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EFFECT OF SALT AND WATER STRESS ON GAS EXCHANGE, DRY MATTER PRODUCTION AND K+/Na+ IONS SELECTIVITY IN SOYBEAN

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Abstract

The experiment was conducted in a vinylhouse at the Banghabandhu Sheikh Mujibur Rahman Agricultural University, Bangladesh during January to May, 2012 to evaluate the effect of salt and water stress on gas exchange characters, dry matter production and K^+/Na^+ ions selectivity in three selected soybean genotypes, namely Galarsum, BD 2331 and BARI Soybean-6. The genotypes were exposed to six treatments viz. (i) control (tap water), (ii) water shortage (irrigation with 70% depletion of available soil water when leaf began to wilt at 10:00 am), (iii) 50 mM NaCl irrigation, (iv) 50 mM NaCl irrigation + water shortage, (v) 75 mM NaCl irrigation, and (vi) 75 mM NaCl irrigation + water shortage conditions. The results revealed that 75 mM NaCl salt + water stress treatment drastically reduced stomatal conductance, photosynthesis and transpiration rate irrespective of soybean genotypes. However, the genotype Galarsum showed minimum transpiritional water loss (1.45 mmol H_2O m^{-2} s^{-1}) and maximum photosynthesis (20.45 µmol CO_2 m^{-2} s^{-1}) as compared to BD 2331 and BARI Soybean-6 under 75 mM NaCl salt + water stress condition. Combined salt and water stress caused greater inhibition of shoot growth than either of the two in soybean. The shoot dry weights were decreased to 24.58, 23.00 and 21.57% of the control in Galarsum, BD 2331 and BARI Soybean-6, respectively at 75 mM NaCl salt + water stress. The genotype Galarsum accumulated higher amount of K^+ (1.19%) and lower amount of Na^+ (0.11%) in leaf tissue under 75 mM NaCl salt + water stress. Results indicated that the genotype Galarsum was more capable to cope with the high levels of salt under water stress condition than the other two genotypes.

Keywords: Soybean; Salt and water stress; Photosynthesis; Respiration; Shoot dry matter; Ion uptake

Introduction

Soybean (*Glycine max* L.) is a minor crop in Bangladesh though it is considered as one of the most nutritious crops in the world (Yaklich *et al*., 2002). Currently, it is gaining popularity in the country for its increasing demand as an ingredient of animal feed as well as for the consciousness of its high nutrition value as human food (Karim *et al.*, 2012).

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Consequently its area is increasing especially in the marginal lands called *charland* (land formed due to accretion of silt on riverbed) and coastal land of southern part of Bangladesh (Islam and Rahman, 2011). Since 1973, the salinity of coastal land has been increased to 27% and the area exceeded one million ha at various levels. More areas are under threat of salinization due to the combined effects of sea level rise, increased tidal effect, introduction of brackish water for shrimp cultivation, continuous reduction of river flow particularly during dry period, capillary upward movement of soluble salts due to presence of high saline ground water table at shallower depth and faulty management of sluice gates in the south and south-western part of Bangladesh (Karim *et al.,* 2014). This causes lower cropping intensity and it is imperative to increase cropping intensity and productivity of the saline belt of Bangladesh. Since soybean is considered as a moderately salt tolerant crop (Mannan *et al*., 2012), it may be a potential candidate crop for exploiting the relatively low saline areas after rainy season rice (*aman*) harvest in the southern Bangladesh. Besides, salt and water stress prevails at the same time in dry seasons, which very often adds extra harm on plant growth (Karim *et al*., 1993). The adverse effects of both salt and water stress are primarily due to the restriction of water uptake by the roots (Karim *et al*., 1993), which decreased relative water content (Orcutt and Nilsen, 2000). Therefore, plants are unable to maintain metabolic activities or turgidity for normal growth because of the low osmotic potential in soil. At the same time, plants absorb damaging amounts of Na^+ and Cl^- (Blum, 1988; Greenway and Munns, 1980; Karim *et al*., 1992). Na^+ is the primary cause of ion specific damage, resulting due to a range of disorders in enzyme activation and protein synthesis (Tester and Davenport, 2003). In addition, Na^+ acts as a competitor of K^+ uptake in plant (Watad *et al*., 1991; Schroeder *et al.*, 1994). In salt-adapted cells, no inhibition of K^+ uptake by NaCl was observed indicating a higher K^+/Na^+ selectivity at the plasma membrane (Watad *et al.*, 1991). Therefore, exclusion of Na^+ at root level and maintenance of high K^+ at shoot level are vital for the plants to grow under saline conditions (Munns *et al*., 2000; Tester and Davenport, 2003). Leaf photosynthetic capacity is suggested to be a key parameter determining crop yield (Jiang *et al.*, 2002; Zhang *et al*., 2007). The rate of photosynthetic CO_2 assimilation is generally reduced by salinity and drought (Lee *et al.*, 2004; Purwanto, 2003). Salt and water stress have various effects on physiological processes in plants. Extent of physiological changes in plants growing under salt and water deficit conditions is considered as an effective tool for identifying stress tolerant soybean for saline belt of Bangladesh. Therefore, this experiment was undertaken to analyze the physiological response in relation to gas exchange, dry matter distribution and mineral ions accumulation pattern in three high yielding soybean genotypes exposed to salt and water stress conditions.

