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Effect of salt stress on morpho-physiology, vegetative growth and yield of rice

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Abstract

Selection of salt tolerant rice varieties has a huge impact on global food supply chain. Five Malaysian rice (*Oryza sativa* L.) varieties, MR33, MR52, MR211, MR219 and MR232 were tested in pot experiment under different salinity levels for their response in term of vegetative growth, physiological activities, development of yield components and grain yield. Rice varieties, BRRI dhan29 and IR20 were used as a salt-sensitive control and Pokkali was used as a salt-tolerant control. Three different salinity levels viz. 4, 8, and 12 dS m^{-1} were used in a randomized complete block design with four replications under glass house conditions. Two Malaysia varieties, MR211 and MR232 performed better in terms of vegetative growth (plant height, leaf area plant^{-1}, number of tillers plant^{-1}, dry matter accumulation plant^{-1}), photosynthetic rate, transpiration rate, yield components, grain yield and injury symptoms. While, MR33, MR52 and MR219 verities were able to withstand salinity stress over salt-sensitive control, BRRI dhan29 and IR20.

Key words

Growth, Photosynthesis, Rice, Salinity, Transpiration, Yield

Introduction

Soil salinity is a global environmental challenge to sustainable agriculture which has been increasing over the time (Hossain *et al*., 2012). This may be due to the use of chemical fertilizer, soil erosion, rising sea level because of global warming and ice-belt melting, as well as natural disasters which occasionally cause wide spread submergence of agricultural land under sea water (Brinkman, 1980). The total salinized land around the world was 323 million hectare in 1980 (Brinkman, 1980) and it is expected to cross 400 million hectare by 2025. Soil salinity, in general, reduces plant growth or may lead to plant death due to osmotic ions and nutrient imbalance (Tao *et al.*, 2008; Afifi *et al.*, 2010). This ecological adaptation of salt-tolerant plants has attracted the researchers all over the world to search for salt tolerant varieties from natural environment.

More than half of the world's population depend on rice for food. Asia alone accommodates approximately two billion rice consuming populace (Rao *et al.*, 2007). In Malaysia, rice is the third top ranking crop, mainly grown in eight granaries, covering an area of about 205, 548 ha in Peninsular Malaysia (Ministry of Agriculture, 2007) and fulfilling approximately 65% of the domestic demand (Najim *et al.*, 2007). To fulfil the current domestic demand and increasing future requirement, Malaysia must expand the size of its rice cultivating land area (Selamat and Ismail, 2009). It is predicted that salinity would affect around one million hectare of rice growing areas by 2056 (Selamat and Ismail, 2008). Continuous intrusion of saline water will result in decreasing rice producing areas, leading to food shortages in domestic and international food supply chain. Therefore, researchers and policy makers must find new ways for the efficient utilization of salinity prone areas. The selection of salt tolerant rice varieties might be the best approach to bring salinity susceptible areas under rice cultivation (Ali *et al*., 2004; Shereen *et al.*, 2005). Although much research has been done understand the influence of saline habitats on seed germination, growth, reproduction and population dynamics of crop plants (Khan *et al*., 2002) but report on Malaysian rice under saline environments is scanty. This experiment was therefore undertaken to search for salt-tolerant rice cultivars and thereby for successful rice production on salt affected soils in Malaysia.

Materials and Methods

This study was conducted in pots (33 diameter and 23 cm depth) placed in the glasshouse of University Putra Malaysia during October 2010 to January 2011. The experiment was laid out in Randomized Complete Block Design with four replicates. Among the selected eight rice varieties chosen, five were of Malaysian varieties (viz. MR33, MR52, MR211, MR232 and MR219) and three were of exotic origin (BRRI dhan29, IR20 and Pokkali). BRRI dhan 29 and IR20 were salt sensitive and were used as negative control. On the other hand, Pokkali is a well-known salt resistant cultivar and was used as a positive control. The rice field soil was collected from Tangjung Karang, Selangor, Malaysia and 10 kg of clean soil was put in each pot. The pot soil was fertilized with urea, triple super phosphate (TSP), muriate of potash (MOP) and gypsum as a source of N, P, K and S @ 170 kg N, 80 kg P_2O_5, 150 kg K_2O and 20 kg S ha^{-1}, respectively. The whole amount of TSP, MOP and gypsum were applied prior to final preparation of pots. Thereafter, the soil in pots was saturated with water. Six week-old rice seedlings were transplanted @ three seedlings per pot. Two weeks after transplantation, the salt solutions were applied in each pot as per treatment. To avoid osmotic shock, salt solutions were added in three equal instalments on alternate days until the expected conductivity was acquired. Salt solutions were collected every 24 hrs from each pot and their electric conductivity was measured with a conductivity meter. Necessary adjustments were made as per treatment specification. One-third of the urea was applied after 15 days after transplantation (DAT) and the remaining 2/3rd top dressed in two equal instalments at 45 and 75 DATs. Weeds growing in the pots were removed manually from time to time. The plants were watered when needed to maintain the required soil moisture and salt concentrations. Leaf area was measured at 45 DAT by using leaf area meter (MODEL: LI-3100 AREA METER, USA). Plant height was measured from the ground level to the tip of the longest leaf just before harvest. Total number of tillers per hill was counted at maturity stage. The collected samples were oven dried at 70 ºC for three days and total dry matter was recorded. The total dry matter was calculated by summation of root and shoot weights. The grain yield was harvested and adjusted to 12% moisture content. Data on yield components including number of panicles per hill, number of filled grains per panicle, 1000-grain weight and grain yield $hill^{-1}$ were also recorded.

