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Salt Tolerance of *Sorghum bicolor* Cultivars during Germination and Seedling Growth

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Sorghum is rated as moderately salt tolerant and can produce profitable crops on saline soils. This study was conducted to evaluate the effect of salinity on the germination and emergence of sorghum cultivars, and to investigate the potential for genetic salt tolerance during the germination and early vegetative growth. Seeds of 13 sorghum cultivars were germinated using U.S.S. lab staff saline solution at 5 different salt concentrations for 10 days. Germination percentage, root and shoot length, seedling dry weight, root/shoot dry weight ratio, and total dry weight salt susceptibility index were investigated in this study. The germination results revealed that the increasing salt concentrations decreased germination and seedling growth in all the cultivars. The extent of decrease varied with cultivars and salt concentrations. All cultivars germinated in all salinities but at 10 and 12 EC level of salinity, the highest and lowest germination percentage was obtained for CSV-15 and PANT-1cultivars respectively. It is found that salt stress significantly decreased root length, shoot length, and seedling dry weight of sorghum cultivars. In the presence of high salt concentration (10 and 12 EC), CSV-15 and HC-171 cultivars showed the greatest shoot length, root length, and total dry weight. At the first development stage, the shoot growth of sorghum cultivar was more adversely affected compared to the root growth by salt stress. Statistical analysis showed substantial intra-specific variation in salinity tolerance. On the basis of germination percentage, total dry weight reduction, root and shoot length reduction, and salt susceptibility indices at 7.2, 10, and 12 EC levels of salinity only three sorghum cultivars (CSV-15, HD-19, and HC-171) out of thirteen were classified as salt tolerant. On the other hand sensitivity against salinity was observed in PANT-1, PANT-2, HC-308, HC-513, and HC-260 and so, these are grouped under salt sensitive group. Based on the results of the experiment, CSV-15, HD-19 and HC-171 can be useful as genetic resources for the development of sorghum cultivars with improved germination under salt stress.

Keywords: sorghum, germination, salinity, seedling growth.

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) belongs to the grass family and was domesticated in different areas of Africa. It is a major crop of the world with various uses. Sorghum was grown primarily as a source of sugar for syrup and is normally used animal feed. Sorghum is known to be an annual C_4 plant of African (tropical) origin and is well adapted to semiarid and arid tropic regions, being highly biomass productive and water efficient. It is the fifth most important cereal crop in the world after wheat, rice, corn and barley. Sorghum possesses a variety of anatomical, morphological, and physiological features that enable it to survive in water-limited environments[1]. Sorghum is a salt tolerant crop. It is more tolerant of salinity than maize but is less tolerant than barley.

Salinity is the most important environmental factor affecting the crop production in many parts of the world. Salinity has reached a level of 19.5% of all irrigated land and 2.1% of dry-land agriculture worldwide[2]. Salinity reduces the ability of plants to utilize water and causes a reduction in growth rate, as well as changes in plant metabolic processes[3-4]. One of the reason of salinity is the high concentration of cations such as sodium, calcium and magnesium whereas chloride, phosphate and nitrate as anions. The effect of salinity on plant growth is a complex trait that involves osmotic stress, ion toxicity, mineral deficiencies, physiological and biochemical perturbations[3-7]. Salinity creates the specific problem of ion toxicity, because a high concentration of sodium is injurious for the cells. The toxic effects of salt can occur at relatively low concentrations, depending on the plant species, so the homeostasis of sodium is important for the tolerance of organisms to salt stress.

The plants that grow in saline soils have diverse ionic compositions and a range in concentrations of dissolved salts. Seed germination in salt affected soils is influenced by the total concentration of dissolved salt as well as by the type of salt involved. Several studies such as genetic variability of cultivated Phaseolus bean cultivars exposed to salinity at germination stage, seedling stage and early vegetative growth have been conducted[8-9]. For sorghum, it has been observed that salt stress reduce leaf growth rate, leaf emergence rate, and overall shoot development[10]. The response of plant growth, ion concentrations of roots, shoots, leaf blades, and sheaths of two sorghum varieties in relation to NaCl salinity has been studied by[11]. They found that the increasing NaCl concentration significantly reduced the relative shoot growth rate and shoot dry weight. Leaf water potential, osmotic potential, leaf pressure potential, and relative water content also declined significantly with increasing salt stress.

The overall effect of salinity on plants is the eventual shrinkage of leaf size, which leads to death of the leaf, and finally the plant. Salinity may also cause reduced ATP and growth regulators in plants. The ability of plants to survive and maintain their growth under saline conditions is known as salt tolerance. There is a continuous spectrum of plant tolerance to saline conditions ranging from glycophytes that are sensitive to salt, to halophytes which survive in very high concentrations of salt. In order to identify the salinity tolerance of plants, the most commonly used characters are yield, survival, vigor, leaf damage, and plant height. Hence, the growth and yield are measured as determinants of salt stress[12]. Other indices of tolerance have been proposed which are based on specific physiological characteristics, for instance, accumulation of a specific ion in shoots or leaves, or the production of a specific metabolite.

The objectives of the present study were to evaluate the effect of the salinity on the germination and early seedling growth of[13] sorghum genotypes widely grown in India, to determine the germination and emergence ability of these cultivars under the saline irrigation regime, and to determine their potential for salt tolerance during germination and seedling growth. The degree of intra-specific variation for salinity tolerance had also been investigated.

Material and Methods

Plant Material: The following 13 genotype of cultivated *Sorghum bicolor* species namely PANT-1, PANT-2, PANT-3, PANT-4, PANT-5, PANT-6, CSV-15, HD-19, HC-171, HC-308, HC-513, and HC-260 were evaluated for their salinity tolerance. Seeds of 13 different genotype of *Sorghum bicolor* were provided by sorghum breeders of I. G. F. R. I., Jhansi, CCS Agriculture University, Hissar (Haryana) and G. B. Pant Agriculture and Technology University, Pantnagar, Uttaranchal.