Materials and Method

A pot experiment was carried out in a vinylhouse of the Department of Agronomy at Banghabandhu Sheikh Mujibur Rahman Agricultural University

(BSMRAU), Gazipur, Bangladesh during January to May, 2012. The location of the experimental site is situated at about 24^0 23´ north latitude, 90^0 08´ east longitude and an altitude of 8.4 m. Three genotypes of soybean (Galarsum, BD 2331 and BARI Soybean-6) were grown in six environmental conditions of salinity and water stress. The environmental conditions were (i) control, (ii) water shortage (irrigation with 70% depletion of available soil water when leaf began to wilt at 10:00 am), (iii) 50 mM NaCl irrigation, (iv) 50 mM NaCl irrigation + Water shortage, (v) 75 mM NaCl irrigation, and (vi) 75 mM NaCl irrigation+ Water shortage. The experiment was arranged in a two factor completely randomized design (CRD) with four replications. The genotypes were selected based on their better performance in previous study (Khan *et al.*, 2014). Treatments were imposed after three weeks of seedling emergence. In salt water irrigation and water shortage treatments, initially all pots were irrigated with salt water for a week then water shortage, and thereafter salt water irrigations were applied. The control plants were irrigated with tap water only at field capacity of the soil. Treatments were applied up to harvest. The soils of each pot contained 12 kg air dried sandy loam soil fertilized uniformly with 0.30 g of urea, 0.90 g of triple super phosphate, 0.60 g of muriate of potash and 0.60 g of gypsum before sowing. Five seeds were sown in the soil medium on 20 January, 2012. After the emergence and establishment, two uniform healthy seedlings per pot were allowed to grow for three weeks in the same environment. Admire 200SL @ 1 ml/liter of water was sprayed at 10 and 25 days after emergence to control Jassids and white flies. Ripcord 10 EC @ 1 ml/liter of water was sprayed at 45 and 55 days after emergence to control leaf roller and pod borer. Gas exchange measurements like photosynthetic rate (Pn), stomatal conductance, total conductance to CO_2 and transpiration (E) were measured at 49 days after emergence (after 4 weeks of treatments imposition) by Li-COR 6400 portable photosynthetic system (Li-COR, Lincoln, NE, United States). All the measurements were taken in a bright day between 11:00 and 13:00 h when photosynthetically active radiation (PAR) was between 1100 and 1200 µ mol $m^{-2}s^{-1}$. Photosynthetic water use efficiency (PWUE) was calculated as the ratio between Pn and E. Plants were harvested at 63 days after emergence and different parts of the plant were separated and then oven dried at 70 ºC for 4 days to measure the dry weight of the shoot. Dried leaf samples were used to measure the Na^+ and K^+ ions concentrations of the respective treatments. Collected data were analyzed using STAR (Statistical Tool for Agricultural Research) program and the treatments means were compared by using Tukeys's Honestly Significant Difference (HSD) Test at $P \leq 0.05$.

Results and Discussion

Stomatal conductance to H_2O: Stomatal conductance to H_2O of soybean genotypes was significantly affected by salinity and water stress treatments (Fig .1). Under water stress treatment, BARI Soybean-6 gave significantly the highest conductance (0.32 mol H_2O $m^{-2}s^{-1}$) to water and BD 2331 (0.14 mol H_2O $m^{-2}s^{-1}$)

showed the least, which was identical to the response of Galarsum. The results however, varied under salt stress and, combined salt and water stress conditions. As compared to the salt stress stomatal conductance to H_2O was highly affected by the combined salt + water stress at both the salinity levels (50 and 75 mM NaCl). However, significantly the highest conductance of 0.21 and 0.16 mol H_2O $m^{-2}s^{-1}$ was recorded in Galarsum at 50 and 75 mM NaCl salt stress, respectively. BD 2331 had the identical response to the conductance at the same treatments. The lowest conductance of 0.13 and 0.12 mol H_2O $m^{-2}s^{-1}$ was obtained by BARI Soybean-6 at 50 and 75 mM NaCl salt stress, respectively. Under 75 mM NaCl salt + water stress condition Galarsum showed significantly the highest conductance (0.04 mol H_2O $m^{-2}s^{-1}$), while both BD 2331 and BARI Soybean-6 genotypes had the least (0.03 mol H_2O $m^{-2}s^{-1}$). Genotypic variation of soybean was observed in respect of stomatal conductance to water. These findings are in conformity with that of Kusvuran (2012) who reported that stomatal conductance of the melon genotypes decreased under salt and drought stress and it was slower in the resistant genotypes than sensitive ones.