Transpiration (µmol H_2O $m^{-2}s^{-1}$) and photosynthesis (µmol CO_2 m^{-2} s^{-1}) were measured from flag leaf of rice at 45 DAT using Li-cor 6400 portable analyser (Li-Cor Inc., Lincoln, NE, USA). Photosynthesis was measured using automatically generated light response curves (Hubbart *et al*., 2007). Three fully expanded leaves were sampled per variety per salinity treatment.

Data analyses : Statistical analyses of the collected data were performed using Analysis of Variance and the significance of variation between the means was tested by Least Significant Difference (LSD) using computerized Statistical Analysis System Software (SAS version 9.0).

Results and Discussion

The overall effect of salinity and also varieties was highly significant ($P< 0.01$) on plant height (Table 1). The plant height of all rice varieties was significantly affected by different level of salinity stresses. BRRI dhan29, MR219 and IR20 were identified as the most susceptible varieties to salinity stress as they showed 24, 17 and 9% height reduction at 4 dS m^{-1}, 47, 36 and 32% at 8 dS m^{-1} and 63, 58 and 50% at 12 dS m^{-1} salinity respectively. The remaining five varieties, namely, Pokkali, MR211, MR232, MR33 and MR52, exhibited a 4-7% height reduction at 4 dS m^{-1}(Table 2). However, Pokkali, MR211 and MR232 were identified as the most tolerant rice varieties since they showed highest level of tolerance even at higher salinity of 12 dS m^{-1}. While the heights of these varieties were reduced by 31-40%, other varieties were reduced by 50-63% at 12 dS m^{-1}.

Choi *et al.* (2003) observed that the plant height of rice decreased significantly in the soil affected by 0.5% salinity.. Similar results have been earlier been reported by Mahmood *et al*. (2009) and Alam *et al*. (2004) where the plant height of rice varieties was found to decrease significantly with increasing salinity. Motamed *et al*. (2008) observed no changes in plant height of rice population at low salt concentration (≤ 2 dS m^{-1}). However, the plant heights were significantly reduced with increasing salinity level. Although the present study was not performed at low concentration. However, it clearly reflected that plant height reduction had a proportional relation with salinity increment. Additionally, the salt tolerant varieties outperformed the sensitive varieties with significant retention of plant height even at higher salinity.

The leaf area were significantly in all rice verities was affected salinity stress (Table 1). At 4 dS m^{-1} salinity, the most affected varieties were IR20, MR219 and BRRI dhan29, where the reduction in leaf area was 22, 18 and 14%, respectively. The least affected varieties were MR232, MR211 and Pokkali, where the reductions in leaf area was 3, 6 and 9%, respectively. MR52 and MR33 showed medium level of tolerance demonstrating reductions of 10 and 11% in leaf areas at 4 dS m^{-1} salinity. These were more clearly reflected at higher level of salinity (12 dS m^{-1})

Table 1 : The main effect of salinity on growth and yield components of eight rice varieties

Treatments	**Growth parameters**					**Yield components and grain yield**				
	Plant height (cm)	**Leaf area (cm^2)**	**Total dry matter (g plant^{-1})**	**Root-shoot ratio**	**Tiller (no.hill^{-1})**	**Panicle (no. hill^{-1})**	**Panicle length (cm)**	**Fertility perce ntage**	**Filled grain (no. hill^{-1})**	**1000 grain wt (g)**
Salinity levels (dSm^{-1})										
0	129.26 a	787.52 a	19.47 a	0.178 b	14.91 a	11.20 a	22.70 a	91.74 a	112.17 a	23.24 a
4	117.91 b	667.01 b	15.49 b	0.168 b	12.36 b	8.21 b	21.06 b	78.82 b	66.02 b	23.24 b
8	96.71 c	458.74 c	10.24 c	0.163 bc	8.40 c	3.93 c	13.47 c	39.52c	24.48 c	12.21 c
12	68.07 d	307.55 d	5.53 d	0.206 a	5.20 d	1.09 d	6.24 d	12.41 d	4.73 d	6.34 d
F-test	**	**	**	**	**	**	**	**	**	**
Variety										
IR20	83.53 d	487.12 e	9.73 d	0.174 d	10.08 bc	4.51 e	9.84 e	37.33 e	38.60 f	8.80 f
Pokkali	164.20 a	495.70 de	10.91 c	0.141e	7.54 d	5.04 de	21.48 a	71.74 b	58.98 c	23.21a
MR33	116.78 b	523.24 cd	11.85 b	0.179 cd	10.56 b	6.19 bc	15.02 c	52.54 c	53.77 d	15.48d
MR52	105.53 c	577.61 b	10.77 c	0.194 abc	10.82 b	6.59 b	14.82 c	54.00 c	63.05 b	15.05 d
MR211	88.55 d	576.51 b	10.75 c	0.165 d	10.80 b	8.15 a	19.70 b	73.00 ab	78.50 a	20.44 c
MR219	88.83 d	554.25 bc	10.60 c	0.196 ab	10.12 bc	5.73 cd	14.70 c	45.40 d	54.15 d	11.42 e
MR232	101.85 c	641.98 a	12.49 a	0.202 a	12.25 a	7.94 a	20.09 b	72.87 a	80.11 a	22.09 b
BRRI dhan29	74.65 e	585.22 b	9.89 d	0.181 bcd	9.59 c	4.72 e	10.92 d	40.40 e	44.55 e	9.19 f
F-test	**	**	**	**	**	**	**	**	**	**
CV (%)	7.024	7.86	9.68		11.25	14.38	7.08		11.85	6.50

Means with the same letter in the columns do not differ significantly ($P \leq 0.05$)

where 70, 68 and 66% reduction in leaf area was observed in BRRI dhan29, IR20 and MR219, respectively. MR211, MR232 and Pokkali varieties showed 43, 48 and 47% reduction in leaf growth at higher salinity, reflecting their highest level of salinity tolerance (Table 2). Leaf areas of MR33 and MR52 were reduced by 57% at higher salinity. Thus leaf area measurement identified MR211, MR232 and Pokkali as salt tolerant varieties and IR20, MR219 and BRRI dhan29 as salt susceptible varieties. Alam *et al.* (2004) observed that the leaf area of rice genotypes reduced greatly with increasing levels of salinity. Similar observation was reported by Cha-um (2009) who found a significant leaf area reduction in different rice varieties exposed to increasing salt concentrations.