Plant Growth and Salinity Conditions: In order to analyze the salinity tolerance of sorghum genotypes, a Petri plate experiment was conducted in laboratory with 3 replications including 5 levels of salinity during June, 2005. For this purpose, 3″ diameter sized Petri plates were thoroughly washed and sterilized in hot air oven at 70^0C for 36 hours. These Petri plates were lined with sterilized filter paper and moistened with 10ml of saline water (3, 6, 7.2, 10, 12 dS/m). Saline water for germination medium was prepared by mixing the salts of NaCl, Na_2SO_4, $NaHCO_3$, $CaCl_2$, as described by the U.S saline laboratory staff (1954). Control sets were moistened with equal amount of distilled H_2O. Before germination, seeds of *Sorghum bicolor* (L.) Moench were immersed for 60 s in 1% of $HgCl_2$ solution and then repeatedly washed and dried in a dry air flow at 25^0C. Successively, 20 seeds of each genotype were placed at equidistant on the filter paper in the Petri plates and moistened with 10 ml of saline water. The Petri plates were kept at 30^0C in BOD incubator. After imbibitions, the germination counts were made in each petri plates. To assess the effect of salinity on seedling growth, three samples of seedling were collected randomly 10 days after moistening in each Petri plates. The sampling was done in triplicate. The observations were recorded on the length of shoot and root. The fresh weight of shoot and root were noted in all replications and then parallel plant samples were kept at 60^0C in hot air oven for 48 h. The dry weight of shoot and root were taken of the corresponding samples.

Statistical Analysis: The data obtained from laboratory experiment were analyzed statistically for analysis of variance using the GLM procedure of the Minitab-14 Statistical package (Minitab Inc., State College, PA). Means were separated using the least significant difference (LSD) test at 5% level. For statistical comparisons the LSD (0.05) value has been used to compare the difference between any combination of two means within a table or figure. Percentage of reduction (PR) due to salinity stress in relation to the control (NS, non-stressed) environment was determined for all traits. The salinity intensity index (SII), SII = $1-X_{SS}/X_{NS}$, where X_{SS} and X_{NS} the mean of all genotype under salinity stress (SS) and non-stressed (NS) environment, and salt susceptibility index (SSI), SSI = $(1-Y_{SS}/Y_{NS})/SII$, where Y_{SS} and Y_{NS} are the mean of a given genotype in SS and NS environment respectively, were also calculated for total dry weight. The index of salinity tolerance provides data on the relative effects of increasing salt concentration on each genotype. A critical difference (CD) was constructed when F-tests indicated statistically significant differences between genotypes using the method described by[13] at P = 0.05.

Results and Discussion

Effect of Salinity on Germination: The germination percentage (P) of the 13 genotypes of Sorghum bicolor is plotted as a function of salt concentration in figure 1.

Analysis of variance exhibits significant differences among the sorghum genotypes for germination percentage. Our results indicated that the germination of Sorghum bicolor genotypes was adversely affected by all salinity treatments. Figure 1 indicates that the percent germination generally decreased with increasing salt concentration and degree of reduction varied with the salinity levels and genotypes of sorghum. Remarkable reduction in germination percent was observed at higher levels from 7.2 to 12 dS/m of salt concentrations as compared to control. Tolerance of the sorghum genotypes against salinity stress showed marked differences. In the case of CSV-15 and HC-171, germination response at 3 dS/m salinity level was not significantly different to control. The average of germination percentage for all genotypes has been found approximately equal to 91, 84, 73, 66, 54, and 36% at control, 3, 6, 7.2, 10, and 12 dS/m levels of salinity respectively. At 3 dS/m salinity level, the germination in PANT-3, PANT-5, PANT-6, CSV-15, and HC-171 is more than 90% whereas in PANT-1, PANT-2, PANT-4, HD-19, HC-308, HC-136, HC-513, and HC-260 the germination varied between 70 and 85%. As salt concentration increases from 3 to 6 dS/m, all sorghum genotypes showed significant differences in germination. The sorghum genotypes such as CSV-15, PANT-3, HC-171, and PANT-6 showed tolerant behavior, while HD-19 and HC-308 exhibited moderately tolerant behavior and rest of the genotypes seemed to be salt sensitive at 6 dS/m salt concentration. Sorghum genotypes such as HC-260, HC-513, HC-136, HC-308, PANT-5, PANT-4, PANT-2, and PANT-1 showed sharp decline in percentage germination while PANT-3, PANT-6, CSV-15, HD-19, and HC-171 exhibited marginal decrease at 7.2 dS/m salinity level. A large reduction was observed in PANT-1, PANT-2, PANT-4, and HC-260, whereas CSV-15 and HC-171 showed reduction in germination with respect to control as salt concentration increase from 10 to 12 dS/m (table 1). The other genotypes of sorghum such as PANT-3, PANT-5, PANT-6, HD-19, HC-308, HC-136 and HC-513 indicated moderate germination from 10 to 12 dS/m level of salinity. The results presented in table 1 also exhibited significant reduction in germination in PANT-1 and PANT-2 at lowest concentration and at highest concentration where germination was projected nearly to zero. Lowest germination percentage was observed in PANT-1 (20.2), whereas highest germination percentage was observed in CSV-15 (70.3) at 12 dS/m level of salinity.

