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EFFECT OF EXOGENOUSLY APPLIED NITRIC OXIDE ON SOME KEY PHYSIOLOGICAL ATTRIBUTES OF RICE (*ORYZA SATIVA* L.) PLANTS UNDER SALT STRESS

NOMAN HABIB[1], MUHAMMAD ASHRAF[2,3] AND MUHAMMAD SHAHBAZ[1]

[1]*Department of Botany, University of Agriculture, Faisalabad, Pakistan*
[2]*University College of Agriculture, University of Sargodha, Sargodha, Pakistan*
[3]*Department of Botany and Microbiology, King-Saud University, Riaydh, Saudi Arabia*
[*]*Corresponding author's e-mail: ashrafbot@yahoo.com*

Abstract

The aim of the present investigation was to assess the ameliorative effect of nitric oxide on some salt stressed rice (*Oryza sativa* L.) plants using some key physiological criteria. The experiment comprised four rice cultivars, two of them being fine (Shaheen Basmati & Basmati PB-95) and two coarse (KS-282 and IRRI-6) rice cultivars, two salt levels (0 and 80 mM of NaCl) and three nitric oxide levels (0, 0.1 and 0.2 mM). Salt stress caused a marked reduction in chlorophyll contents, photosynthetic rate, transpiration rate, stomatal conductance and intrinsic CO_2 concentration of all four rice cultivars. Similarly, chlorophyll fluorescence attributes were also markedly altered due to imposition of NaCl stress. Pre-sowing seed treatment with nitric oxide significantly improved chlorophyll content, and gas exchange and chlorophyll fluorescence attributes in salt-stressed and non-stressed plants of all four rice cultivars. Of rice cultivars, Shaheen basmati and IRRI-6 performed better than cvs. Basmati PB-95 and KS-282 in terms of the parameters measured in this study.

Introduction

A huge area of available land on our Earth is affected by salinity (Ashraf, 2009). Like many other abiotic stresses, salt stress considerably suppresses growth and development of a number plants by affecting various physiological and biochemical processes (Ashraf & Khanum, 1997; 2000; Läuchli & Grattan, 2007; Ashraf 2009; Shahbaz *et al*., 2011, 2012; Shahbaz & Ashraf, 2013). For example, salt stress markedly decreased photosynthesis, transpiration, stomatal conductance and water-use-efficiency in different plant species (Ashraf, 2004; Ashraf 2009; Perveen *et al*., 2010; Shahbaz *et al*., 2011; Habib *et al.*, 2012). Under salt stress reduced chlorophyll content is responsible for decreased net CO_2 assimilation rate up to some extent (Ashraf, 2004). Salt stress also disturbs the cellular ion balance, causing not only the ion toxicity but also the osmotic stress (Ashraf & Harris, 2004).

Nitric oxide (NO) is a free radical, lipophilic and volatile compound (Hayat *et al*., 2010), which shows various regulatory roles at different stages of crop development, especially as promoter of seed germination in most of plant species (Liboural *et al.*, 2006; Bethke *et al.*, 2007; Habib *et al.*, 2010). Nitric oxide also acts as a mediator in ABA-induced stomatal closure (Desikan *et al.*, 2004). Besides its regulatory role in plants, its role in stress tolerance has also been reported against both biotic and abiotic stresses, such as drought (Gracia-Mata & Lamattina, 2001), and salt stress (Zhao *et al.*, 2007; Habib *et al.*, 2010; Kausar & Shahbaz, 2013). Therefore, external application of nitric oxide can be helpful in enhancing the plant stress tolerance (Zhao *et al.*, 2007; Habib *et al.*, 2010). Zhang *et al.* (2006) reported that the ability of maize seedlings to tolerate salt stress was enhanced when nitric oxide applied as pre-sowing seed treatment.

Rice (*Oryza sativa* L.) is one of the most important cereal crops in Asia including Pakistan, more than half of the world population uses rice as food (Ahmad *et al*., 2007; Ma *et al*., 2007). Rice is the second major cereal crop after wheat and is grown on 2.57 Mha of land with an average paddy yield of 2.39 t ha^{-1} (Economic Survey of Pakistan, 2012). Rice plant is very sensitive to salt stress (Zeng *et al*., 2003). Since the role of nitric oxide in various physiological processes under salt stress has been reported, so it is assumed that the ability of rice plants to tolerate salt stress can be enhanced with the increased endogenous nitric oxide level by its exogenous application. Therefore, in the present study our main objective was to assess the effect of exogenous application of nitric oxide on various physiological attributes of rice plants under salt stress.