The estimation of total dry matter (TDM) is viewed as a valuable index for monitoring the vegetative growth of plant. The TDM of all varieties were significantly influenced under different saline conditions. The highest dry matter production was found in MR232 (Table 1). The study reflected that MR232, MR211 and Pokkali can significantly tolerate salinity shocks even at 12 dS m^{-1} of salinity. These varieties demonstrated 5-9, 27-29 and 52-55% reduction in TDM at 4, 8 and 12 dSm^{-1} salinity level, respectively. The TDM reduction in susceptible varieties, BRRI dhan29, IR 20, MR219, MR52 and MR33, were 11-25% at 4 dS m^{-1}, 37-61% at 8 dS m^{-1} and 68-79% at 12 dS m^{-1}. BRRI dhan29, IR20 and MR219 were most susceptible; MR33 and MR52 were moderately susceptible and MR232, MR211 and Pokkali were tolerant varieties found in this study. Earlier Asch *et al.* (2000) reported that the salt tolerant genotypes showed less reduction in dry matter while the susceptible genotype showed greater reduction in TDM of the plants. These findings are in confirmation with the previous studies of Sultana *et al.* (2000) and Razzaque *et al.* (2009).

The effect of salinity on root/shoot ratio of rice varieties differed significantly (Table 1). The highest average value (0.206) was obtained at 12 dS m^{-1} and the lowest value (0.164) at 8 dS m^{-1} (Table 1). Alam *et al.* (2004) reported that rice shoot growth was generally suppressed more by salinity than root growth. On the other hand, Hussain *et al.* (2003) observed that roots were more sensitive to salinity compared to the shoots. Other researchers also reported that tolerant lines had higher root/shoot ratio than susceptible ones (Ali *et al.*, 2004; Ali and Awan, 2004).

Tillering in rice is an important agronomic trait for the production of grain as well as a model system for the study of branching in monocotyledonous plants. The counting of tiller number provides valuable information on the stress profile of a plant under abiotic conditions (Nobuhiro *et al.*, 2005). The tiller numbers were significantly affected in all salinity levels as compared to control but the response differed with variety (Table 1). In respect of interaction effect, the results showed that the tillers of all rice varieties were greatly affected even at 4 dS m^{-1}. However, MR232, MR211 and Pokkali were least affected

Table 2 : Interaction effect of variety and salinity levels on growth parameters of eight rice varieties

Treatments		Plant height (cm)	Total number of tiller hill^{-1}	Leaf area hill^{-1} (sq cm)	Total dry matter (g hill^{-1})	Root-shoot ratio
Rice variety	Salinity levels (dSm^{-1})					
IR20	0	110.23 de	16.1 abc	748. 93 cde	16.61 c	0.167 cd
	4	99.70 (9) def	13.2 ab (19)	586.43 e (22)	13.29 d (20)	0.146 d
	8	74.66 (32)d	6.6 c (59)	401.17 d (46)	7.45 d (55)	0.189 ab
	12	49.53 (50) c	3.7c (77)	241.92 c (68)	4.47 d (73)	0.197 abc
Pokkali	0	183.56 a	10.4 d	657.02 e	15.93 d	0.154 d
	4	177.00 (4)a	9.1 c (12)	594.66 e (9)	14.53 cd (9)	0.145 d
	8	170.13 (7)a	6.4c (38)	481.80 bc (27)	11.63 b (27)	0.111 e
	12	126.10 (31) a	4.3 bc (59)	349.33 ab (47)	7.18 b (55)	0.155 c
MR33	0	148.26 b	14.3 c	757.79 cd	18.71 a	0.167 cd
	4	142.20 (4) b	12.4ab (13)	676.49 cd (11)	16.37 ab (11)	0.151 cd
	8	109.33 (26) b	9.6 ab (33)	482.34 bc (36)	11.35 b (39)	0.181 bc
	12	67.33 (63) b	5.8 ab (59)	322.42 ab (57)	5.69 c (69)	0.181 ab
MR52	0	133.83 c	15.2 abc	798.07 bc	17.35bc	0.181 bc
	4	125.93 (6) bc	12.5 ab (18)	717.77 bc (10)	14.59 cd (16)	0.181 ab
	8	96.10 (28) bc	9.6 ab(37)	495.22 b (38)	10.88 bc (37)	0.165 cd
	12	66.26 (50) b	5.9 ab (61)	339.38 ab (57)	5.56 c (68)	
MR211	0	103.43 e	14.4 bc	700.40 e	15.57 d	0.169 cd
	4	96.47 (7) ef	12.8 ab (11)	657.81 de (6)	14.33 cd (8)	0.166 bcd
	8	84.83 (18) cd	9.5 ab (34)	591.00 ab (15)	11.06 b (29)	0.149 d
	12	69.50 (33) b	6.5 a (55)	399.75 a (43)	7.35 b (53)	0.177 bc
MR219	0	122.63 cd	15.5 abc	870.32 ab	18.96 a	0.198 ab
	4	102.23 (17) de	13.2 ab (15)	704.53 bcd (18)	15.0 bc (21)	0.178 ab
	8	78.80 (36) d	8.1 bc (48)	704.53 bcd (18)	9.77 c (48)	0.186 abc
	12	51.66 (58) c	4.2 c(73)	289.89 bc (66)	4.82 d (74)	0.222 ab
MR232	0	119.83 d	16.3 ab	837.72 ab	17.85 b	0.211 a
	4	114.83 (5) cd	14.8 a (7)	819.18 a (3)	16.94 b (5)	0.202 a
	8	100.33 (16) b	11.8 a (26)	668.58 a (81)	12.98 a (27)	0.191 a
	12	72.43 (40) b	7.6 a (52)	433.46 a (48)	8.54 a (52)	0.205 abc
BRRI dhan 29	0	112.33 de	16.9 a	904.87 a	18.89 a	0.179 bcd
	4	84.96 (24) f	12.5 b (26)	778.19 ab (14)	14.22 cd (25)	0.178 abc
	8	59.53 (47) e	6.5 c (62)	414.56 d (54)	7.42 d (61)	0.166 bcd
	12	41.80 (63) c	3.4 bc (80)	268.26 c (70)	3.99 d (79)	0.201 abc