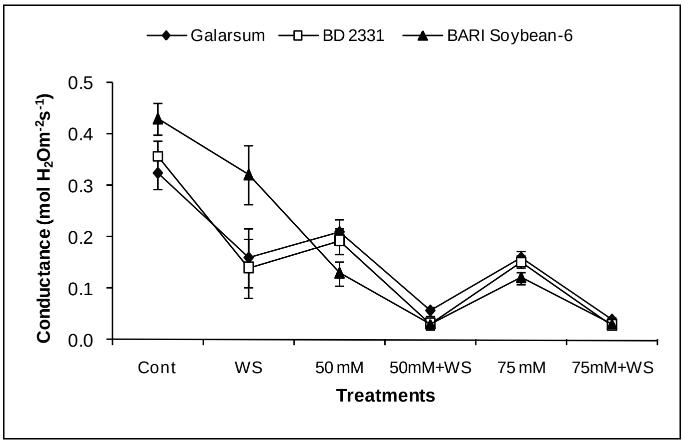

Fig. 1. Stomatal conductance to water as affected by salinity and water stress treatment. Bar represents mean ± S.E. of the genotypes at the same level of treatment.

Here, Cont = Control, WS = Water stress and mM = NaCl concentration in mM.

Total conductance to CO_2: Total conductance to CO_2 of soybean genotypes was distinctly reduced under water stress, salt stress and, combined salt + water stress conditions as compared to control (Fig. 2). Conductance to CO_2 was significantly high in BARI Soybean-6 (0.29 mol CO_2 $m^{-2}s^{-1}$) under only water stress condition, though drastically reduced in Galarsum and BD 2331. The genotype BD 2331 showed the least conductance (0.14 mol CO_2 $m^{-2}s^{-1}$) under water stress. The total conductance reduced lesser extent in the salt stress conditions as compared to the combined salt + water stress conditions at both the salinity levels (50 and 75 mM NaCl). At the lower level of salt stress conditions Galarsum showed significantly the highest conductance (0.20 mol CO_2 $m^{-2}s^{-1}$), which was identical with that of

BD 2331. BARI Soybean-6 showed the least conductance (0.12 mol CO_2 $m^{-2}s^{-1}$). At the highest level of salt stress (75 mM NaCl), Galarsum and BD 2331 showed the highest conductance (0.12 mol CO_2 $m^{-2}s^{-1}$) and BARI Soybean-6 the least (0.10 mol CO_2 $m^{-2}s^{-1}$).

Under the low level of salinity + water stress condition genotype Galarsum showed the highest conductance (0.05 mol CO_2 $m^{-2}s^{-1}$), which was identical with that of BD 2331 and BARI Soybean-6. Under the high level of salinity + water stress conditions all genotypes had similar conductance to CO_2. Total conductance to CO_2 through stomata and mesophyll decreased due to low water availability under salt and water stress. Turner *et al*. (1998) reported that stomatal conductance decreased as the osmotic potential decreased in sorghum and sunflower. Similar results were also found by Dadkhah (2010) in sugar beet.

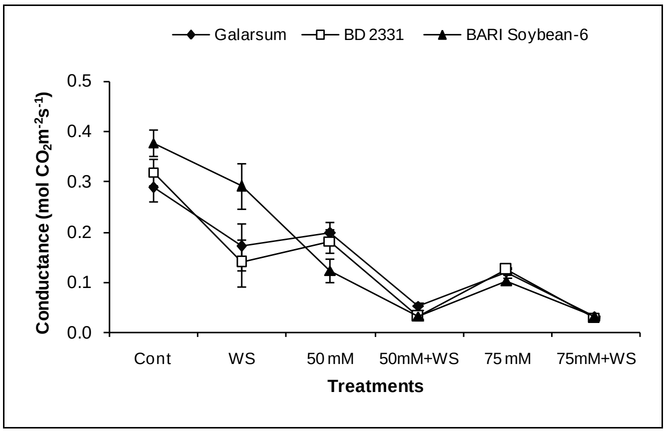

Fig. 2. Total conductance to CO_2 as affected by salinity and water stress treatment. Bar represents mean ± S.E. of the genotypes at the same level of treatment.

Here, Cont = Control, WS = Water stress and mM = NaCl concentration in mM.

