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Evaluation of Salt Tolerance of Jute (*Corchorus* spp.) Genotypes in Hydroponics using Physiological Parameters

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Abstract: Evaluation of jute genotypes for salt tolerance is highly important because of salt affected areas are constantly increasing worldwide especially in Bangladesh where salt tolerant jute variety is unavailable. A hydroponics experiment was conducted in the glasshouse to evaluate the salt tolerance of various jute (*Corchorus* spp.) genotypes. Sixty jute genotypes were evaluated in a factorial experiment under Hoagland's nutrient solution with three levels of salinity (0, 100 and 200 mM NaCl) in a randomized complete block design with three replications. Root length, shoot length, root dry matter, shoot dry matter, total dry matter and leaf Relative Water Content (RWC) decreased significantly with increasing salinity. However, the chlorophyll content of jute leaves was higher at 100 mM NaCl (42.89) than in control plants (37.76). The *C. capsularis* genotypes demonstrated higher levels of salt tolerance than did *C. olitorius* genotypes. The physiological traits shoot length (R^2 = 0.95), RWC (R^2 = 0.80) and chlorophyll content (R^2 = 0.91) was strongly correlated with total dry matter production and was exhibited good potential for evaluation of salt tolerance in jute. The *C. capsularis* accessions 4965 and 4955 were the most salt tolerant in terms of their high index of salt tolerance (85.20 and 84.10% at 100 mM NaCl) and lowest reduction in shoot length, RWC and chlorophyll content under salt stress. These accessions could be useful for agriculture in saline areas, particularly at 100 mM NaCl (EC = 10 dS m^{-1}) salinity.

Key words: Chlorophyll content, jute, total dry mater, salinity, salt tolerance index

INTRODUCTION

Jute (*Corchorus* spp.) is the world's second largest crop grown for plant fiber after cotton (Kundu, 1951) and as a completely biodegradable lingo-cellulosic fiber, is also very environmentally friendly. The genus *Corchorus* consists of around 100 species (Saunders, 2001). Of these, *Corchorus capsularis* L. and *Corchorus olitorius* L. are grown commercially in tropical and subtropical regions (Edmonds, 1990).

Bangladesh is the second largest jute producer in the world (FAO, 2010) and earns a significant proportion of its foreign exchange annually from the export of jute products. In addition, this crop is particularly important in Bangladesh where many small family farms depend on the income from growing and selling jute.

Salinity is a worldwide problem in agriculture and Bangladesh is not exempt from this impediment. In Bangladesh, the soil of around 1.02 million ha of farmland is somewhat saline (Haque, 2006). The area of land characterized as moderately to highly saline (8-15 dS m^{-1}) or highly saline (>15 dS m^{-1}) is rapidly increasing in Bangladesh because of changing global climate (SRDI, 1998a, b). At the same time, due to population pressure, Bangladesh needs more arable land for food crops. So, jute cultivation is constantly being pushed to the marginal lands with higher degrees of soil salinity year round. Although jute must now be cultivated in these areas, there is little to no information available regarding salinity-tolerant jute varieties appropriate for such salinized soils.

Physiological parameters such as root length, shoot length, dry matter accumulation (Jamil and Rha, 2004; Akram *et al*., 2010), relative water content (Suriya-Arunroj *et al*., 2004; Ziaf *et al*., 2009) and an index of salt tolerance traits (Bagci *et al*., 2007) can be used to evaluate salt tolerance.

Salt stress negatively affects plant growth and development at both physiological and biochemical levels (Munns, 2002). For example, Khandker *et al*. (1992) and Islam *et al*. (2011) have reported adverse effects of salinity on root length, shoot length and dry

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matter accumulation in jute. Moreover, salt stress reduces relative water content of leaves in *Capsicum annuum* (Ziaf *et al*., 2009) and chlorophyll content in rice (Ali *et al*., 2004) and radish (Jamil *et al*., 2007) but these studies are rare in jute.

Researchers have adopted several strategies to overcome the adverse effect of salinity. Screening for and identifying genotypes that maintain productivity under saline conditions is an effective approach (Ashraf *et al*., 2006). However, screening for salt tolerance under field conditions is often not feasible due to the heterogeneous nature of field soil and seasonal fluctuations in rainfall (Akram *et al*., 2010). It was therefore necessary to identify an appropriate standard growing media to use for investigating the physiological responses of jute under salinity stress. Evaluation of a large number of jute genotypes (up to 60) under salt stress in hydroponics had apparently not yet been performed. Consequently, the development of a hydroponics system to evaluate the physiological responses of jute to salinity was necessary. Further, the salt tolerance of jute accessions is typically tested on seedlings (Ma *et al*., 2011) which are particularly susceptible to salt stress (Rhoades *et al*., 1992). Therefore, the evaluation of salinity tolerance of jute at seedling stages in hydroponics was considered a suitable and efficient approach for generating information on the prevalence and nature of salt tolerance in this crop. The objectives of the present study were (1) To evaluate the effect of salinity on various physiological parameters of jute (2) To determine the appropriate physiological traits that signify salinity tolerance in jute and (3) To identify salt tolerant jute genotype(s).

MATERIALS AND METHODS

Plant materials: Sixty genotypes of the two cultivated species of jute (Table 1) of differing geographic origin were used in this study. Seeds of all the genotypes were obtained from the Bangladesh Jute Research Institute.

Experimental design and salt treatments: A hydroponics experiment was carried out in 2011 in the glasshouse at the Department of Agronomy at Kasetsart University, Thailand. Sixty jute accessions were evaluated under three levels of salinity (0, 100 and 200 mM NaCl) a randomized complete block design with three replications. Five seeds of each genotype were treated with fungicide (Vitavex-200 WP 0.4%) for surface sterilization prior to seed sowing. The seeds were then sown 1.2 cm apart in small plastic pots containing vermiculite and supplemented with 20 mL of distilled water and were allowed to germinate 7 days.