Means with the same letter in the columns do not differ significantly ($P \leq 0.05$); Values within parenthesis indicate percent reduction to the control

varieties where the reduction in tiller numbers per hill were 7, 11 and 12%, respectively at 4 dS m^{-1}. At 12 dS m^{-1} salinity level these varieties lost 52, 55 and 59% of tiller number hill^{-1} as compared to control group, respectively (Table 2). In contrast, BRRI dhan29, MR219, IR20, MR52 and MR33 were identified as susceptible varieties to all salinity levels. They demonstrated 13-26, 33-62 and 59-80% reduction in tiller number hill^{-1} at 4, 8 and 12 dS m^{-1} salinity levels, respectively. Earlier Mahmood *et al*. (2009) found that the number of tillers plant^{-1} was significantly reduced with increasing salinity. Choi *et al.* (2003) observed that tiller number of rice decreased significantly at 0.5% salinity level. Zeng *et al.* (2001) reported that reduction in tiller number plant^{-1} was significant only when plants were salinized for 20 days before initiation of panicle. A significant decrease in number of tiller at 15.62 dS m^{-1} salinity level in BR11 rice has been reported by Gain *et al*. (2004). Similar results were also observed by Motamed *et al*. (2008) where salinity significantly affected the number of tillers in rice populations.

Adverse effects of salinity on photosynthetic rate (*A*) was associated with a significant ($P < 0.001$) decrease in the stomatal conductance in all varieties (Fig. 3). The photosynthesis of eight rice varieties decreased significantly with increased salinity. The highest *A* value was obtained in MR33 (*A*=11.93) under control conditions, while the lowest value was in IR20 (*A*=2.77) at 12 dS m^{-1} salinity level. At 4 dS m^{-1}, the highest *A* rate was observed in MR211 (*A*=10.69) and the lowest value was found in MR219 (*A*=6.68). However, at 8 dS m^{-1}, maximum value (*A*=8.44) was observed in MR232, while the most affected variety was BRRI dhan29 (*A*=4.66) (Fig. 3). This was probably due to reduced leaf area, changes in rubisco, protein, and chlorophyll per unit leaf area due to salinity effect. Another reason might also partially be

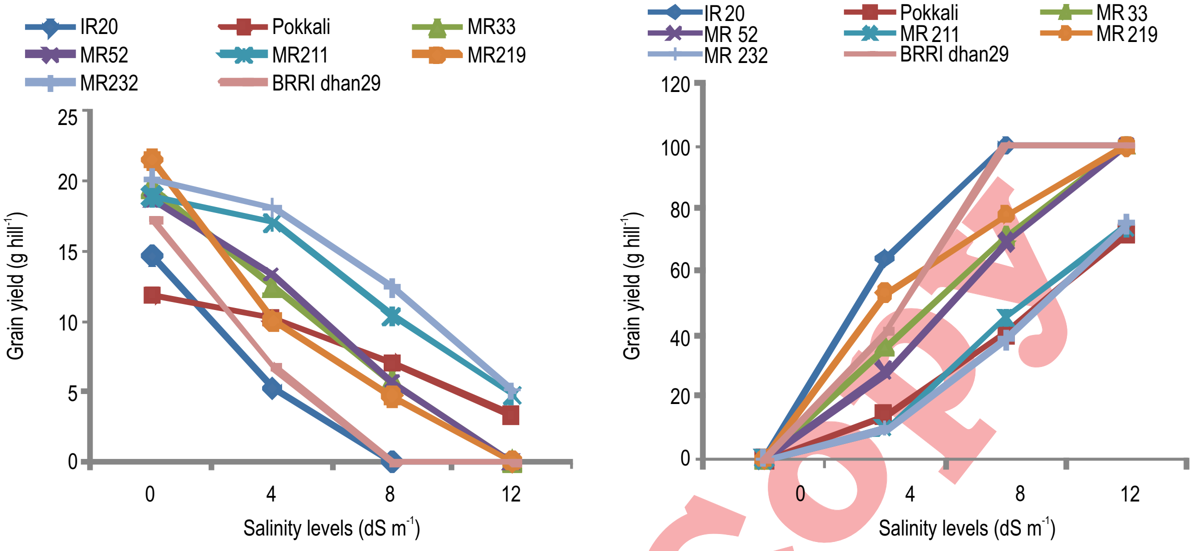

Fig. 1 : Effect of salinity on (a) grain yield, (b) percent reduction in grain yield compared to control of eight rice varieties under different saline conditions

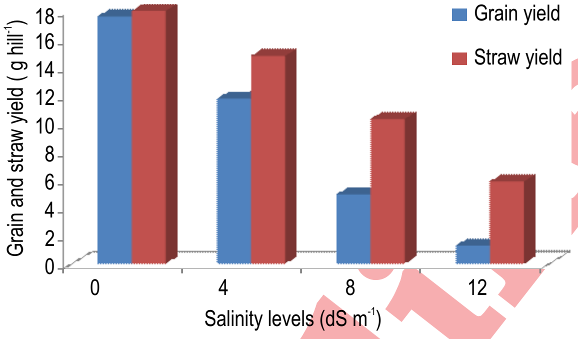

Fig. 2 : Rice grain and straw yields under different saline conditions (pooled across eight varieties)

attributed to the lower leaf water potential and reduction in relative leaf water content, which resulted in loss of turgor and in turn cause stomatal closure, limited CO_2 assimilation and finally reduced photosynthetic rate. The present results are in accordance with the finding of several researchers that salinity is well known to inhibit photosynthesis in several plant species (Dionsio-Sese and Tobita, 2000; Moradi and Ismail, 2007).