Photosynthetic rate: Photosynthetic rate (Pn) of soybean genotypes significantly declined when plants were exposed to water stress, salt stress and, combined salt + water stress conditions (Fig. 3). Under only water stress condition, BARI Soybean-6 depicted significantly the highest photosynthetic rate (35.44 µmol CO_2 $m^{-2}s^{-1}$), while it drastically reduced in Galarsum (25.24 µmol CO_2 $m^{-2}s^{-1}$) and BD 2331 (21.34 µmol CO_2 $m^{-2}s^{-1}$) genotypes. As compared to only the salt water stress and, the combined salt + water stress conditions, Pn rate reduced lesser extent in the salt stress condition. However, the reduction was higher at higher salt stress both in only salt stress and, the combined salt + water stress conditions due to more restriction of water uptake by the roots. The results are in agreement with that of Netondo *et al*. (2004) who reported that photosynthetic activity decreased when plants were grown under saline conditions. However, significantly the highest photosynthetic rates of 34.49 and 29.47 µmol CO_2 $m^{-2}s^{-1}$ were recorded in Galarsum at 50 and 75 mM NaCl salt stress, respectively. BD 2331 had identical rate at the same treatments. The lowest photosynthetic rate of

29.70 and 27.30 µmol CO_2 $m^{-2}s^{-1}$ were recorded in BARI Soybean-6 at 50 and 75 mM NaCl salt stress, respectively. Under 50 mM NaCl + water stress condition, Galarsum (23.62 µmol CO_2 $m^{-2}s^{-1}$) showed significantly the highest Pn rate followed by BARI Soybean-6 (21.55 µmol CO_2 $m^{-2}s^{-1}$). BD 2331 (20.76 µmol CO_2 $m^{-2}s^{-1}$) showed the lowest rate. Galarsum (20.45 µmol CO_2 $m^{-2}s^{-1}$) also showed significantly the highest Pn rate under 75 mM NaCl + water stress condition. BD 2331 showed the least rate (20.36 µmol CO_2 $m^{-2}s^{-1}$), which was identical with the Pn rate of BARI Soybean-6 (20.38 µmol CO_2 $m^{-2}s^{-1}$) in the same treatment. The rate of photosynthetic CO_2 assimilation is generally reduced by salinity and drought. This reduction is partly due to a reduced stomatal conductance and consequent restriction of the availability of CO_2 for carboxylation (Brugnoli and Lauteri, 1991). Wang *et al*. (2011) reported that photosynthetic rate decreased under salt and water severity in tamarisk seedlings. Eisa *et al*. (2012) also reported that the net photosynthesis rates were greatly decreased by high salinity and salt-induced photosynthesis inhibition was accompanied with a decrease in transpiration rates but also with improved water use efficiency.

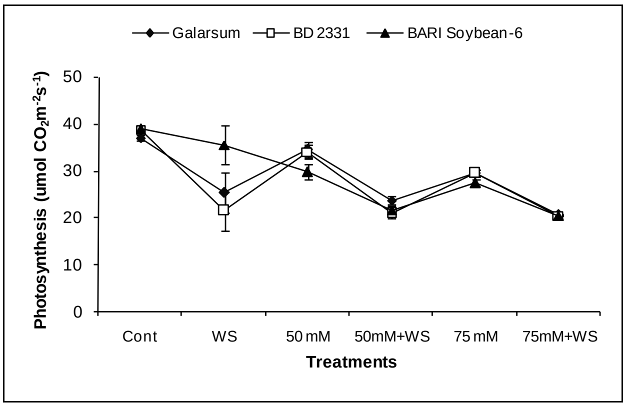

Fig. 3. Leaf photosynthesis as affected by salinity and water stress treatment. Bar represents mean ± S.E. of the genotype at the same level of treatment.

Here, Cont = Control, WS = Water stress and mM = NaCl concentration in mM.