Table 1: Accessions and cultivars of the two species of jute evaluated in this study and their countries of origin

No.	Genotype	Status	Country/origin
1	CVL-1	C	Bangladesh
2	BJC-83	C	Bangladesh
3	2596	A	Bangladesh
4	4374	A	Taiwan
5	4467	A	Thailand
6	4520	A	Thailand
7	4588	A	Nepal
8	4617	A	Tanzania
9	4619	A	Brazil
10	4620	A	Brazil
11	4621	A	Brazil
12	4683	A	Thailand
13	4701	A	Nepal
14	4705	A	Nepal
15	4711	A	Nepal
16	4724	A	China
17	4727	A	China
18	4731	A	China
19	4879	A	Nepal
20	4937	A	China
21	4939	A	China
22	4955	A	China
23	4958	A	China
24	4964	A	China
25	4965	A	China
26	4988	A	China
27	4995	A	China
28	5000	A	China
29	5002	A	China
30	5005	A	Nepal
31	5062	A	Nepal
32	5064	A	Nepal
33	5065	A	Nepal
34	O-9897	C	Bangladesh
35	3705	A	Kenya
36	3727	A	Kenya
37	3728	A	Kenya
38	3732	A	Kenya
39	3784	A	Kenya
40	3835	A	Kenya
41	4177	A	Tanzania
42	4178	A	Tanzania
43	4189	A	Tanzania
44	4191	A	Tanzania
45	4231	A	Tanzania
46	4232	A	Tanzania
47	4245	A	Tanzania
48	4461	A	Thailand
49	4466	A	Thailand
50	4546	A	Indonesia
51	4566	A	Nepal
52	4574	A	Nepal
53	4579	A	Nepal
54	4580	A	Nepal
55	4739	A	China
56	4740	A	China
57	4792	A	Brazil
58	4793	A	Brazil
59	4794	A	Brazil
60	4796	A	Niger

C and A indicate cultivar and accession, respectively. Salt tolerance status of all the genotypes is unknown, No. 1-33 and 34-60 belong to *C. capsularis* and *C. olitorius*, respectively

The hydroponics setup, comprised a plastic box containing aerated Hoagland's nutrient solution (Hoagland and Arnon, 1950) covered with a foam support over the treatment solution, through which the plants grew. The nutrient solution was replaced by new solution at 3 days intervals and its pH was checked daily and maintained at 5.8±0.2 (using 0.01 N HCl to lower pH, or 0.01 N KOH to increase pH) for optimum plant growth. Seven days after seed sowing, two seedlings of each genotype per replicate ~3.0 cm in length were transferred in their plastic pots into the hydroponics system. Five days after transplantation, seedlings were thinned to one seedling of each genotype per pot. After seedling establishment (at 12 day), three levels of salinity (0 (control), 100 or 200 mM NaCl) were applied in hydroponics solutions. Salt treatments were prepared by dissolving pure NaCl in deionized water and adding to the hydroponics solutions to achieve the appropriate concentrations during the experimental period. Electrical conductivity of each treatment solution was kept constant by adding NaCl. Electrical conductivity and pH of the solutions were monitored daily using a portable EC and pH meter (YOA EC meter, CM 14P, TOA Electronics Ltd., Japan) to avoid buildup of EC and pH. Plants were harvested after 35 days of seedling growth in hydroponics.

Data collection: At harvest time, the chlorophyll content (SPAD value) and leaf Relative Water Content (RWC) of each plant were recorded. The youngest fully expanded leaves of each plant were used for measuring chlorophyll content and RWC. Chlorophyll content was measured using a portable chlorophyll meter (SPAD 502, Minolta, Japan). For RWC, the leaves were sampled, plased in polythene bags and immediately stored in ice. The Fresh Weight (FW) of the sample leaves for each treatment was recorded, then the leaves were immersed in distilled water in Petri dishes for 4 h at room temperature. After 4 h, the leaves were removed from the dishes, the surface water was blotted off and the Turgid Weights (TW) were recorded. The samples were then oven dried at 65°C to constant weight for determining Dry Weight (DW). RWC was calculated according to the equation of Smart and Bingham (1974):

$$\text{RWC (\%)} = \frac{\text{FW-DW}}{\text{TW-DW}} \times 100$$

After harvest, the plants were separated into roots and shoots and root and shoot lengths were recorded on a metric scale. For dry matter, the roots and shoots (stem with leaf) of all plant samples were dried separately in an oven at 65°C until a constant weight was reached and dry weight (g plant^{-1}) was measured on an electronic precision balance. The Salt Tolerance Index (STI) was calculated according to Cano *et al*. (1998):

$$\text{STI} = \frac{\text{Total DW in NaCl solution}}{\text{Total DW in NaCl-free solution (control)}} \times 100$$

The broad-sense heritability (H_b) of the traits measured in this study was calculated using the formula of Allard (1960). Information regarding the proportion of population phenotypic variability that is due to genetic rather than environmental factors is useful for gauging the level of variation available for selective breeding purposes.

Statistical analysis: Analysis of variance (ANOVA) was calculated using IRRISTAT software (version 5.0). Duncan's Multiple Range Test (DMRT) was used to compare the treatment means. LSD values at the 5% level of significance were also used to compare the differences in all studied traits among genotypes in the present study.