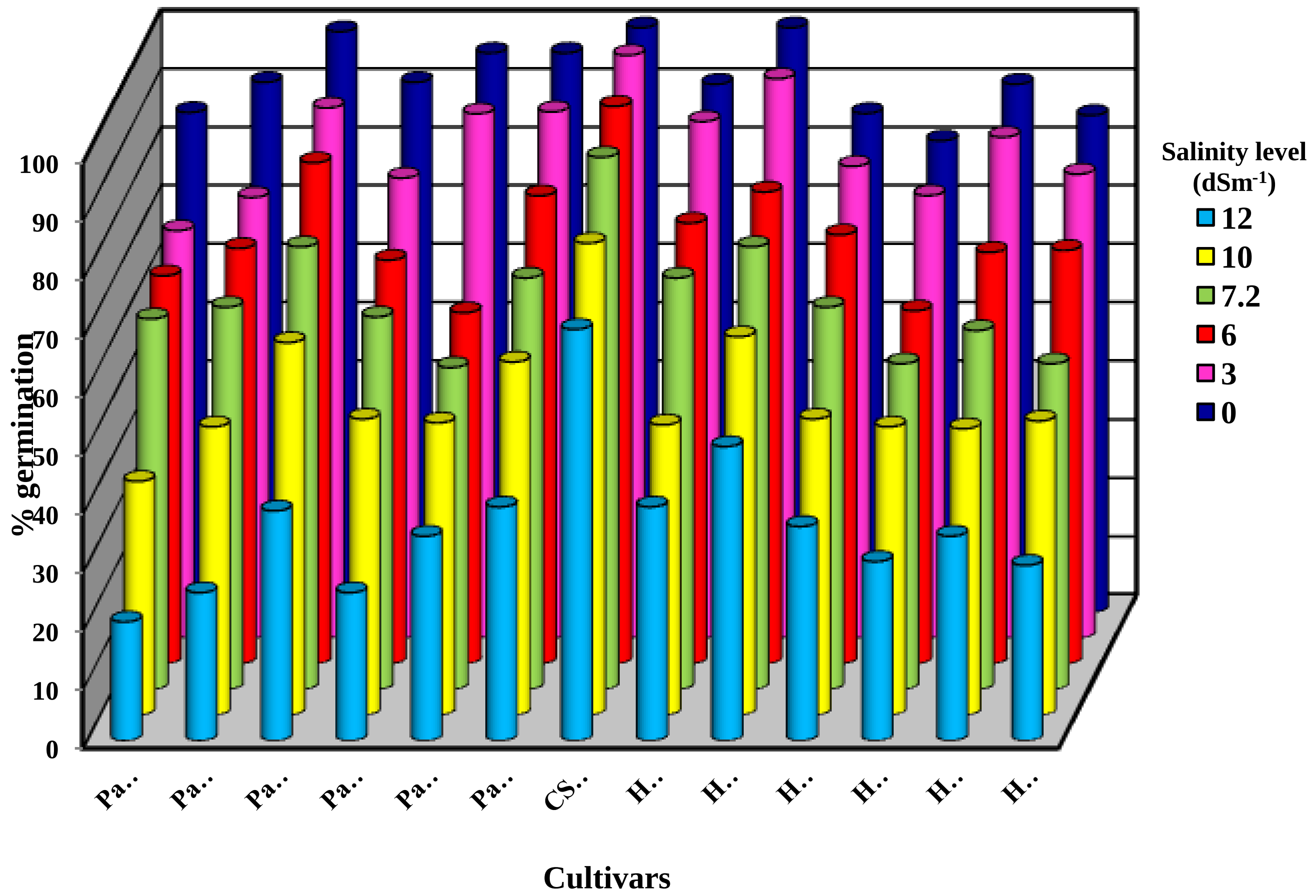

Figure-1

Effect of saline water irrigation on percentage germination at 10 dag in some sorghum cultivars

Table-1
Effect of salinity on germination percentage, shoot length, root length, shoot dry weight, root dry weight and SSI in total dry weight of Sorghum cultivars, 10 Days after Germination (DAG)

Varieties	Salinity (ds m^{-1})	% Germination (P)	Length (cm)		PR in length		Dry Weight (mg)		PR in dry weight		Root Shoot Ratio	PR in Germination	SSI in total dry weight
			Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot			
PANT-1	0	85.5	7.6	11.7			3.38	5.02			.67		
	3	70.3	5.3	7.8	29.8	33.3	2.36	3.31	30.0	34.0	.71	17.7	.061
	6	65.8	4.6	6.1	38.7	47.3	2.07	2.74	38.7	45.4	.75	23.0	.15
	7.2	63.4	4.1	5.1	45.7	55.9	1.91	2.23	43.5	55.5	.85	25.8	.29
	10	40.0	2.3	3.0	69.3	74.3	1.21	1.33	64.2	73.5	.90	53.2	.47
	12	20.2	1.6	1.5	78.0	86.6	0.81	1.02	76.0	79.7	.61	76.3	.64
CD at 5%			**0.329**	**0.437**			**0.12**	**0.052**					
PANT-2	0	90.7	8.0	12.5			4.87	7.03			.69		
	3	75.3	7.0	10.3	12.5	17.6	3.69	4.53	24.2	35.5	.81	17.0	.058
	6	70.7	4.6	8.3	41.8	33.6	2.07	3.71	56.5	47.2	.55	22.	.19
	7.2	65.4	3.0	3.7	62.5	70.4	1.23	2.18	74.7	68.9	.56	27.9	.41
	10	50.0	1.1	1.8	85.5	85.2	0.91	1.37	81.3	80.5	.44	44.8	.56
	12	25.3	1.01	1.1	87.3	91.2	0.61	0.84	87.5	88.0	.53	72.0	.71
CD at 5%			**0.72**	**0.41**			**.078**	**0.081**					
PANT-3	0	100	7.4	13.8			5.04	7.31			.68		
	3	90.8	5.3	12.6	28.4	8.7	2.31	7.01	54.1	4.1	.32	9.2	.046
	6	85.1	4.3	8.8	41.5	36.2	1.99	3.91	60.5	46.5	.50	15.0	.19
	7.2	75.6	3.6	4.4	50.5	68.1	1.91	2.71	62.1	62.9	.70	24.4	.36
	10	63.7	3.0	3.5	59.4	74.6	1.67	2.16	66.8	70.4	.77	36.3	.46
	12	40.1	1.9	2.1	74.3	84.8	0.87	1.08	82.7	85.2	.72	59.9	.67
CD at 5%			**0.636**	**0.707**			**.085**	**0.252**					
PANT-4	0	90.2	8.2	15.6			5.11	8.32			.61		
	3	80.6	6.4	14.6	21.6	6.4	3.39	7.96	33.6	4.3	.42	10.6	.03
	6	70.1	6.0	11.1	26.8	28.8	3.12	4.88	38.9	41.3	.63	22.2	.15
	7.2	65.8	3.3	9.0	59.4	42.3	1.82	3.98	64.4	52.1	.45	27.0	.33
	10	50.4	2.8	4.8	65.8	69.2	1.49	2.74	70.8	67.0	.54	44.0	.46
	12	25.0	1.7	1.8	79.2	88.4	0.81	1.26	84.1	84.8	.51	72.0	.68
CD at 5%			**0.337**	**0.573**			**.037**	**0.084**					
PANT-5	0	95.7	6.6	14.6			3.36	7.98			.42		
	3	90.2	5.3	12.6	19.9	13.7	2.33	7.02	30.6	12.0	.33	5.7	.03
	6	60.4	5.0	8.3	24.0	42.9	2.18	3.70	35.1	53.6	.58	36.8	.18
	7.2	55.5	4.6	6.8	30.0	53.4	2.09	2.86	37.8	64.1	.73	42.0	.32
	10	50.5	3.1	4.7	53.0	67.8	1.81	2.64	46.1	66.9	.68	47.0	.41
	12	35.3	1.9	2.6	71.2	82.2	0.87	1.65	74.1	79.3	.40	63.0	.63
CD at 5%			**0.386**	**0.625**			**0.36**	**0.365**					
PANT-6	0	95.4	7.0	15.6			3.64	8.33			.43		
	3	90.1	5.0	12.6	28.6	19.2	2.18	7.02	40.1	15.7	.31	5.5	.044
	6	80.6	4.3	10.6	38.1	32.0	1.98	4.09	45.6	50.9	.48	15.5	.18
	7.2	70.8	3.4	7.6	51.0	51.3	1.90	3.52	47.8	57.7	.53	25.7	.32
	10	60.6	2.6	5.8	62.0	62.8	1.37	2.43	62.3	70.8	.56	36.4	.46
	12	40.4	1.6	1.8	77.1	88.4	0.76	1.12	79.1	86.5	.46	57.6	.69
CD at 5%			**0.223**	**0.54**			**0.15**	**0.081**					
CSV-15	0	100	7.1	13.8			4.01	7.39			.54		
	3	100	6.3	13.5*	11.2	2.1	3.23	6.96	19.4	5.8	.46	0	**.02**
	6	95.8	6.3	11.8	11.6	14.2	3.19	6.33	20.4	14.3	.50	4.2	**.06**
	7.2	90.7	5.3	10.3	25.2	25.1	2.41	4.13	39.9	44.1	.58	9.3	**.25**
	10	80.6	4.6	8.7	34.6	36.5	2.11	3.91	47.3	47.0	.53	19.4	**.32**
	12	70.3	4.1	7.1	42.2	48.5	1.98	3.31	50.6	55.2	.58	29.7	**.43**