Transpiration rate: Water stress, salt stress and, combined salt + water stress led to a remarkable reduction in transpiration rate (E) of soybean genotypes as compared to control (Fig. 4). The reduction in water loss through transpiration was mainly due to the reduction of stomatal conductance to H_2O under salinity and water stress conditions. Genotypes varied in transpiration rates under different stresses. Under only water stress, condition BARI Soybean-6 transpired significantly the highest (11.96 mmol H_2O $m^{-2}s^{-1}$) compared to others. Galarsum transpired the lowest (4.01 mmol H_2O $m^{-2}s^{-1}$), which was identical with BD 2331 (4.07 mmol H_2O $m^{-2}s^{-1}$). Transpiration rate reduced to lesser extent in the salt stress condition than the combined salt + water stress condition. However, at lower level of salt stress (50 mM NaCl) treatment, significantly the highest transpiration rate (7.58 mmol H_2O $m^{-2}s^{-1}$) was recorded in BD 2331, which was identical (7.38 mmol H_2O $m^{-2}s^{-1}$) with the rate of Galarsum. BARI Soybean-6 had the lowest rate (6.69 mmol H_2O $m^{-2}s^{-1}$). At higher level of salt stress (75 mM NaCl), significantly the highest transpiration (6.66 mmol H_2O $m^{-2}s^{-1}$) was recorded in BARI Soybean-6 which was identical with the rate of BD 2331 (6.42 mmol H_2O $m^{-2}s^{-1}$). Galarsum showed significantly the least transpiration rate (6.06 mmol H_2O $m^{-2}s^{-1}$). In the combined salt + water stress conditions the transpiration rate was higher in BARI Soybean-6 than other genotypes. At the 50mM NaCl + with water stress, the highest transpiration rate (2.22 mmol H_2O $m^{-2}s^{-1}$) was recorded in BARI Soybean-6, which was identical with the rate (2.73 mmol H_2O $m^{-2}s^{-1}$) of Galarsum. On the contrary, BD 2331 showed the least rate (2.55 mmol H_2O $m^{-2}s^{-1}$). At higher level of salinity (75mM NaCl) + water stress treatment, BARI Soybean-6 showed the highest transpiration rate (2.22 mmol H_2O $m^{-2}s^{-1}$), which was identical to that of BD 2331(1.80 mmol H_2O $m^{-2}s^{-1}$). At this condition Galarsum showed the lowest transpiration rate (1.45 mmol H_2O $m^{-2}s^{-1}$). The results are in agreement with the findings of Wang *et al*. (2011) in tamarisk (*Tamarix chinensis* Lour.) seedlings. Eisa *et al*. (2012) reported that the transpiration rates were decreased by high salinity in quinoa. Plants subjected to water and salinity stress had lower stomatal conductance resulted in lower rate of transpiration. Water stress and salinity cause stomatal closure which reduced transpiration rate as reported by Halim *et al*. (1990).

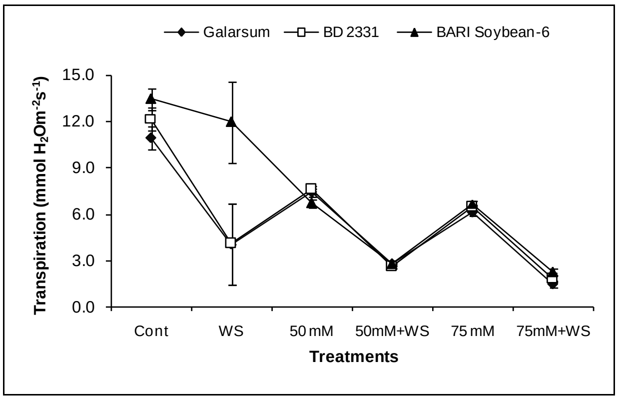

Fig. 4. Leaf transpiration as affected by salinity and water stress treatment. Bar represents mean ±S.E. of the genotype at the same level of treatment.

Here, Cont = Control, WS = Water stress and mM = NaCl concentration in mM.

Photosynthetic water use efficiency: Water stress, salt stress and, combined salt + water stress led to a strong reduction in soybean plants transpiration rate (E), which reached minimum at higher level of salinity irrespective of water stress and non-water stress conditions (Fig. 5). This led to significantly increase in photosynthetic water use efficiency (PWUE) under different stresses as compared to control. PWUE of soybean genotypes varied under different stresses. Under only water stress condition the highest PWUE (6.35) was recorded in Galarsum, which was identical with PWUE (5.30) of BD 2331, though the lowest (2.97) was obtained in BARI Soybean-6.

Under salt stress conditions, PWUE was maximum (4.67 and 4.86 in 50 mM and 75mM NaCl, respectively) in Galarsum and minimum (4.44 and 4.10 in 50 mM and 75mM NaCl, respectively) in BARI Soybean-6. At lower level of salinity combined with water stress condition, PWUE was the highest (8.79) in Galarsum, which was identical with the efficiency (8.28) of BD 2331. BARI Soybean-6 showed the lowest efficiency (7.78). At higher level of salinity + water stress conditions, significantly the highest PWUE (14.20) was obtained by Galarsum, which was identical with the efficiency (11.36) of BD 2331 and the lowest (9.19) in BARI Soybean-6. Plants under salt and water deficit conditions usually minimize transpirational water loss and maximize photosynthesis and show higher water-use efficiency (Xu *et al*., 1994). This is a kind of adaptation mechanism that allows plants to survive water deficit conditions. Salt-induced increase in water use efficiency in *Chenopodium* was also reported by Eisa *et al*. (2012).