RESULTS AND DISCUSSION

ANOVA results (Table 2) showed that the mean square values were highly significant (p<0.01) for salinity, genotype and the salinity×genotype interaction for root length, shoot length, root dry matter, shoot dry matter, total dry matter, leaf relative water content and chlorophyll content. This implies that there was considerable variation among genotypes and that salinity significantly affected physiological parameters in the jute accessions evaluated in this study. The coefficient of variation ranged from 0.50-5.40% which indicated that the predictions made by this ANOVA model fit the data obtained in the present study well.

Root and shoot length: The root and shoot lengths of these jute genotypes decreased significantly with

Table 2: Analysis of variance (ANOVA) for root length, shoot length, root dry matter, shoot dry matter, total dry matter, leaf relative water content and chlorophyll content of 60 jute genotypes in response to growth for 35 days in hydroponics under one of three levels of salinity

Source of variation	df	Root length (cm)	Shoot length (cm)	Root dry matter (g plant^{-1})	Shoot dry matter (g plant^{-1})	Total dry matter (g plant^{-1})	Leaf relative water content (%)	Chlorophyll content (SPAD value)
Replication	2	0.0826	0.6792	0.0001	0.0030	0.0028	0.3125	0.6725
Salinity	2	22643.5000**	105136.0000**	9.5610**	207.1860**	305.2610**	16590.6000**	4667.1200**
Genotype	59	280.8540**	715.2940**	0.0964**	1.6708**	2.5399**	28.3842**	53.8897**
Salinity×Genotype	118	18.8530**	76.7360**	0.0157**	0.2022**	0.3076**	5.0349**	7.6154**
Error	358	0.5946	0.5158	0.0002	0.0021	0.0022	0.2107	0.3737
CV (%)		3.10	1.40	5.40	2.90	2.60	0.50	1.60

**Significant at 0.01 level of probability, CV: Co-efficient of variation

Table 3: Effects of NaCl concentrations on physiological parameters of jute after 35 days in hydroponics

Salinity levels (mM)	Root length (cm)	Shoot length (cm)	Root dry matter (g plant^{-1})	Shoot dry matter (g plant^{-1})	Total dry matter (g plant^{-1})	Leaf relative water content (%)	Chlorophyll content (SPAD value)	Salt tolerance index (%)
0	35.69^{a}	74.51^{a}	0.53^{a}	2.63^{a}	3.16^{a}	94.12^{a}	37.76^{b}	100.00
100	26.28^{b}	49.27^{b}	0.26^{b}	1.59^{b}	1.85^{b}	85.83^{b}	42.89^{a}	57.33
200	13.35^{c}	26.19^{c}	0.07^{c}	0.48^{c}	0.55^{c}	74.96^{c}	32.66^{c}	16.61

Means followed by different letters in columns are statistically significant at 0.05 level of probability by DMRT

Table 4: Salt tolerance indices of the top 10 most salt-tolerant and the most salt-susceptible genotypes of each species of jute for each physiological parameter after 35 days in hydroponics under all salinity levels

Genotype	Root length (cm)	Shoot length (cm)	Root dry matter (g plant^{-1})	Shoot dry matter (g plant^{-1})	Total dry matter (g plant^{-1})	Leaf relative water content (%)	Chlorophyll content (SPAD value)	Salt tolerance index (%)
C. capsularis								
Tolerant								
4965	38.09	70.28	0.558	2.554	3.112	89.25	43.80	72.53
4955	38.30	69.27	0.543	2.470	3.013	88.88	43.55	71.65
4683	35.75	66.11	0.562	2.393	2.956	88.71	42.95	70.63
4988	33.61	63.74	0.502	2.318	2.819	87.72	41.46	69.72
2596	33.89	63.29	0.385	2.166	2.551	87.28	40.46	67.75
4964	33.40	62.73	0.502	2.331	2.833	88.25	42.39	67.31
4939	34.88	65.33	0.389	2.251	2.640	86.63	40.35	67.00
5002	29.74	57.51	0.377	2.024	2.401	86.95	40.02	65.99
4374	29.37	56.45	0.372	1.661	2.034	87.13	38.56	65.91
4701	30.84	60.47	0.426	2.048	2.475	86.15	39.27	64.58
Most susceptible								
4619	26.48	53.39	0.287	1.713	2.000	84.41	38.46	51.52
C. olitorius								
Tolerant								
4191	24.21	49.92	0.335	1.763	2.099	85.17	38.87	62.03
4793	25.33	48.66	0.316	1.660	1.976	85.01	38.53	60.86
4466	24.16	48.97	0.266	1.355	1.621	85.33	37.12	60.54
4580	24.21	48.91	0.309	1.603	1.911	85.29	38.01	60.39
3835	21.99	44.94	0.252	1.351	1.603	84.07	36.89	59.74
4189	19.83	40.92	0.192	1.188	1.380	84.09	36.94	58.90
4794	25.17	49.66	0.313	1.665	1.978	84.93	38.01	58.86
4574	20.43	42.05	0.176	1.287	1.463	83.63	35.45	57.49
4739	21.13	44.49	0.237	1.082	1.320	84.28	36.57	56.92
O-9897	21.11	46.89	0.264	1.340	1.604	84.02	36.15	56.57
Most susceptible								
3784	18.29	34.74	0.169	0.888	1.057	81.96	34.57	44.61
Overall LSD (0.05)	00.71	00.67	0.014	0.043	0.044	00.42	00.57	-------

LSD: Least significant difference

increasing salinity (Table 3). Significant genotypic variation in root and shoot length was observed at all salinity levels. Among these genotypes, the longest root length (38.30 cm) and shoot length (70.28 cm) were found in *C. capsularis* accessions 4955 and 4965, respectively while the shortest root (18.29 cm) and shoot length and (34.74 cm) were recorded in *C. olitorius* accession 3784 (Table 4).