Materials and Methods

An experiment was conducted in the net-house of the Botanical Garden, University of Agriculture, Faisalabad-Pakistan. During the experiment, PPFD, 1275 µmol m^{-2} s^{-1}, day and night temperatures 36±3^{o}C and 27±2^{o}C respectively, relative humidity 45.2% and day length 13.8 h were recorded. The seeds of four rice (*Oryza sativa* L.) cultivars were used in this experiment. Two fine rice cultivars, Shaheen Basmati and Basmati PB-95, were obtained from the Soil Salinity Research Institute, Pindi Bhatian, while two coarse-rice cultivars, KS-282 and IRRI-6 from the Rice Research Institute, Kala Shah Kaku, Pakistan. The seeds were surface sterilized with 10% sodium hypochlorite solution for 5 min and washed three times with sterilized distilled water. After sterilization, these seeds were soaked in different levels (0, 0.1, and 0.2 mM) of sodium nitroprusside (nitric oxide donor) for 20 h for pre-sowing seed treatment. Thirty day-old seedlings of all four rice cultivars were transplanted to plastic pots, filled with 8 kg soil. The pots were arranged in a completely randomized design with four replicates. After one week of transplantation, when the rice seedlings were established, salt treatments (0 and 80 mM of NaCl) were applied by a gradual increase. Data for growth, gas exchange characteristics and chlorophyll fluorescence were recorded after 15 days of start of the salt treatments.

Leaf chlorophyll content: Leaf chlorophyll content was determined following the method described by Arnon (1949).

Gas exchange: Measurements for different gas exchange attributes were made as described elsewhere (Ashraf, 2003).

Chlorophyll fluorescence: A fluorescence meter (Multimode chlorophyll fluorometer, OPTISciences, OS5P) was used to measure the values of different chlorophyll florescence attributes following the method of Strasser *et al*., (1995).

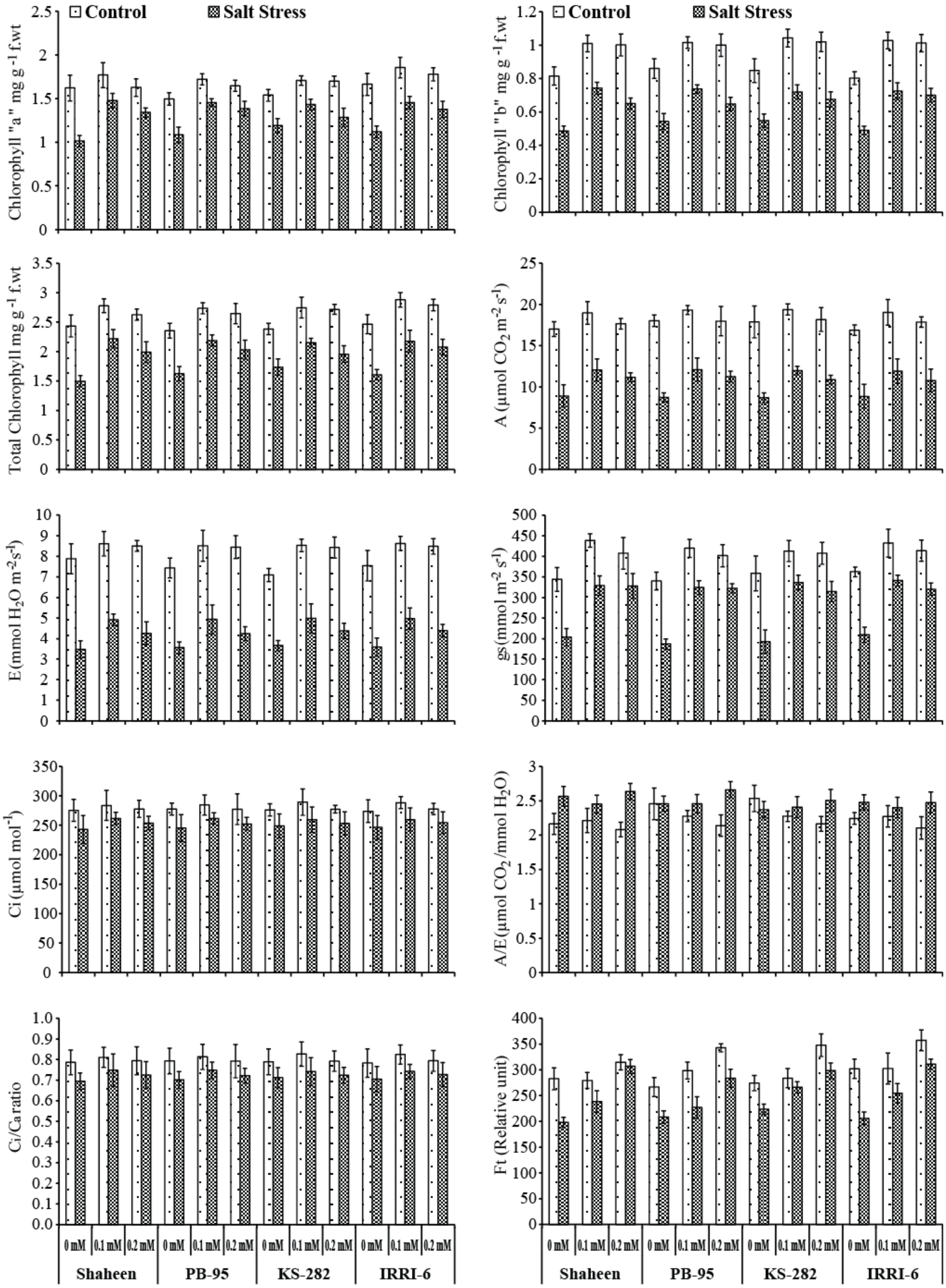
Statistical analysis: The experiment was arranged in a completely randomized design (CRD) with four replicates and the data were analyzed using a software named CoSTAT V 6.3 (developed by, Cohort software, Berkeley, California).