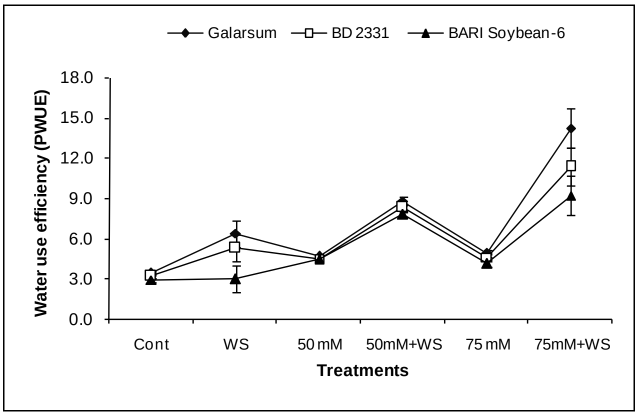

Fig. 5. Photosynthetic water use efficiency (Pn/E) as affected by salinity and water stress treatment. Bar represents mean ± S.E. of the genotype at the same level of treatment.

Here, Cont = Control, WS = Water stress and mM = NaCl concentration in mM.

Shoot dry weight: Salinity and water stress significantly affected the shoot dry weight of soybean genotypes measured at 63 days after emergence (Table 1). The lowest shoot dry weight (3.38 g) was produced by BARI Soybean-6 at 75 mM NaCl salt + water stress condition which was identical with the dry matter (3.51 g) of BD 2331 and Galarsum (3.54 g) at the same treatment. The shoot dry weights were decreased to 24.58, 23.00 and 21.57% of the control in Galarsum, BD 2331 and BARI Soybean-6, respectively. Shoot dry weight significantly affected in the combined salt + water stress condition as compared to only salt stress in both the salinity levels (50 and 75 mM NaCl). It was drastically reduced with the increasing salinity levels along with water stress. However, all the genotypes produced identical shoot dry weight at the same level of treatment. At the 75 mM NaCl salt stress condition BD 2331 produced the lowest shoot dry weight (5.68 g) followed by BARI Soybean-6 (6.41 g) and Galarsum (6.94 g). Shoot dry weight of soybean genotypes was significantly affected by water stress as compared to control. The lowest shoot dry weights of 4.63 g, 5.36 g and 5.37 g were recorded in BD 2331, Galarsum and BARI Soybean-6, respectively under water stress conditions. Application of salt water increased the soil salinity and thus decreased the soil water potential though did not decrease water flow to the roots. Root cortical cells can osmotically adjust to some extent allowing water to readily move into the root. Therefore, shoot dry weight of soybean was affected more under salt + water stress conditions than only in salt or water stress conditions. When the soil dries under water stress conditions the soil matric potential is decreased, therefore increased the resistance of water flow to the roots in a non-linear fashion (Homaee *et al*., 2002). The findings was also an agreement with the findings of Meiri (1984) that the matric potential preferentially affected the shoot growth of bean more than that did the osmotic potential. Wang *et al* (2011) also reported that shoot biomass decreased significantly in tamarisk seedlings due to water severity under

Table 1. Shoot dry weight of soybean genotypes (g/plant) as affected by salinity and water stress at 63 days after emergence

Treatment	Genotypes		
	Galarsum	BD 2331	BARI Soybean-6
Control	14.39 ± 1.54a (100)	15.26 ± 2.00a (100)	15.67 ± 2.22a (100)
Water stress (WS)	5.36 ± 0.98cde (37.25)	4.63 ± 0.65de (30.34)	5.37 ± 0.51cde (34.25)
50 mM NaCl	9.56 ± 0.88b (66.44)	8.73 ± 1.16bc (57.21)	8.36 ± 1.42bc (53.35)
50 mM NaCl + WS	4.82 ± 0.71de (33.47)	4.21 ± 1.04de (27.57)	4.26 ± 0.19de (27.21)
75 mM NaCl	6.94 ± 1.24bcd (48.25)	5.68 ± 0.82cde (37.24)	6.41 ± 0.17bcde (40.88)
75 mM NaCl + WS	3.54 ± 0.43e (24.58)	3.51 ± 0.37e (23.00)	3.38 ± 0.81e (21.57)
HSD (0.05)		3.38	
Std Error		0.90	
CV (%)		15.27	

Different letters indicate a significant difference at P = 0.05. Lettering was made for observing the variation in genotype x environmental response.

Data in parenthesis indicate percentage of shoot dry weight to control.

salt and water stress condition. The reduction in shoot dry weight due to salinity was reported by Karim *et al*. (1993) in triticale, Khan *et al*. (1997) in rice, Aziz *et al*. (2005) in mungbean, Chookhampaeng (2011) in pepper plant and Mannan *et al*. (2013a) in soybean.