In terms of the salinity×genotype interaction, *C. capsularis* accession 4955 produced the highest root length (46.78 cm) and accession 4965 exhibited the highest shoot length (90.44 cm) under 0 mM NaCl control conditions while the shortest root length (4.44 cm) and shoot length (12.55 cm) was observed in accession 3784 of *C. olitorius* at 200 mM NaCl.

Percent root and shoot length reduction under different levels of salinity relative to respective controls, varyied among the genotypes. *C. capsularis* accession 4965 demonstrated the least reduction in root and shoot length (11 and 16%, respectively) followed by accession 4955 (12 and 17%, respectively) at 100 mM NaCl. The maximum reduction in root and shoot length occurred in *C. olitorius* accession 3784 (85 and 78%, respectively) at 200 mM NaCl. The average reductions in root and shoot length of these jute genotypes were 28 and 34%, respectively at 100 mM NaCl, but were 64 and 65%, respectively at 200 mM NaCl (Table 5).

Roots are important plant organs that are in direct contact with growth media and supply plant nutrients from the growth media to the plant. Therefore, the behavior of roots under salt stress is important for adaptation to saline environments. In this study, the accessions 4965 and 4955 demonstrated relatively low reduction in root length under salt stress. The comparatively better adaptation of roots of these genotypes under salt stress might be due to efficient osmotic adjustment at the cellular level. In contrast, the sensitive accession (3784) showed the greatest reduction

Table 5: Salt tolerance indices of the top 10 most salt-tolerant and the most salt-susceptible genotypes of each species of jute for root length, shoot length, root dry matter and shoot dry matter after 35 days in hydroponics at different salinity levels

	NaCl levels (mM)																			
	Root length (cm)					Shoot length (cm)					Root dry matter (g plant^{-1})					Shoot dry matter (g plant^{-1})				
Genotype	0	100	Red. (%)	200	Red. (%)	0	100	Red. (%)	200	Red. (%)	0	100	Red. (%)	200	Red. (%)	0	100	Red. (%)	200	Red. (%)
C. capsularis																				
Tolerant																				
4965	46.03	41.12	11	27.11	41	90.44	75.62	16	44.78	50	0.754	0.724	4	0.197	74	3.551	2.944	17	1.167	67
4955	46.78	41.26	12	26.85	43	89.65	74.62	17	43.55	51	0.718	0.671	7	0.239	67	3.472	2.853	18	1.084	69
4683	45.62	39.52	13	22.10	52	88.25	70.34	20	39.74	55	0.778	0.689	11	0.220	72	3.407	2.787	18	0.986	71
4988	44.80	38.27	15	17.76	60	85.89	68.75	20	36.57	57	0.675	0.643	5	0.187	72	3.369	2.632	22	0.952	72
2596	43.44	37.13	15	21.10	51	83.33	67.73	19	38.80	53	0.584	0.424	27	0.146	75	3.181	2.432	24	0.885	72
4964	44.47	38.68	13	17.04	62	87.22	71.75	18	29.22	66	0.734	0.599	18	0.173	76	3.475	2.704	22	0.814	77
4939	46.02	38.52	16	20.10	56	85.22	70.55	17	40.22	53	0.617	0.379	39	0.172	72	3.323	2.583	22	0.846	75
5002	38.93	31.66	19	18.63	52	73.50	59.47	19	39.55	46	0.612	0.354	42	0.165	73	3.026	2.065	32	0.980	68
4374	38.62	32.24	17	17.25	55	79.44	56.44	29	33.47	58	0.616	0.407	34	0.094	85	2.469	1.875	24	0.640	74
4701	41.66	34.87	16	16.00	62	84.62	65.55	23	31.23	63	0.668	0.485	27	0.126	81	3.164	2.389	24	0.592	81
Most susceptible																				
4619	36.25	27.26	25	15.93	56	82.90	49.10	41	28.17	66	0.618	0.164	74	0.078	87	3.264	1.318	60	0.558	83
Species mean	39.22	30.91	22	16.23	59	80.28	56.38	30	30.74	62	0.587	0.346	42	0.098	84	2.953	1.933	35	0.612	80
C. olitorius																				
Tolerant																				
4191	34.43	26.14	24	12.07	65	72.62	51.72	29	25.42	65	0.667	0.251	62	0.088	87	2.716	1.888	30	0.686	75
4793	35.62	28.55	20	11.82	67	72.90	52.55	28	20.53	72	0.552	0.359	35	0.038	93	2.695	1.947	28	0.337	87
4466	34.24	25.11	27	13.13	62	67.80	49.45	27	29.66	56	0.500	0.227	55	0.070	86	2.177	1.362	37	0.527	76
4580	35.22	25.55	27	11.87	66	73.72	48.55	34	24.47	67	0.578	0.261	55	0.088	85	2.587	1.609	38	0.612	76
3835	31.10	21.25	32	13.63	56	64.44	45.21	30	25.17	61	0.491	0.227	54	0.037	92	2.192	1.451	34	0.411	81
4189	27.70	20.55	26	11.23	59	61.66	38.56	37	22.55	63	0.397	0.142	64	0.038	90	1.946	1.248	36	0.369	81
4794	35.80	28.32	21	11.40	68	77.77	50.22	35	21.00	73	0.585	0.335	43	0.019	97	2.775	1.848	33	0.372	87
4574	29.30	20.28	31	11.70	60	69.55	37.93	45	18.68	73	0.382	0.135	65	0.012	97	2.163	1.290	40	0.407	81
4739	30.33	22.00	27	11.07	64	62.45	46.13	26	24.88	60	0.402	0.245	39	0.063	84	1.916	1.001	48	0.331	83
O-9897	30.13	21.00	30	12.20	60	69.56	42.36	39	28.74	59	0.534	0.186	65	0.072	87	2.302	1.238	46	0.481	79
Most susceptible																				
3784	30.62	19.80	35	4.44	85	56.11	35.57	37	12.55	78	0.394	0.107	73	0.006	98	1.976	0.647	67	0.042	98
Species mean	31.29	20.64	34	9.83	69	66.95	40.52	39	20.62	69	0.459	0.166	65	0.037	93	2.229	1.167	48	0.322	86
Overall mean	35.71	26.36	28	13.40	64	74.38	49.36	34	26.26	65	0.530	0.266	53	0.071	88	2.632	1.594	41	0.484	83
Overall LSD (0.05)	1.24					1.15					0.025					0.074				