There was no noticeable reduction found in transpiration rate among the varieties at 4 dS m^{-1}. Higher reduction was apparent in MR219, while lower reduction was found in MR52. At 8 dS m^{-1}, the severe reduction was observed in IR20 while lowest reduction in MR52. A similar trend was observed at 8 dS m^{-1}. However, at higher salinity level, high transpiration rate was observed in Pokkali, MR211 and MR232 with values >3, while the lowest value was recorded in MR219, followed by BRRI dhan29 and IR20 with values <2 (Fig. 4). The observed reduction in transpiration rate might be one of the important adaptive mechanisms of salinity tolerance in rice. The transpiration rate reduced which indicated that photosynthesis affected the stomatal number and transpiration rate. Possible reasons of decreased efficiency of rubisco, displacement of essential cations from the endo-membrane structure weare that the direct effects of salt on stomatal conductance via a reduction in guard cell turgor and intercellular CO_2 partial pressure had occurred (Flowers and Yeo, 1995; Dionisio-Sese and 2T obita, 2000). Our findings are similar to the above mentioned findings.

The panicle number in general provides information about the architecture of plant lateral organs. However, panicle number in cereal crops is an informative index for the production of flowers and ultimate seeds. The panicle numbers of rice plant were significantly decreased ((P< 0.01) and overall the highest panicle numbers plant^{-1} were produced in MR211 followed by MR232 with 8.15 and 7.94, respectively and the lowest was observed in IR20 (4.51) (Table 1). Panicle numbers of MR211, MR232 and Pokkali varieties decreased by 1-3, 22-24 and 52-57% at 4, 8 and 12 dS m^{-1} of salinity, respectively, indicating they have relatively better salt tolerance to salinity than the other varieties tested (Table 3). On the other hand, the corresponding reduction in panicle numbers of BRRI dhan29, MR219, IR20, MR52 and MR33 were 20-28, 54-83 and 100% under similar conditions, suggesting that these varieties of rice population were highly vulnerable to salinity stress. The highest level of salt sensitivity was recorded with BRRI dhan29, IR20 and MR 219. MR33 and MR52 reflected moderate level of sensitivity between 4-8 dS m^{-1} salinity. MR211 and MR232 outperformed, Pokkali which was a salinity tolerant variety, in withstanding salinity stress in terms of panicle yield. Reduction in panicle number under

Table 3 : Interaction effect of variety and salinity levels on yield components of eight rice varieties

Treatments		Number of	Panicle length	Fertility percentage	Number of filled	1000 grain
Rice variety	Salinity levels (dSm^{-1})	panicles $hill^{-1}$	(cm)		grain $panicle^{-1}$	weight (g)
IR20	0	10.43 a	20.47 b	90.77 a	94.2 a	18.03 e
	4	8.00 bc (23)	18.05 c (22)	56.57 d	60.2 c(38)	15.93 e (12)
	8	2.0 d (81)	10.06 e (51)	0.0 d	0.0 e	0.0 d
	12	0.0 c	0.0 c	0.00 b	0.0 c	0.0 b
Pokkali	0	6.86 b	25.07 a	90.43 a	77.2 b	26.16 a
	4	6.73 c (2)	24.23 a (4)	86.63 ab	73.9 b (4)	25.43 a (3)
	8	5.36 b (22)	21.80 a (23)	73.64 a	63.4 b (18)	23.00 a (12)
	12	2.97 b (57)	18.3 a (26)	36.28 a	32.4 b (58)	17.56 a (33)
MR33	0	10.57 a	22.60 ab	89.39 a	98.5 a	21.90 bc
	4	8.47 ab (20)	21.16 b (6)	80.55 b	76.3 b (22)	21.56 bc (2)
	8	4.83 bc (54)	17.3bc (23)	31.07 bc	41.3 d (58)	17.76 c (19)
	12	0.0 c	0.0 c	0.00 b	0.0 c	0.0 b
MR52	0	10.53 a	22. 20 ab	92.61 a	102.7 a	20.43 cd
	4	8.20 bc (22)	20.57 b (7)	87.25 ab	97.8 a (5)	19.16 d (6)
	8	4.50 bc (57)	17.5bc (21)	37.17 b	52.7 c (49)	16.47 c (19)
	12	0.0 c	0.0 c	0.00 b	0.0 c	0.0 b
MR211	0	9.98 a	23.06 ab	93.60 a	99.9 a	22.73 b
	4	9.80 a (1)	21.63 ab (6)	90.12 a	95.0 a (5)	21.46 c (5)
	8	7.60 a (24)	19.46 ab (15)	76.28 a	87.5 a (12)	19.53 b (14)
	12	4.57 a (54)	16.6 b (28)	32.01 a	42.2 a (58)	16.83 a (26)
MR219	0	9.80 a	23.06 ab	92.32 a	105.0 a	22.83 b
	4	7.33 bc (25)	20.23 b (12)	67.37 c	75.5 b (28)	20.30 cd (11)
	8	3.60 c (63)	16.33 cd (29)	21.92 c	39.6 d (62)	17.23 c (24)
	12	0.0 c	0.0 c	0.00 b	0.0 c	0.0 b
MR232	0	10.03 a	22.63 ab	91.62 a	100.6 a	23.46 b
	4	9.70 a (3)	21.45 ab (5)	91.71 a	95.6 a (5)	23.06 b (2)
	8	7.57 a (24)	20.16 ab (11)	77.11 a	82.1 a (18)	20.76 b (11)
	12	4.80 a (52)	17.7 a (22)	31.04 a	43.16 a (57)	17.30 a (26)
BRRI dhan29	0	10.33 a	23.00 ab	93.19 a	105.2 a	18.40 de
	4	7.35 bc (28)	20.50 b (11)	68.43 c	73.0 b (31)	16.50 e (10)
	8	1.75 d (83)	10.40 e (55)	0.0 d	0.0 e	0.0 d
	12	0.0 c	0.0 c	0.0 b	0.0 c	0.0 b