Sodium accumulation: The accumulation of Na^+ in the leaves of soybean genotypes was significantly affected by salinity and water stress treatments (Table 2). The highest accumulation (0.171%) was obtained from BARI soybean-6 at 75 mM NaCl salt stress, which was followed by BD 2331 (0.149%). The genotype Galarsum accumulated significantly lower (0.138%) than others at the same treatment. The lowest accumulation (0.061%) was obtained from Galarsum under only water stress treatment, which was identical with BD 2331 (0.066%) in the same treatment and also from Galarsum (0.066%) under control. The results revealed that the accumulation of Na^+ was higher in the salt stress conditions at both the salinity levels (50 and 75 mM NaCl) than the combined salt + water stress conditions, and the accumulation increased with the rise of salinity level. However, at 75 mM NaCl + water stress treatment, all the three genotypes accumulated identical amount of Na^+. Among the genotypes, BARI Soybean-6 accumulated maximum (0.116%) followed by BD 2331 (0.113%) and the Galarsum accumulated minimum (0.110%) at the same treatment. The higher accumulation of Na^+ in leaves under salinity and water stress might be due to higher transpiration rate. Differences in Na^+ accumulation in soybean genotypes revealed that the genotype Galarsum, which accumulated lower Na^+ was more tolerant than that of BD 2331 and BARI Soybean-6. The mechanisms of plant responses to salt and water stress have much in common, because salinity leads to many metabolic changes that are identical to those caused by water stress. The results of the study are in agreement with the earlier reports that the tolerant genotypes accumulate less amounts of Na than susceptible ones (Karim *et al*., 1992; Khan *et al*., 1997; Ahmadi *et al*., 2009; Mannan *et al*., 2013). The excess amount of Na^+ creates a toxic effect on plant metabolic processes and therefore, the susceptible cultivars having high amounts of Na^+ suffer more from the effect than the tolerant cultivars (Blum, 1988; Karim *et al*., 1992). Kao *et al*. (2006) also reported that differences among soybean species in leaf accumulation of Na^+ might be responsible for the differential sensitivity to NaCl treatments.

Table 2. Sodium (Na) uptake in leaf tissue (%) of soybean genotypes after 6 weeks of imposition of the stress treatments

Treatment	Genotypes		
	Galarsum	BD 2331	BARI Soybean-6
Control	0.066 ± 0.001ij	0.072 ± 0.004hi	0.077 ± 0.005h
Water stress (WS)	0.061 ± 0.003j	0.066 ± 0.001ij	0.072 ± 0.0041hi
50 mM NaCl	0.127 ± 0.002d	0.127 ± 0.002d	0.143 ± 0.003bc
50 mM NaCl + WS	0.094 ± 0.003g	0.099 ± 0.003g	0.101 ± 0.003fg
75 mM NaCl	0.138 ± 0.003c	0.149 ± 0.003b	0.171 ± 0.007a
75 mM NaCl + WS	0.110 ± 0.003ef	0.113 ± 0.004e	0.116 ± 0.004e
HSD (0.05)		0.01	
Std Error		0.003	
CV (%)		3.15	

Different letters indicate a significant difference at P = 0.05. Lettering was made for observing the variation in genotype x environmental response.

Potassium accumulation: The accumulation of K^+ in the leaves of soybean genotypes was significantly affected by salinity and water stress treatments (Table 3). The highest accumulation (1.25%) was obtained in Galarsum at 50 mM NaCl salt combined with water stress, which was identical with the same genotype at 50 mM NaCl (1.24%), and also BD 2331 (1.22%) and BARI Soybean-6 (1.24%) at only water stress. The accumulation of K^+ was significantly decreased at 75 mM NaCl salt stress and also combined water stress treatment irrespective of variety. However, the accumulation was to some extent increased in the combined salt + water stress conditions than only the salt stress conditions. The lowest (1.12%) amount of K^+ accumulation was obtained from BARI Soybean-6 at 75 mM NaCl salt stress, which was identical with the same genotype at 75 mM NaCl salt + water stress (1.13%) and BD 2331 (1.16%) at 75 mM NaCl salt stress. At 75 mM NaCl + water stress treatment, genotype Galarsum accumulated the maximum (1.19%) amount of K^+, which was identical with the same genotype at 75 mM NaCl salt stress (1.18%) and with BD 2331 both at salt and water stress treatments. Under water and salt stress conditions K^+ plays an important role in osmoregulation and the tolerant genotype accumulates higher amounts than the susceptible ones (Blum, 1988; Qadar, 1988). Maintenance of high cytoplasmic levels of K^+ is essential for survival of plants in saline habitats (Chow *et al.*, 1990). Here, the soybean genotype Galarsum accumulated higher amount of K^+ in leaves than others under salt and water stress conditions. It could be due to high potentiality of the genotype.