Red.: Reduction

in root length under different levels of salinity which might indicate a relatively lower capacity for osmotic adjustment at the cellular level compared to that of tolerant accessions. Ziaf *et al*. (2009) and Akram *et al*. (2010) observed that root growth decreased upon increasing salinity and that this decrease was greater in sensitive genotypes than in tolerant ones which is consistent with the present results.

Reduction in shoot length is a common physiological response in plants under high salt concentrations and has been reported specifically for jute by Khandker *et al*. (1992) and Islam *et al*. (2011). Moreover, shoot length at all salinity levels was highest in accession 4965 which also exhibited the lowest shoot length reduction under salt stress.

Dry matter accumulation: Root, shoot and total dry matter accumulation of various jute genotypes decreased significantly ($p<0.05$) with increasing NaCl concentration in Hoagland's nutrient solution (Table 3). The magnitude of decrease varied significantly ($p<0.05$) among genotypes of the two species of jute. Among these genotypes, *C. capsularis* accession 4683 produced the most root dry matter (0.562 g plant^{-1}). Accession *C. capsularis* 4965 produced the most shoot dry matter and total dry matter (2.554 and 3.112 g plant^{-1}). In contrast, the growth of *C. olitorius* accession 3784 was markedly affected by salt stress and produced the lowest root, shoot and total dry matter (0.169, 0.888 and 1.057 g plant^{-1}, respectively) (Table 4).

The salinity×genotype interaction was indicated by the fact that the maximum amount of root dry matter (0.778 g plant^{-1}) obtained in accession *C. capsularis* 4683 of under 0 mM NaCl control (Table 5). *C. capsularis* accession 4965 produced the highest shoot and total dry matter (3.551 and 4.305 g plant^{-1}) under control conditions, whereas, *C. olitorius* accession 3784 produced the least root, shoot and total dry matter in (0.006, 0.042 and 0.048 g plant^{-1}, respectively) at 200 mM NaCl (Table 5 and 6).

Table 6: Performance bases on salt tolerance indices of the top 10 most salt-tolerant and the most salt-susceptible genotypes of each species of jute for total dry matter, leaf relative water content, chlorophyll content and salt tolerance index after 35 days in hydroponics at different salinity levels

	NaCl levels (mM)																	
	Total dry matter (g plant^{-1})					Leaf relative water content (%)					Chlorophyll content (SPAD value)					Salt tolerance index (%)		
Genotype	0	100	Red. (%)	200	Red. (%)	0	100	Red. (%)	200	Red. (%)	0	100	Inc. (%)	200	Red. (%)	0	100	200
C. capsularis																		
Tolerant																		
4965	4.305	3.668	15	1.394	68	96.26	91.57	5	79.92	17	41.37	51.20	24	38.83	6	100.00	85.20	32.38
4955	4.190	3.524	16	1.293	69	95.85	91.07	5	79.71	17	41.23	50.80	23	38.61	6	100.00	84.10	30.86
4683	4.185	3.476	17	1.206	71	96.44	90.73	6	78.95	18	41.30	49.17	19	38.37	7	100.00	83.07	28.81
4988	4.044	3.275	19	1.139	72	95.65	88.64	7	78.88	18	40.03	47.03	17	37.33	7	100.00	80.99	28.18
2596	3.765	2.856	24	1.031	73	96.28	88.77	8	76.78	20	38.90	46.53	20	35.95	8	100.00	75.87	27.40
4964	4.209	3.303	22	0.987	77	95.98	90.42	6	78.35	18	40.57	48.80	20	37.80	7	100.00	78.47	23.45
4939	3.940	2.962	25	1.018	74	95.91	87.90	8	76.08	21	39.43	45.73	16	35.90	9	100.00	75.16	25.83
5002	3.638	2.419	34	1.145	69	94.57	87.39	8	78.90	17	38.43	46.03	20	35.61	7	100.00	66.50	31.49
4374	3.085	2.282	26	0.733	76	95.12	87.62	8	78.64	17	37.77	45.70	21	32.22	15	100.00	73.96	23.77
4701	3.832	2.874	25	0.718	81	95.84	88.32	8	74.30	22	39.17	45.90	17	32.75	16	100.00	75.02	18.74
Most susceptible																		
4619	3.882	1.482	62	0.636	84	94.65	84.40	11	74.18	22	40.07	43.00	07	32.31	19	100.00	38.18	16.39
Species mean	3.540	2.278	36	0.710	80	94.91	87.16	08	75.96	20	38.57	45.14	17	33.87	12	100.00	64.07	19.63
C. olitorius																		
Tolerant																		
4191	3.383	2.139	37	0.774	77	94.00	86.91	8	74.59	21	38.43	43.52	13	34.66	10	100.00	63.22	22.88
4793	3.247	2.306	29	0.375	88	93.44	87.60	6	74.00	21	38.27	44.13	15	33.20	13	100.00	71.03	11.55
4466	2.677	1.588	41	0.597	78	94.44	85.65	9	75.90	20	37.93	40.53	7	32.91	13	100.00	59.33	22.29
4580	3.165	1.870	41	0.699	78	94.34	85.77	9	75.75	20	38.07	43.07	13	32.88	14	100.00	59.07	22.10
3835	2.683	1.678	37	0.448	83	92.96	85.02	9	74.22	20	36.97	41.00	11	32.71	12	100.00	62.53	16.68
4189	2.343	1.390	41	0.407	83	92.25	83.92	9	76.10	18	37.40	41.30	10	32.11	14	100.00	59.34	17.36
4794	3.361	2.183	35	0.391	88	94.68	87.21	8	72.89	23	38.47	43.97	14	31.58	18	100.00	64.96	11.63
4574	2.545	1.425	44	0.419	84	92.12	84.21	9	74.56	19	36.10	38.43	6	31.81	12	100.00	55.99	16.46
4739	2.318	1.246	46	0.394	83	92.75	83.19	10	76.89	17	36.20	41.50	15	32.01	12	100.00	53.76	16.99
O-9897	2.836	1.424	50	0.553	81	93.54	84.78	9	73.75	21	37.07	39.03	5	32.35	13	100.00	50.52	19.48
Most susceptible																		
3784	2.370	0.754	68	0.048	98	92.62	81.95	12	71.31	23	37.23	38.60	4	27.88	25	100.00	31.81	02.03
Species mean	2.688	1.333	51	0.359	87	93.13	84.15	10	73.71	21	36.74	40.06	9	31.13	15	100.00	48.89	12.84
Overall mean	3.163	1.860	43	0.555	83	94.12	85.83	9	74.96	20	37.76	42.89	13	32.66	14	100.00	57.35	16.63
Overall LSD (0.05)	0.076					00.74					00.98							