Means with the same letter in the columns do not differ significantly (P d”0.05); Values within parenthesis indicate percent reduction to the control

salinity stress has earlier been reported by Zeng *et al.* (2003) and Shereen *et al.* (2005). These authors found that the panicle number $plant^{-1}$ decreased with increase in salinity levels.

Among varieties, the panicle length were different in different varieties but the highest panicle length was produced in Pokkali followed by MR232 (≥ 20 cm) and the shortest in IR20 ≤ 10 cm (Table 1). The longest panicle (25.07 cm) was produced in Pokkali under control conditions, while the shortest panicle (10.06 cm) was obtained in IR20 at 8 dS m^{-1}. At 4 dS m^{-1}, the longest panicle (24.23 cm) with a relative value of 96% was found in Pokkali, which was statistically identical to MR211, MR33, MR232 and MR52, while the shortest panicle (18.05 cm) was recorded in IR20. MR232 appeared to be the least affected genotype with an 89% relative value at 8 dS m^{-1}, while IR20 and BRRI dhan29 were severely affected and produced shorter panicles (10.06, 10.40 cm, respectively). At 12 dS m^{-1}, Pokkali produced longest panicles followed by MR232 and MR211with relative value of >70%, while other varieties failed to produce any panicle (Table 3). The reduction in seedling survival rates and growth might have been major cause for reduction in panicle length. The results are in accordance with the findings of Abdullah *et* al. (2001), Ali *et al.* (2004), Shereen *et al.* (2005) and Mahmood *et al.* (2009).

Under control conditions, the highest value was found in MR211 and BRRI dhan29 with 93% fertility, while the lowest (89%) value was observed in MR33. At 4 dS m^{-1}, MR232 and MR211 produced highest fertility percentage of 90%, followed by Pokkali, while the lowest value (56.5%) was recorded in IR20, followed by BRRI dhan29 with 68.4% fertilty (Table 1 and 3). A similar trend was observed at 8 dS m^{-1}, but at this salinity IR20 and BRRI dhan29 did not form any fertile grains. At 12 dS m^{-1}, only

Table 4 : Pearson's correlation coefficients between yield components of eight rice varieties

	Tiller/hill	TDM	Panicle length	Panicle no.	No. of filled grains	Fertility %	1000 grain wt	Grain yield
Tiller hill^{-1}	-							
TDM	0.64 *							
Panicle length	-0.13^{ns}	0.56^{ns}	-					
Panicle length	0.52^{ns}	0.79 *	0.84 **	-				
No. of filled grains	0.68 *	0.83**	0.58^{ns}	0.96 **	-			
% Fertility	0.17^{ns}	0.69 *	0.95 **	0.87 **	0.80 **	-		
1000 grain wt	-0.08^{ns}	0.58^{ns}	0.97**	0.73 *	0.62^{ns}	0.94 **	-	
Grain yield	0.48^{ns}	0.85 **	0.73 *	0.93 **	0.95 **	0.88 **	0.80 **	-

Note : *, ** indicate significant at 5 and 1% levels, respectively; ns = non-significant

three varieties viz. Pokkali, MR211 and MR232 produced fertile grains with 36, 32, and 31% fertility (Table 3). It is assumed that fertility percentage decreased because of almost similar reasons as the filled grain per panicle. The results showed that fertility percentage decreased significantly due to salinity. Similar reduction in fertility has been earlier reported by Zeng and Shanon, 2000; Ali *et al*, 2004; Shereen *et al*., 2005 and Motamed *et al.,* 2008 in rice cultivars.

Grain is the most sensitive part of panicle and is directly related to crop yield. Abiotic stress such as temperature (Yamakawa *et al*., 2007) often produce chalky and small grain, tremendously affecting rice yield during harvest. The filled grains were reduced significantly under different saline condition and also different varieties (Table 1). The number of filled grains in MR232, MR211 and Pokkali varieties were reduced by 4-5, 12-18 and 57-58% at 4, 8 and 12 dS m^{-1} of salinity respectively, demonstrating their better tolerance to salinity stress (Table 3). On the other hand, the filled grain yield in BRRI dhan29 and IR20 was reduced by 31 and 36%, respectively, at 4 dS m^{-1} salinity. Dramatically, no grain production was found at 8 and 12 dS m^{-1} salinity in these varieties, suggesting their strongest susceptibility to salinity stress of higher levels. In contrast, the grain yield in MR219, MR33 and MR52 was reduced by 5-28 and 49-62% at 4 and 8 dS m^{-1} salinity respectively, showing their moderate level of tolerance. However, no grain yield was recorded in these varieties at 12 dS m^{-1}. Baloch *et al.* (2003) observed little effect of moderate or low salinity on the filled grains panicle^{-1} salt tolerant mutant Iratom24. On the other hand, Nejad *et al.* (2010) observed that the filled grains in rice varieties were significantly reduced with the increasing level of salinity.