CD at 5%			**0.233**	**0.889**			**0.09**	**0.342**					
HD-19	0	90.5	14.6	17.5			6.04	9.33			.64		
	3	85.3	9.3	14.1	36.3	19.4	5.07	7.86	16.1	15.7	.64	5.7	**.03**
	6	75.7	7.0	12.6	52.2	27.6	3.71	7.01	38.5	25.8	.52	16.3	**.11**
	7.2	70.6	6.1	11.3	58.2	35.4	2.61	4.29	56.7	54.0	.60	22.0	**.32**
	10	50.3	5.5	9.3	62.5	46.8	2.48	3.97	58.9	57.4	.62	44.0	**.39**
	12	40.5	3.0	3.4	79.4	80.5	0.89	1.38	85.2	85.2	.42	55.0	**.69**
CD at 5%			**0.542**	**1.303**			**.056**	**0.069**					
HC-171	0	100	8.3	16.8			5.01	9.01			.55		
	3	95.8	6.8	15.3	17.6	8.9	3.79	8.37	24.3	7.1	.45	4.2	**0.025**
	6	80.4	5.3	14.0	36.0	16.6	3.27	7.81	34.7	13.3	.41	19.6	**0.077**
	7.2	75.3	4.9	11.8	41.0	29.6	3.01	4.37	39.2	51.5	.48	24.7	**0.31**
	10	65.7	4.6	10.0	44.0	40.4	2.78	4.11	44.5	54.4	.46	34.3	**0.38**
	12	55.2	4.4	8.9	46.9	46.5	2.27	3.98	54.6	55.8	.42	44.8	**0.47**
CD at 5%			**0.06**	**0.124**			**.093**	**0.143**					
HC-308	0	85.9	7.6	10.6			4.28	5.24			.81		
	3	80.6	5.2	9.0	30.9	15.0	2.69	3.91	37.1	21.4	.68	6.1	**.058**
	6	75.4	4.3	7.8	43.8	26.4	2.02	3.31	52.8	36.8	.61	12.2	**.16**
	7.2	65.6	2.2	3.5	70.8	66.9	1.19	1.36	72.2	70.0	.87	23.6	**.42**
	10	50.5	1.3	2.0	82.6	81.1	0.89	0.97	79.2	81.5	.59	41.2	**.57**
	12	35.3	0.96	1.3	87.3	87.7	0.61	0.74	85.7	85.8	.43	58.9	**.71**
CD at 5%			**0.112**	**0.856**			**.037**	**0.046**					
HC-136	0	80.4	6.3	9.8			3.23	3.98			.81		
	3	75.2	4.0	7.5	36.8	23.5	2.03	3.21	37.1	19.3	.63	6.4	.051
	6	60.3	2.8	4.3	55.3	56.1	1.52	2.69	52.9	32.4	.56	25.0	.15
	7.2	55.5	1.6	2.2	74.7	77.5	0.97	0.96	69.9	75.8	.68	30.9	.45
	10	50.4	1.03	1.9	83.7	80.6	0.89	0.84	72.4	78.9	.66	37.3	.55
	12	30.3	0.78	0.98	88.0	90.0	0.56	0.62	82.9	84.4	.58	62.3	.69
CD at 5%			**0.090**	**0.255**			**.040**	**0.064**					
HC-513	0	90.8	7.0	16.5			3.68	8.91			.41		
	3	85.2	6.3	14.8	9.6	10.3	3.31	7.98	10.0	10.4	.41	6.1	**.019**
	6	70.6	5.6	13.6	19.1	17.6	2.81	7.31	23.6	17.9	.38	22.2	**.072**
	7.2	60.6	4.6	8.1	33.4	50.9	1.78	3.72	51.6	58.2	.47	33.2	**.32**
	10	50.7	2.0	2.5	71.4	84.8	1.02	1.23	72.2	86.2	.82	44.0	**.56**
	12	35.3	0.91	1.8	87.0	89.0	0.71	0.91	80.7	89.7	.63	61.1	**.72**
CD at 5%			**0.174**	**0.299**			**.043**	**0.155**					
HC-260	0	85.4	6.5	8.6			3.31	3.89			.85		
	3	80.6	5.0	7.5	23.0	12.8	2.16	3.72	34.7	4.3	.58	5.6	**.034**
	6	70.1	3.0	7.0	53.8	18.6	1.72	3.01	48.0	22.6	.57	18.0	**.13**
	7.2	55.5	2.0	5.5	69.2	36.0	1.12	2.01	66.1	48.3	.55	35.0	**.33**
	10	50.3	1.0	4.0	84.6	53.5	0.84	1.65	74.6	56.8	.33	41.0	**.47**
	12	30.6	0.95	1.2	85.3	86.0	0.74	0.87	77.6	77.6	.32	64.0	**.67**
CD at 5%			**0.244**	**0.964**			**.166**	**.136**					