Inc.: Increase

At 100 mM NaCl, *C. capsularis* accession 4965 exhibited the least reduction in root dry matter, shoot dry matter and total dry matter (4, 17 and 15%, respectively). The second lowest reduction for root dry matter (5%) at 100 mM NaCl was observed in accession 4988. The second lowest reduction for shoot and total dry matter at 100 mM NaCl was observed in aaccession 4955 (18 and 16%). The greatest reduction (98%) was observed for root, shoot and total dry matter in *C. olitorius* accession 3784 at 200 mM NaCl. The average reduction in dry matter production followed a similar pattern as the reductions observed for root and shoot length under salt stress (Table 5 and 6). Dry matter is highly correlated to plant yield (Romero-Aranda *et al*., 2001). In the present study, dry matter accumulation (root, shoot and total) was significantly reduced under increasing salinity. The observed decrease in total dry matter accumulation by plants under salt stress may be explained by reduced growth of roots and shoots under salinity. The observed shoot dry matter reductions were correlated with reduced chlorophyll contents which imply inhibition of photosynthesis, accompanied by loss of cell turgidity under salinity stress. The results of this study agree with the findings of Khandker *et al*. (1992) and Islam *et al*. (2011), who reported reduced dry matter production with increasing salinity. However, the observed variation in dry matter production might be due to genetic diversity among these jute accessions.

The *C. capsularis* accession 4965, followed by accession 4955, exhibited the lowest relative reduction in total dry matter at 100 mM NaCl and at all salinity levels which implies that 4965 is more salt tolerant than the other accessions. Higher dry matter production results from the combination of higher shoot and root dry matter production. In jute, high shoot dry matter production is directly related to fiber yield. Under salt stress, accession 4965, followed by accession 4955 showed superior salt tolerance by sustaining higher leaf relative water content and chlorophyll content which may result in higher levels of carbon accumulation and subsequently, higher dry matter production. Naidu and Swamy (1995) and Paliwal *et al.* (1986) also reported that higher leaf relative water content and chlorophyll content are related to higher dry matter production.

Leaf relative water content: The Relative Water Content (RWC) of leaves of these jute accessions was significantly affected by increasing salinity levels. The highest RWC (94.12%) for each accession occurred under control conditions while the lowest RWC (74.96%) occurred at 200 mM NaCl (Table 3). Decrease in the RWC of leaves upon increased salinity with has been reported by Ziaf *et al.* (2009) in hot pepper and Suriya-Arunroj *et al.* (2004) in rice, among others.

Significant genotypic variation was also observed in leaf RWC at all levels of salinity. The *C. capsularis* accession 4965 showed the highest RWC (89.25%) while the lowest RWC (81.96%) was observed in accession *C. olitorius* 3784 (Table 4) which suggests the existence of genetic variation for this trait. These results parallel the findings of Ziaf *et al.* (2009), who observed variation in RWC among hot pepper genotypess.

Regarding the salinity×genotype interaction, the highest RWC (96.44%) was observed in *C. capsularis* accession 4683 which was not significantly different from that of accessions 2596 (96.28%), 4965 (96.26%), 4964 (95.98%), 4939 (95.91%), 4955 (95.85%) and 4701 (95.84%) under control conditions. However, the lowest (71.31%) RWC was observed in *C. olitorius* accession 3784 at 200 mM NaCl (Table 6).

The lowest reduction (5%) in leaf RWC was observed in *C. capsularis* accessions 4965 and 4955 at 100 mM NaCl while the greatest (23%) reduction in RWC was observed in *C. olitorius* accession 4794 and 3784 at 200 mM NaCl concentration. The average reduction observed for RWC at 200 mM NaCl was higher (20%) than that observed at 100 mM NaCl (9%) concentration (Table 6).