To study the effect of salinity on grain size and consequent rice yield, the average weight of 1000 grains of different rice varieties grown under control and three different salinity conditions were measured. Grain weight significantly decreased under saline condition and was severely affected at higher salinity levels (Table 1). The grain weight reduced by 2-5, 11-14 and 26-33% in MR232, MR211 and Pokkali varieties grown under 4, 8 and 12 dS m^{-1} saline treatment. respectively, reflecting their extraordinary adaptation to salinity stress (Table 3). Grain yield reduction in cultivar BRRI dhan29 and IR20 was 10 and 12%, respectively, at 4 dS m^{-1}. However, no yield in grain of these varieties was recorded at 8 and 12 dS m^{-1} salinity, showing that BRRI dhan29 and IR20 were the most sensitive varieties to salinity stress. MR33 and MR52 again showed moderate level of salt tolerance. They demonstrated 2-6 and 19% reduction in grain output at 4 and 8 dS m^{-1} salinity and no yield at 12 dS m^{-1} salinity (Table 3). These results are in agreement with the findings of Mahmood *et al.* (2009); Saleque *et al.* (2005) ; Shereen *et al.* (2005) where grain weight decreased significantly with increasing levels of salinity.

Salinity treatment led to significant reduction in the grain yield (g hill^{-1}) in all varieties with the most drastic reduction being observed at 12 dS m^{-1} salinity level. The grain yield of MR211, MR232 and Pokkali varieties were reduced by 10-14, 38-45 and 72-75% at 4, 8 and 12 dS m^{-1} salinity, respectively, demonstrating them as the salt tolerant varieties among the studied population of 8 rice varieties (Fig.1). Maximum yield reduction at 4 dS m^{-1} occurred in IR20 and BRRI dhan29 with respective value of 64 and 41%. With further increase of salinity to 8 and 12 dS m-1, these varieties failed to produce any grain, reflecting them as the most sensitive varieties to salinity. MR219, MR52 and MR33 demonstrated medium sensitivity level. These three varieties showed 28-53%, 69-78% and 100% reduction in grain yield as compared to control at a salinity level of 4, 8 and 12 dS m^{-1}, respectively.

The reduction in grain yield in all rice population was manifestation of the cumulative reduction of plant height, leaf area, total dry mater, panicle number, grain number and weight of individual seeds. The growth of rice plant was arrested at highest salinity (12 dS m^{-1}) level. The middle and the young leaves of highly sensitive (BRRI dhan29 and IR20) and moderately sensitive (MR219, MR52 and MR33) varieties were rolled and withered within 3 days of salt application but leaf chlorosis was observed on 7th day. Plants seemed to recover from initial but the salt injury symptoms were clearly visible in the majority of varieties tested. The degree of salt-injury symptoms were evident