Effect of Salinity on Seedling Growth: The experiment was conducted to observe the influence of salinity on the seedling growth of sorghum genotypes. The results obtained indicate that increasing salt concentration caused delayed emergence of plumule and redicle as compared to control. At the early seedling stage, PR (percentage reduction) in root length, shoot length, root dry weight, and shoot dry weight, root shoot ratio of dry weight, and SSI (Salt Susceptibility Index) for total dry weight clearly demonstrated genetic variation in vegetative growth responses to salinity among sorghum genotypes. Salinity stress significantly affects root length, shoot length, root dry weight, shoot dry weight, and root shoot ratio for all genotypes of sorghum. The average length of root and shoot for 13 genotypes of sorghum shows a strong inhibition with the increasing salinity levels particularly at high salt concentration (7.2 to 12 dS/m). Figures 2a and 2b indicate that the reduction of root and shoot growth in PANT-2, HC-308, HC-136, and HC-513 was highest in comparison with HC-171, CSV-15, and HD-19 at 7.2, 10 and 12 dS/m salinity levels. These results showed sign of great inhibition of shoot and root growth with salt treatments. The percentage reduction in shoot length was more pronounced in PANT-1, PANT-2, PANT-3, PANT-4, PANT-5, PANT-6, CSV-15, HC-136 and HC-513 compared to reduction in root length at highest salt concentration. The PR in root length was more marked in four genotypes *i.e* shoot growth was more effected than root growth at increasing salt concentration. HD-19 had more length of root and shoot as compared to other genotypes. It showed tolerant behavior up to 10 dS/m but growth sharply declined thereafter. At 6 dS/m PR in root length were more prominent in PANT-2, HD-19, HC-

308, HC-136, and HC-260 than rest of the genotypes. Higher percentage reduction in shoot length was also recorded in PANT-1, PANT-3, PANT-5 and HC-136 at 6 dS/m salt concentration in comparison with other genotypes. Percentage reduction in average shoot length at 3 dS/m salt concentration is 13.6 while percent reduction in root length is 20.0.

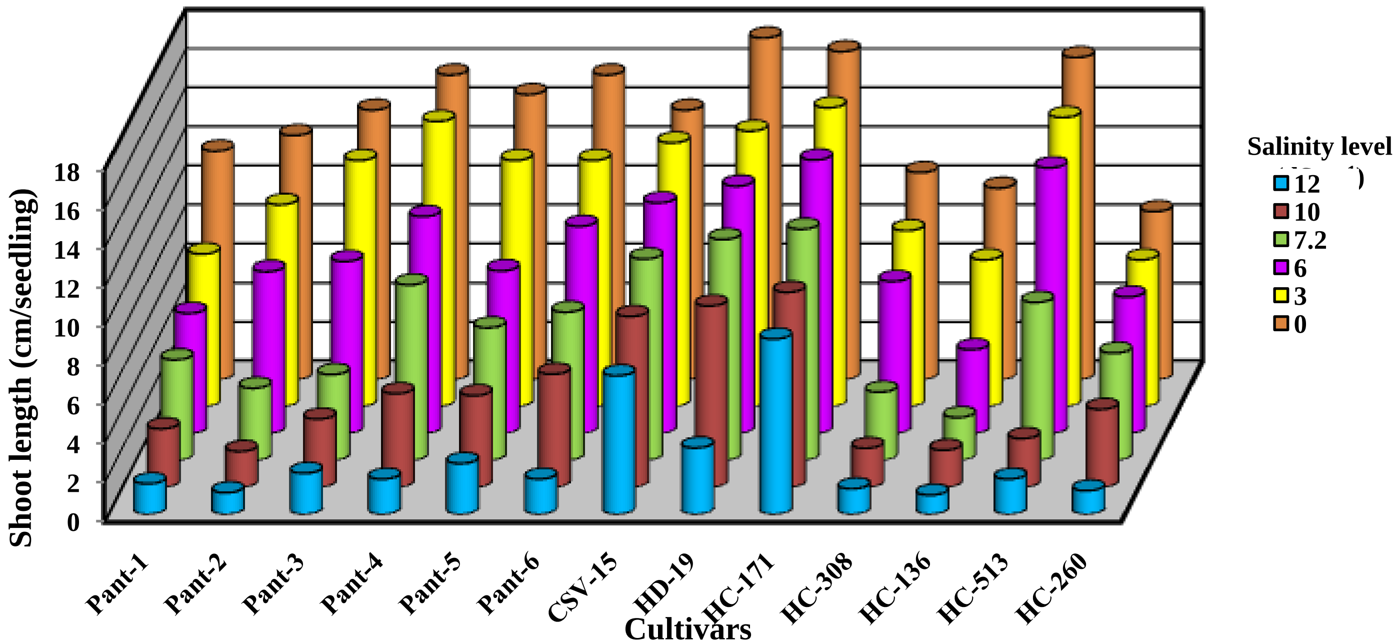

Figure-2a
Effect of saline water irrigation on shoot length at 10 dag in some sorghum cultivars

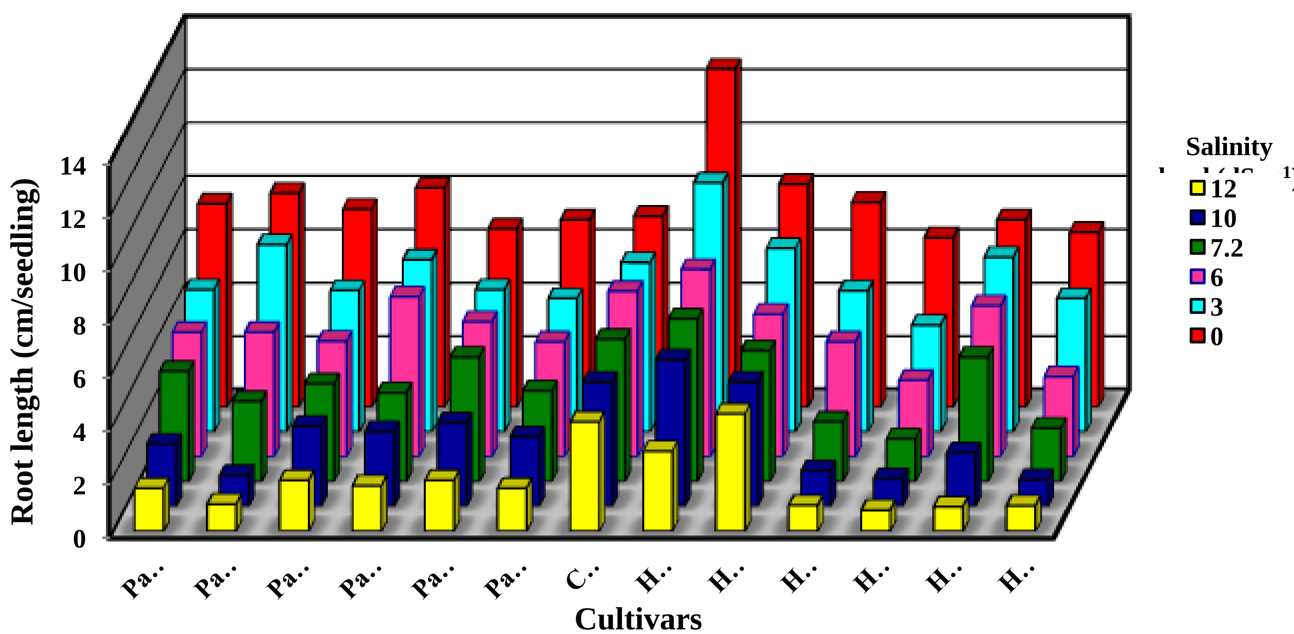

Figure-2b
Effect of saline water irrigation on root length of 10 days old seedling of some sorghum cultivars