In general, plants with higher dry matter production or yield should have high RWC. Accession *C. capsularis* 4965 showed the highest RWC under all salinity levels, indicating its relative salt tolerance. The osmotic potential of the nutrient solution increases with increasing salinity (Munns and Termaat, 1986), reducing plant water uptake and ultimately affecting RWC. The decreased in RWC can result in decreased leaf area due to reduced leaf turgor which interferes with light interception and can suppress stomatal conductance (Lycoskoufis *et al.*, 2005). Therefore, decreases in RWC may limit plant photosynthetic rates (no data recorded) and ultimately in reduce plant dry matter accumulation.

Chlorophyll content: The chlorophyll content (SPAD value) of these jute accessions was significantly increased at 100 mM NaCl (42.89) but significantly decreased at 200 mM NaCl (32.66), relative to control (37.76) (Table 3). Among these genotypes, the highest chlorophyll content (43.80) was recorded in *C. capsularis* accession 4965 while the lowest (34.57) was recorded in accession *C. olitorius* 3784 (Table 4). The salinity×genotype interaction was indicated by the fact that highest chlorophyll content (51.20) was recorded for accession *C. capsularis* 4965 at 100 mM NaCl while the lowest chlorophyll content (27.88) was recorded for *C. olitorius* accession 3784 at 200 mM NaCl (Table 6).

C. capsularis accession 4965 demonstrated the highest (24%) increase in chlorophyll content at 100 mM NaCl, followed by accession 4955 (23%). The greatest reduction (25%) in chlorophyll content was observed in *C. olitorius* accession 3784 at 200 mM NaCl relative to control. The average increase in chlorophyll content was 13% at 100 mM NaCl while the average decrease in chlorophyll content was 14% at 200 mM NaCl (Table 6).

In general, salt stress reduced leaf chlorophyll content but the increase in chlorophyll content observed at 100 mM NaCl relative to control might indicates a tolerance to moderate salt concentrations in jute. Increased chlorophyll contents under salt stress were also reported by Ziaf *et al.* (2009) in hot pepper. An increase in chlorophyll content due to an increase in the number of chloroplasts in the leaves of stressed plants has been reported (Aldesuquy and Gaber, 1993). Therefore, the increase in chlorophyll content at 100 mM NaCl relative to control might be due such a mechanism or due to changes in relative chlorophyll concentration under lower RWC. In contrast, the chlorophyll content decrease under high (200 mM NaCl) salinity relative to control indicated possible increased chlorophyll degradation, inhibition of chlorophyll synthesis, or disintegration of chloroplasts (no data recorded). In this study, *C. capsularis* accessions 4965 and 4955 maintained high chlorophyll content, a key factor for maintaining photosynthetic capacity under salinity indicating the good potential of these accessions of jute under salt stress.

Salt tolerance index: A salt tolerance index can reliably indicate the relative salt tolerance of plants (Bagci *et al.*, 2007). The Salt Tolerance Index (STI) of each of these jute accessions was strongly reduced under increasing salinity (Table 3) and genotypic variation was also observed in this trait. *C. capsularis* genotype 4965 showed the highest salt tolerance index (STI = 72.53%) at all salinity levels, whereas *C. olitorius* accession 3784 exhibited the lowest salt tolerance index (STI = 44.61%) which indicates that it was the most susceptible accession (Table 4). Regarding the salinity×genotype interaction, *C. capsularis* accession 4965 exhibited the highest salt tolerance index (STI = 85.20%) at 100 mM NaCl, followed by accession 4955 (STI = 84.10%) while *C. olitorius* accession 3784 was the most salt-susceptible (STI = 02.03%) at 200 mM NaCl. The average STI was 57.35% at 100 mM and 16.63% at 200 mM NaCl (Table 6) suggesting that STI decreases with increasing salinity.

In the preseent study, the *C. capsularis* accessions 4965 and 4955 demonstrated the best salt tolerance among these jute genotypes.

Comparative salt tolerance of two species of jute: The mean values for all the physiological parameters studied in *C. capsularis* and *C. olitorius* are summarized in Table 7. Mean root length, shoot length, root dry matter, shoot dry matter, total dry matter, leaf relative water content and chlorophyll content were significantly higher in *C. capsularis* than in *C. olitorius* at all salinity levels. The salt tolerance index of *C. capsularis* was higher (61.23%) than that of *C. olitorius* (53.91%) and the mean percentage reductions in all studied parameters under all salinity levels were lower in *C. capsularis* than in *C. olitorius* (Table 5 and 6). These results suggest that *C. capsularis* is more tolerant to salinity stress than *C. olitorius*, in agreement with the findings of Almgir and Nasrat (1989).

In this study, *C. capsularis* maintained significantly higher relative water content and chlorophyll content in leaf tissue which are key for photosynthetic performance and thereby attained enhanced dry biomass accumulation under each level of salinity stress relative to *C. olitorius*. This physiological advantage of *C. capsularis* might be due to genetic factors that have allowed this species to better adapt to saline conditions due to greater salt tolerance.

Heritability: Broad-sense Heritability (H_b) percentages under all salinity levels for each physiological parameter studied are shown in Table 8. Heritability of all parameters was above 80%. Such high heritability values indicate that selection based on these parameters would be effective for genetic improvement of salinity tolerance in jute.

Relationships among physiological parameters affected by salt stress in jute: Linear regression was used to investigate the relationships among physiological parameters affected by salt stress in jute, under different levels of salinity. The correlation between leaf relative water content and total dry matter was significant (Fig. 1a, R^2 = 0.80). This implies that greater water content in leaf tissue allows accumulation of more carbon through stomata which enhances dry matter gain by the plant. A significant positive relationship between plant biomass production and RWC was also found by Naidu and Swamy (1995). Furthermore, as also reported by Paliwal *et al.* (1986), a significant positive relationship between chlorophyll content (SPAD value) and total dry matter (Fig. 1b, R^2 = 0.91) was observed in the present study which suggests that maintaining or increasing chlorophyll content enhances photosynthesis and subsequent dry matter accumulation. Shoot length is an important component of biomass production in jute and exhibits a highly significant positive correlation (Fig. 1c, R^2 = 0.95) with total dry matter. Additionally, leaf relative water content and chlorophyll content are integral components of the photosynthetic machinery and the correlation between these two traits (Fig. 1d, R^2 = 0.78) indicates that processes that maintain these two physiological parameters are related at a basic level.

