2.90	1.70	38.82	64.14	3.11 e
83/5 (b)	8.16	5.51	3.69	32.47	54.78	5.79 cb
290/3	7.49	5.24	3.19	30.4	57.41	5.31 d
268/8	5.76	5.10	2.88	**11.46**	50.00	4.58 d
281/3	9.38	7.88	6.83	**15.99**	**27.19**	8.03 b
239/2	6.67	5.13	4.34	23.09	34.93	5.38 d
242/3	12.15	10.3	8.00	**15.23**	34.16	10.15 a
272/4	8.79	6.47	5.12	26.39	41.75	6.79 cb
274/6	7.59	5.75	4.01	24.24	47.17	5.78 cb
279/1	9.17	7.24	6.20	21.05	32.39	7.54 b
277/2	7.48	6.14	3.14	**17.91**	58.02	5.59 cb
260/6	5.85	4.40	3.86	24.78	34.02	4.70 d
291/3	7.47	5.19	2.65	30.52	64.52	5.10 de
279/2	6.12	4.39	2.28	28.27	62.74	4.24 de
Mean	7.55 a	5.74 b	4.10 c			
Percent decrease		23.97	45.69			

Means sharing same letters do not differ significantly at the 5% level of significance according to DMRT.

stronger rooting system, which plays a key role in osmotic adjustment under saline conditions (Khanzada et al., 2001). Salinity stress not only causes ion toxicity but also creates drought conditions for plants by decreasing soil osmotic potential. The plants with longer roots are capable of absorbing more water from far below the salinity zone. Roots are directly in contact with soil salinity and are potentially the first line of defence, i.e., salinity inhibits the long-term root growth and disturbs the mineral nutrition of plants (Khan et al., 1992; Cramer, 1994; Kamal et al., 2003). Under saline conditions, depletion of O_2 deprives the plant of its primary energy sources, and thus root growth declines. Accumulation of high levels of internal ethylene under stressed conditions can inhibit root elongation (Konings and Jackson, 1979). Decreased root length may lead to yield losses in legumes (Noble and Rogers, 1994), The salt-tolerant accession 281/3 of guar might have developed osmoregulatory mechanisms (Ashraf et al., 1994), hormonal balance and ion exchange to minimize the adverse effects of salinity on root growth. The data of the present study for guar are consistent with those of Kumar et al. (1988), who observed a decrease in root growth of guar with a progressive increase in salt stress.

4. CONCLUSION

From the present study it can be concluded that roots played a basic role in salt tolerance of plants. Plants with better root growth are tolerant to salinity and produce more yield/productivity under saline conditions.

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