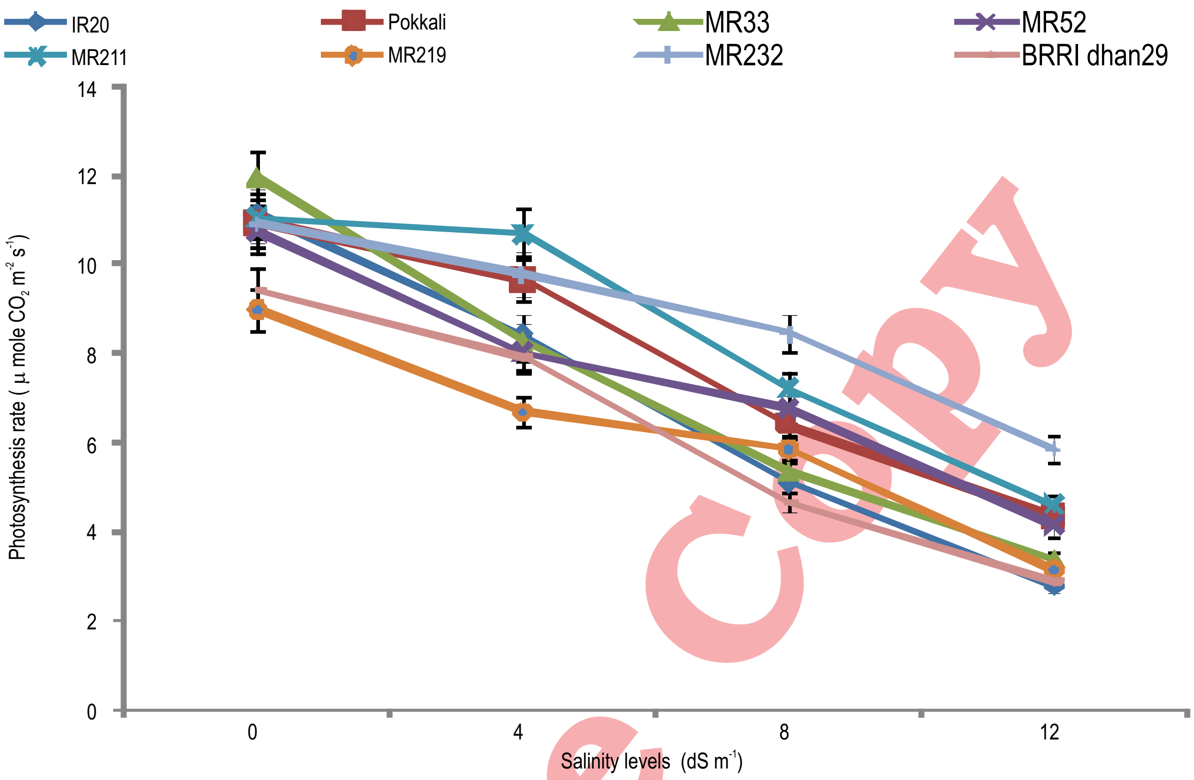

Fig. 3 : Effect of salinity on photosynthesis rate of eight rice varieties

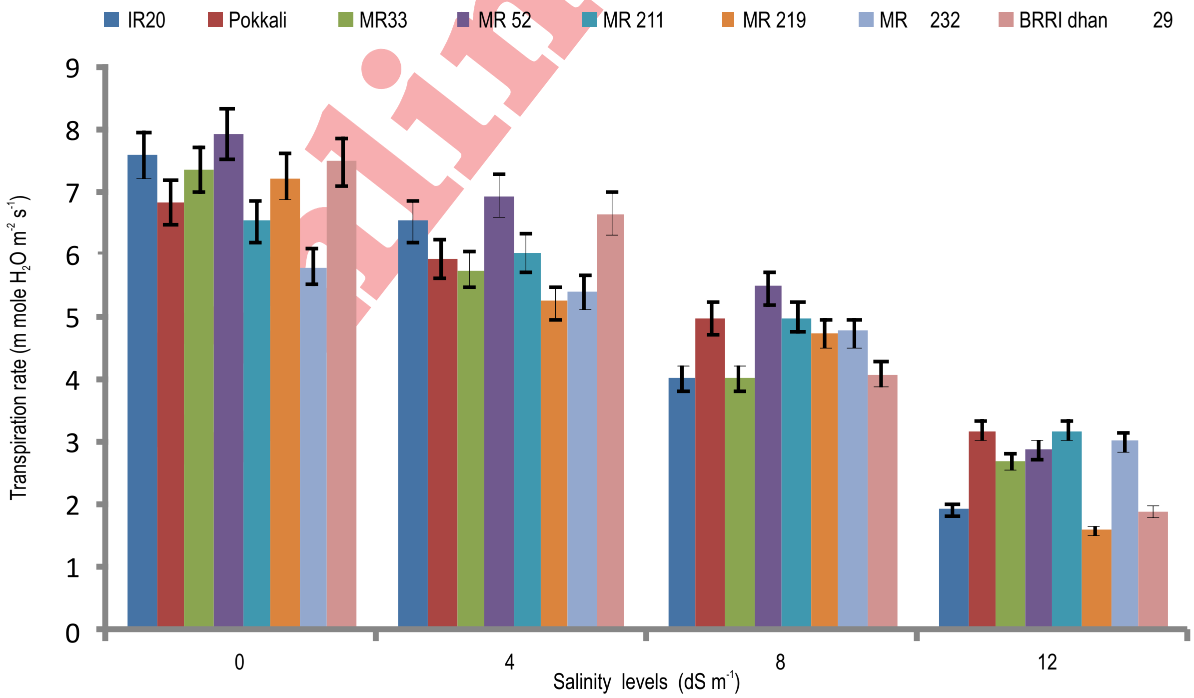

Fig. 4 : Effect of salinity on transpiration rate of eight rice varieties

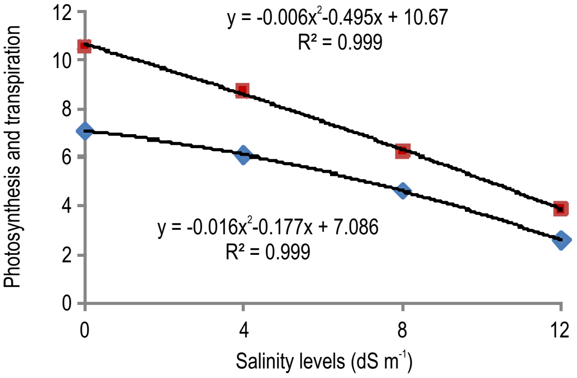

Fig. 5 : Photosynthesis and transpiration rate of rice leaves under different salinity levels (pooled across eight varieties)

at highest salinity level (12 dS m^{-1}). The younger leaves of affected plants were succulent and looked dark green. The affected plants became stunted and most of the young tillers died. After eight days of salt application the whole plant population died at higher salinity level. The major inhibitory effect of salinity on the plant growth are attributed to osmotic shock, ion toxicity and nutritional imbalance leading to reduced photosynthetic activity and other physiological functions (Ali and Awan, 2004). The factor may be involved is sodium uptake through root and its subsequent distribution in different vegetative and floral parts. Consequently, it adversely affected the transportation of total assimilates to the growing regions (Munns, 2002).

Salinity strongly reduced the tissue turgor as a result, the plant growth and development were directly inhibited, leading to low grain yield (Mansour *et al*., 2003; Chinnusamy *et al*., 2005; Lauchli and Grattan, 2007). It might also be posible decrease in cell metabolic activities and shrinkage of cell contents reduced development and differentiation of tissues and finally imbalanced nutrition (Munns, 2002).

A significant reduction in grain yield plant^{-1} of rice genotypes under salinity stress has earlier been reported by Mahmood *et al*. (2009) and Nejad *et al.* (2010).

The correlation matrix of related eight agronomic traits of rice with different salinity levels are presented in Table 4. Grain yield was positively correlated with TDM, panicle number, number of filled grain, fertility percentage and 1000-grain weight. The correlation of these parameters were showed strong significance at p<0.001. (Table 4).

It can therefore be concluded that the Malaysian rice varieties, MR211 and MR232 were salt tolerant while MR52, MR33 and MR219 performed better than the salt sensitive varieties, BRRI dhan29 and IR20. The grain yield of BRRI dhan29 and IR20 were totally ceased at 8 dS m^{-1} salinity level while, at same salinity level 69-71% yield loss was observed in MR52, MR33 and MR219 varieties.

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