Table 7: Comparative performance of two cultivated species of jute for physiological parameters studied after 35 days in hydroponics at all salinity levels

Species	Root length (cm)	Shoot length (cm)	Root dry matter (g plant^{-1})	Shoot dry matter (g plant^{-1})	Total dry matter (g plant^{-1})	Leaf relative water content (%)	Chlorophyll content (SPAD value)	Salt tolerance index (%)
Corchorus capsularis	28.78^a	55.80^a	0.34^a	1.83^a	2.18^a	86.01^a	39.19^a	61.23
Corchorus olitorius	20.59^b	42.70^b	0.22^b	1.24^b	1.46^b	83.66^b	35.98^b	53.91

Means followed by different letters in columns are statistically significant at 0.05 level of probability by DMRT

Table 8: Broad-sense heritability (H_b) of physiological parameters studied under salt stress in hydroponics for jute genotypes

Trait	Root length (cm)	Shoot length (cm)	Root dry matter (g plant^{-1})	Shoot dry matter (g plant^{-1})	Total dry matter (g plant^{-1})	Leaf relative water content (%)	Chlorophyll content (SPAD value)
Heritability (H_b) (%) (broad-sense)	93.29	89.27	83.71	87.90	87.89	82.26	85.87

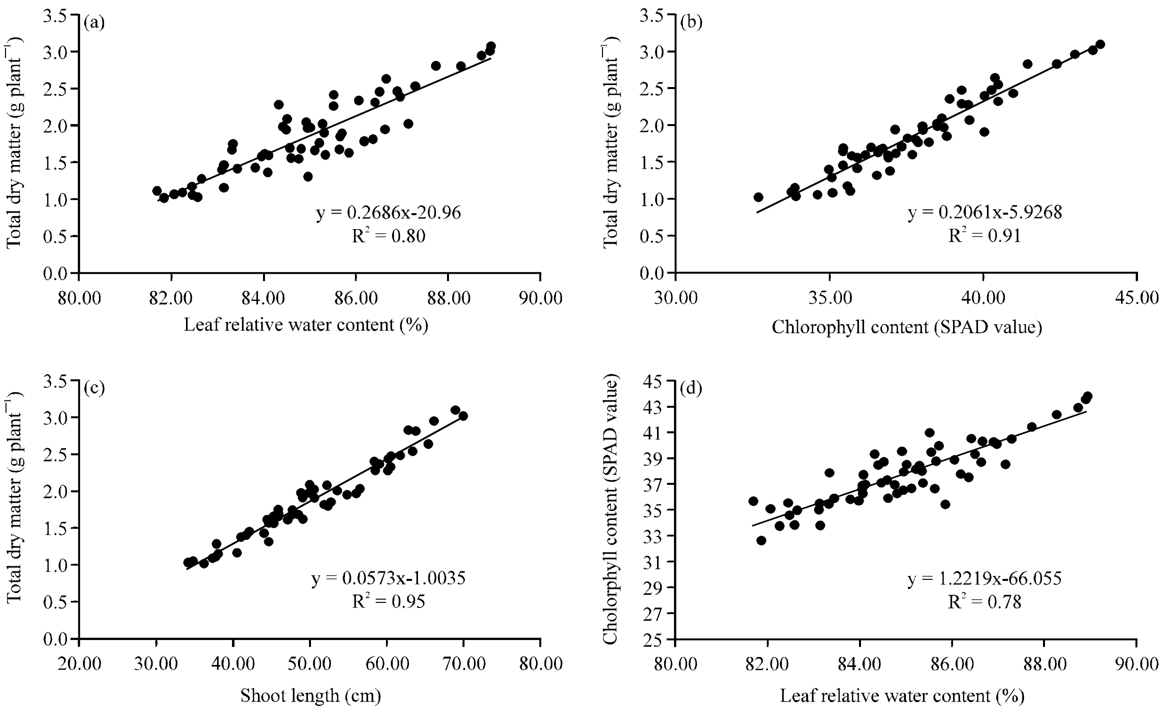

Fig. 1(a-d): Relationship between (a) Total dry matter and leaf relative water content, (b) Total dry matter and chlorophyll content, (c) Total dry matter and shoot length and (d) Chlorophyll content and leaf relative water content of jute after 35 days in hydroponics under all salinity levels

CONCLUSION

The results described here indicate that salt stress significantly reduced leaf relative water content, chlorophyll content and consequently root length, shoot length and dry matter production of jute genotypes analyzed in the present study. The existence of significant genotypic variation among jute genotypes for response to salt stress provides an ample resource for developing salt tolerance. The significant positive relationships among the traits analyzed here demonstrate the potential of these jute genotypes to adapt to various degrees of salt stress. Moreover, the high broad-sense heritability of the physiological parameters studied here indicates that directional selection of these parameters will allow genetic improvement of salt tolerance in jute. In this study, *C. capsularis* accessions 4965 and 4955 demonstrated the best salt tolerance in terms of highest salt tolerance index and lowest reductions in physiological parameters under salt stress. Further investigation of the salt tolerance of these jute accessions, including biochemical parameters under prolonged salinity stress, should be undertaken.

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