Statistical analysis showed that there were highly significant differences among all the genotypes for root and shoot dry weight. Figures 3a and 3b show that dry weight of root and shoot in all genotypes were adversely affected at all salinity levels. In pant-1, pant-3, pant-5, pant-6, CSV-15 and HC-513 shoot dry weight was reduced more as compared to the dry weight of root. Maximum reduction in shoot and root dry weight was recorded in pant-2, HC-308, HC-136, HC-513, and HC-260 at 10 and 12 dS/m salt concentration. However CSV-15, HC-171 showed lesser reduction at 10 and 12 dS/m salt level. Genotypes such as pant-1, pant-3, pant-4, pant-5, pant-6, and HD-19 showed moderate reduction in dry weight at similar salt concentration. Root and shoot dry weights were strongly inhibited at higher salt concentrations. At 7.2 dS/m salinity level pant-2, pant-3, pant-4, HD-19, HC-171, HC-308, HC-513, HC-260 showed more than 50 percent reduction in dry weight. However, CSV-15 was less affected at the same salinity level. On the other hand, dry weight of root and shoot were significantly declined at 3 and 6 dS/m salinity level but some genotypes such as CSV-15, HD-19, HC-171, HC-513, pant-4, and pant-1 showed lesser reduction as compared to pant-2, pant-3 and pant-6. The decrease was moderate in rest of the genotypes.

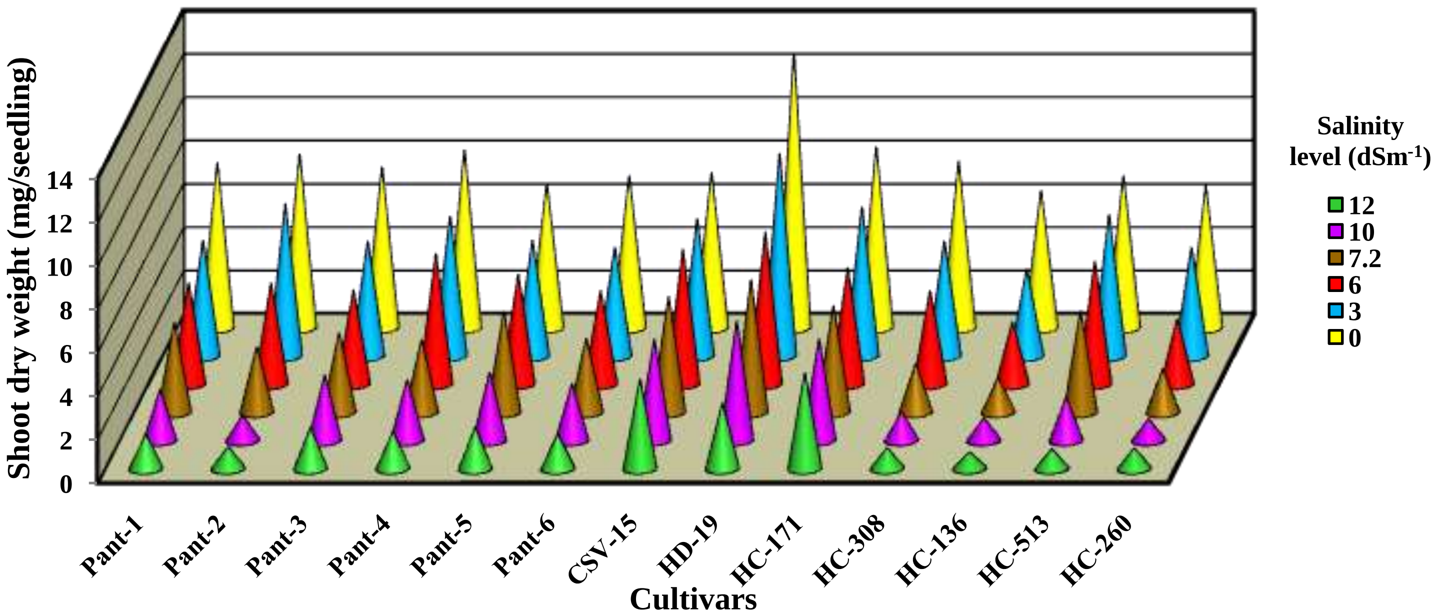

Figure-3a
Effect of saline water irrigation on shoot dry weight at 10 DAG in some sorghum cultivars

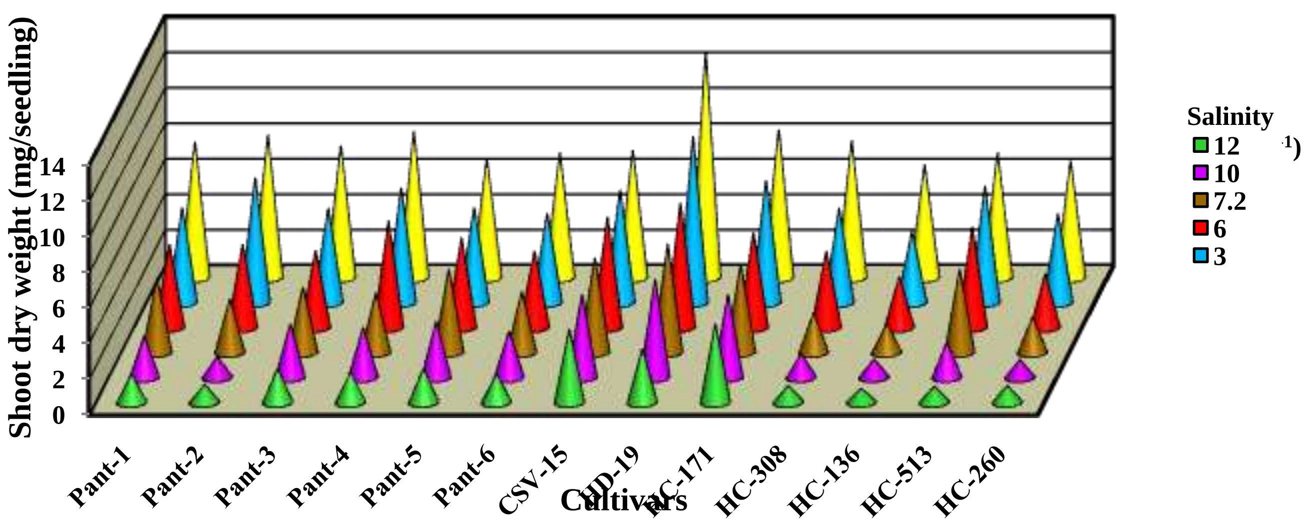

Figure-3b
Effect of saline water irrigation on root dry weight at 10 dag in some sorghum cultivars