Table 3. Potassium (K) uptake in leaf tissue (%) of soybean genotypes after 6 weeks of imposition of the stress treatments

Treatment	Genotypes		
	Galarsum	BD 2331	BARI Soybean-6
Control	1.166 ± 0.006e-g	1.176 ± 0.007d-f	1.155 ± 0.013f-h
Water stress (WS)	1.197 ± 0.009c-e	1.218 ± 0.005a-c	1.239 ± 0.006ab
50 mM NaCl	1.239 ± 0.006ab	1.197 ± 0.009c-e	1.187 ± 0.005c-f
50 mM NaCl + WS	1.250 ± 0.026a	1.208 ± 0.033b-d	1.197 ± 0.009c-e
75 mM NaCl	1.176 ± 0.007d-f	1.155 ± 0.013f-h	1.124 ± 0.006h
75 mM NaCl + WS	1.187 ± 0.005cd-f	1.166 ± 0.007e-g	1.134 ± 0.006gh
HSD (0.05)		0.039	
Std Error		0.01	
CV (%)		1.07	

Different letters indicate a significant difference at P = 0.05. Lettering was made for observing the variation in genotype x environmental response.

Ratio of Potassium and Sodium: The ratio of K^+ and Na^+ was decreased under salt and water stress treatments and decreased sharply at the higher salt concentration (Fig. 6). Under only water stress treatment, significantly the highest ratio (17.73) of potassium and sodium was obtained from Galarsum, which was identical with the ratio (16.45) in BD 2331, while the lowest (15.00) in BARI Soybean-6. Under 75 mM NaCl salt stress treatment, the highest K^+ : Na^+ ratio (8.55) was obtained from Galarsum, which was identical with the ratio (7.78) obtained from BD 2331 and the lowest (6.59) from BARI Soybean-6. The ratio was to some extent increased in the combined salt and water stress conditions than only in the salt stress treatments. However, at 75mM NaCl salt + water stress treatment the highest ratio (10.79) was also obtained from Galarsum, and the lowest (9.82) from BARI Soybean-6, which was identical with the ratio (10.31) obtained from BD 2331. The results are in agreement with the findings that tolerant genotypes maintain a higher K^+/Na^+ ratio than susceptible ones (Nair and Khulbe, 1990; Mannan *et al*., 2013b). A greater degree of salt tolerance in plants was found to be associated with a more efficient system for selective uptake of K^+ over Na^+ (Neill *et al*., 2002). The selective uptake of K^+ in contrast to Na^+ was considered as one of the important physiological mechanisms contributing to salt tolerance in many plant species (Poustini and Siosemardeh, 2004).

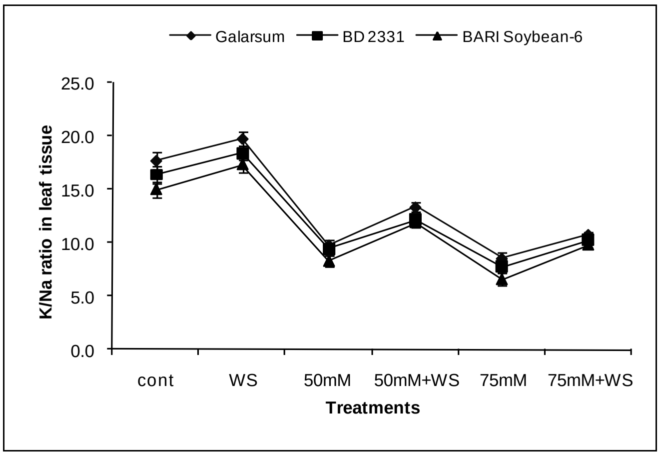

Fig. 6. K/Na ratio in leaf tissue of soybean genotypes after 6 weeks of beginning of the stress treatments. Bar represents mean ± S.E. of the genotype at the same level of treatment.

Here, Cont = Control, WS = Water stress and mM = NaCl concentration

Conclusion

Salinity and water stress had severe adverse effect on stomatal conductance, photosynthesis and transpiration rate of soybean genotypes. The genotype Galarsum minimized transpiritional water loss and maximized photosynthesis as compared to BD 2331 and BARI Soybean-6 under salt and water stress environments. Combined salt + water stress caused greater inhibition of shoot growth than either only salt or water stress in soybean. Galarsum accumulated higher amount of K^+ and lower amount of Na^+ in leaves under salt and water stress. The results indicated that the genotype Galarsum is more capable in tolerating high levels of salt under water stress condition than BD 2331 and BARI Soybean-6.

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