Salinity Tolerance in Terms of Root/Shoot Ratio and SSI: The SSI for the total dry weight has been determined for all the cultivars of sorghum as a measure of salinity tolerance. The lowest value of SSI implies the greater tolerance against salinity. The value of SSI gradually increased for all cultivars with the intensity of salinity. The value of SSI is very low for CSV-15 and HC-171 cultivars in relation to other cultivars at each salinity level, signifying there greater salinity tolerance. The genotypes which have high SSI value indicate susceptibility to salt stress. Therefore, the cultivars PANT-2, HC-308, HC-513 present lesser tolerance to salinity due to the high value of SSI with regard to other cultivars. The lower values of root/shoot ratio represent higher salt resistance of the cultivars. The value of root shoot ratio in cultivar PANT-6 and HC-171are lower (≈0.46) whereas in PANT-1, PANT-2, HC-136, HC-308 cultivars of sorghum root shoot ratio are very high (≥0.61). The value of root and shoot ratio for other genotypes range from 0.52 to 0.57. Therefore, the response of the genotypes in terms of root shoot ratio suggests that root growth is less inhibited by salt stress than shoot growth.

From this study, it is clear that the genotype CSV-15 and HC-171 of Sorghum bicolor have superior vegetative growth and low salt susceptibility index under intense salt stress. These two genotypes also have lowest total dry weight reduction and highest level of salinity tolerance with SSI ≈ 0.20. The genotype PANT-2, HC-260, and HC-308 have inferior vegetative growth and lowest salinity tolerance with SSI ≈ 0.32. Therefore, on the basis of the growth pattern shown by different genotypes under various salinity conditions, it can be concluded that the genotype CSV-15 is most salt-tolerant and PANT-2 is most salt-sensitive.

In order to find out the relationship between salinity and germination percentage, and between salinity and seedling growth parameters, linear regression analysis has been performed using Minitab-14 statistical software package. The correlation coefficients and relationship between salt stress, germination percentage, and seedling growth are shown in figure 4. A negative relationship was observed between salt stress and germination percentage, root length, shoot length, root dry weight, shoot dry weight, and total dry weight. It has been examined that there was a strong negative significant correlation between salinity and germination percentage (r = 0.87, P<0.001), root length (r = 0.83, P<.001), shoot length (r = 0.80, P<.001), root dry weight (r =0.84, P<.001), and total dry weight (r =0.83, P<.001). It is also evident from figure () that there was a negative significant correlation between salinity and shoot dry weight (r =0.79, P<.001)

Because of the significant correlation between salinity and germination percentage, seedling growth parameters, we are able to find out the correlation between germination percentage and root length, shoot length, root dry weight, shoot dry weight, and total dry weight. It is also easy to predict in the same manner the relationship between total dry weight and root length, and shoot length. These relationships have been shown in figure 5. Significant positive relationship was examined between germination and root length (r =0.82, P<.001), shoot length (r =0.87, P<.001), root dry weight (r =0.778, P<.001), shoot dry weight (r =0.84, P<.001), and total dry weight (r =0.86, P<.001). Therefore, germination has strong positive correlation with shoot length, shoot dry weight, and total dry weight. A perfect positive correlation has been examined between root dry weight and root length (r=0.964, P<.001), shoot dry weight and shoot length (r=0.975, P<.001), and total dry weight and shoot length (r=0.97, P<.001).

At the early seedling stage germination percentage, PR in root length, shoot length, root dry weight, shoot dry weight, and total dry weight, and SSI for total dry weight clearly indicate genetic variation in germination and seedling growth responses to salinity among the sorghum genotypes. Increasing salt stress reduced the germination percentage and seedling growth in all sorghum genotype. Dry matter reduction due to increased salinity, as estimated for five salinity indices, and regression coefficients for each genotypes confirmed the variable responses of the thirteen sorghum genotypes to increasing salinity stress levels. All genotypes of sorghum except CSV-15 and HC-171 show sharp decline in germination percentage with increasing salinity levels. Our findings regarding the effect of salinity on seed germination are very similar to[14] who found that the germination decreases significantly with increasing salt concentration. The salinity tolerance in Phaseolus species during the early vegetative growth was studied by[15] and found that increasing salt concentration delayed the germination percentage.

Since the root of the plant is in the direct contact with soil, it absorbs water from soil and supplies to rest of the plant. It is therefore, necessary to consider that the root length, shoot length, root dry weight, and shoot dry weight will be important parameters to evaluate the salt tolerance of plants. It has also been observed by[16] that the root and shoot length provide an important clue of plants response against salt stress. We observed that the percent reduction in root length and shoot length relative to control increases with the increasing salt concentration for all sorghum genotypes. Our results presented here for salinity tolerance in sorghum genotypes clearly indicate that salt stress mostly affect the shoot length rather than root length. The observed reduction in root length and shoot length in saline conditions may be due to toxic effects of the NaCl used as well as unbalanced nutrient uptake by the seedlings.

It has been found for all sorghum genotypes that the dry weight of root and shoot were adversely reduced as the salinity of medium increases. PANT-2, PANT-3, PANT-4, HC-308, HC-136 and HC-513 showed approximately 80% reduction in their dry weight at 16 and 20 EC. It is interesting to note that the percentage reduction in shoot dry weight was much higher than the reduction in root dry weight. It has been reported by several researchers that the increasing NaCl salt concentration decline the dry matter yield[17-19].

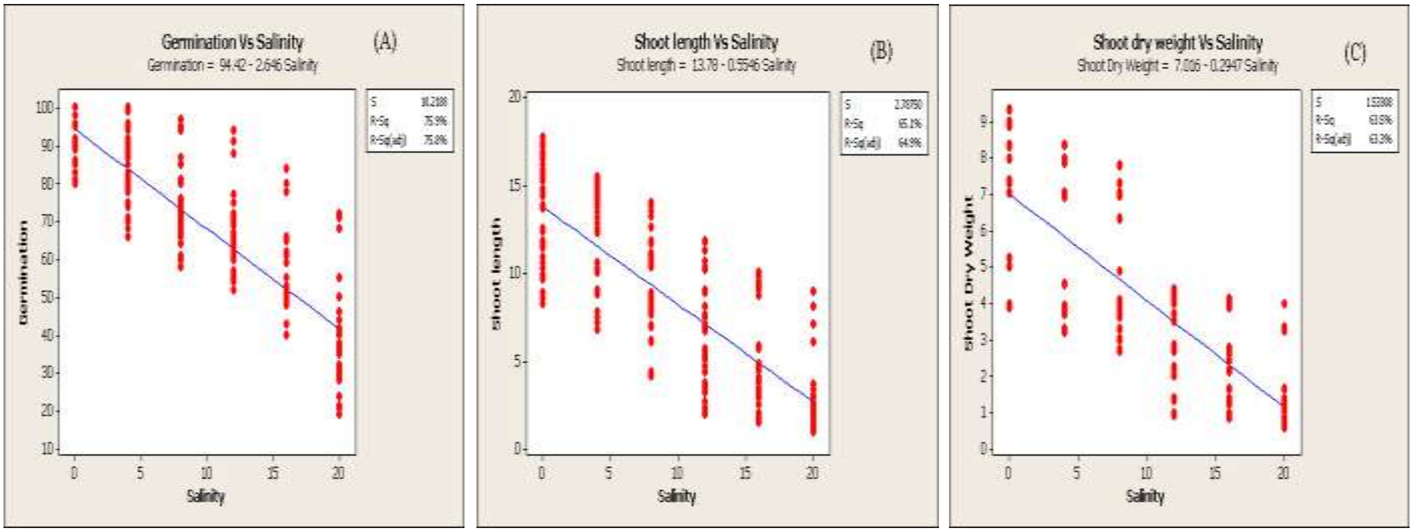

Figure-4
Regression analysis between salinity and (A) percent germination (b) shoot length (c) shoot dry weight in 13 cultivars of *Sorghum*

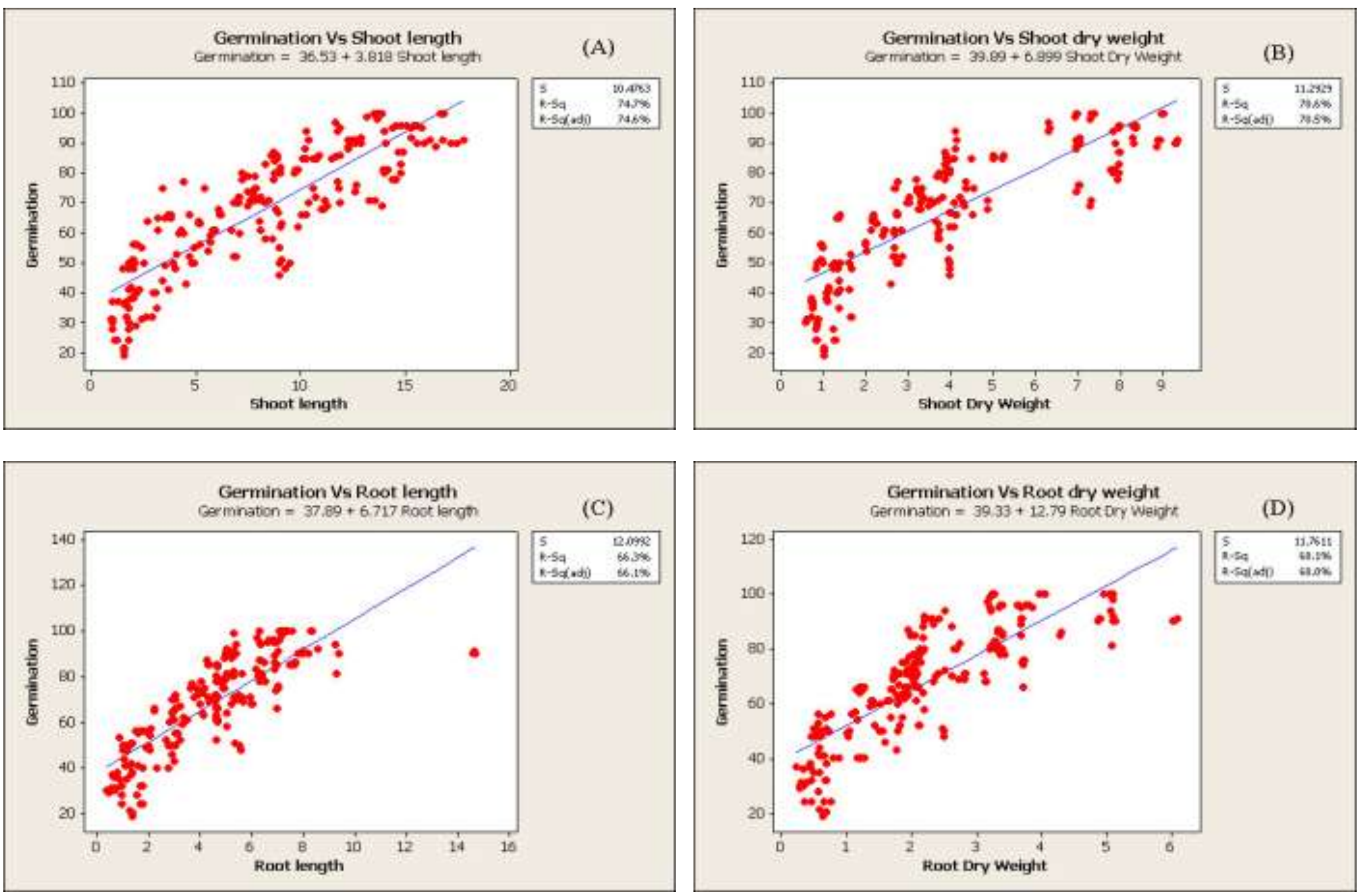

Figure-5
Regression analysis between % germination and (a) shoot length (b) shoot dry weight (c) root length and (d) root dry weight in 13 cultivars of *Sorghum*

The lowest value of SSI implies the greater tolerance against salinity[16]. We found that the value of SSI increases with increasing salinity levels for all genotypes. We therefore, based on the average SSI estimated for dry matter separated the thirteen sorghum genotypes into three groups namely, salt tolerant (CSV-15, HC171), moderately salt tolerant (PANT-1, PANT-5, PANT-6, HD-19, and HC-260), and salt sensitive(PANT-2, PANT-3, PANT-4, HC-308, HC136, and HC-513).

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