Results

Increased NaCl content in the root zone, markedly decreased the chlorophyll *a*, *b* and total chlorophyll contents in all rice cultivars (Fig 1). Nitric oxide application as pre-sowing seed treatment significantly increased the chlorophyll *a*, *b* and total chlorophyll contents in all four rice cultivars under both control and saline conditions. Both nitric oxide levels (0.1, and 0.2 mM) were equally effective in improving chlorophyll *a*, *b* and total chlorophyll contents under control conditions. However, 0.1 mM was more effective under NaCl stress. Of the rice cultivars, IRRI-6 showed higher chlorophyll *a* content under both control and saline conditions, however, the cultivars remained almost indifferent for chlorophyll *b* and total chlorophyll contents. Of gas exchange attributes, salt stress significantly reduced transpiration rate (*E*) and net CO_2 assimilation rate (*A*) in all four rice cultivars (Fig. 1). Exogenous application of nitric oxide as a pre-sowing seed treatment significantly increased photosynthetic rate (*A*) and transpiration rate (*E*) under salt stress, and maximal increase was observed at 0.1 mM level in all four rice cultivars. However, under control conditions, cv. Basmati PB-95 showed a maximum photosynthetic rate (*A*) at 0.2 mM of nitric oxide. Root-zone salinity also caused a marked reduction in sub-stomatal CO_2 concentration (C_i) and stomatal conductance (g_s) in all four rice cultivars. Pre-sowing seed treatment with both levels (0.1 and 0.2 mM) of NO enhanced the C_i and g_s in the stressed and non-stressed plants of all four rice cultivars. For *Ci* the effect of 0.1 mM was more prominent, however in case of g_s both levels of NO were equally effective under salt stress. Water use efficiency (*A/E*) increased in all four rice cultivars with the imposition of salt stress. Exogenously applied NO significantly affected the *A/E* ratio in all four rice cultivars under stress and non-stress conditions (Fig. 1). Leaf *A/E* ratio decreased significantly under non-saline conditions with the exogenous application of NO. In contrast under saline conditions leaf *A/E* ratio was increased, but with the pre-sowing seed treatment of 0.1 mM of NO there was a slight decrease in *A/E* ratio in cvs. Shaheen basmati and IRRI-6. C_i/C_a ratio decreased with the imposition of salt stress (Fig. 1), however, there was a slight increase in C_i/C_a ratio with 0.1 mM NO under both control and salt stress conditions in all four rice cultivars. In the present study, various chlorophyll fluorescence parameters were markedly altered by salt stress in all four rice cultivars. Minimum fluorescence in light (*Ft*) decreased significantly in all four rice cultivars under salt stress (Fig. 1). Pre-sowing seed treatment with NO significantly increased the *Ft* both under control and salt stress condition. A maximal increase in *Ft* was observed at 0.2 mM level of NO under salt stress. Minimum fluorescence in dark (*Fo*) decreased under salt stress in all four rice cultivars (Fig. 2). A significant increase in *Fo* value was observed with pre-sowing seed treatment with nitric oxide under salt stress. A maximal increase in *Fo* value was observed at 0.1 mM level of nitric oxide in cvs. Shaheen Basmati and Basmati PB-95 under salt stress, however, under control conditions a decrease in *Fo* value was observed at 0.2 mM of NO. The values of leaf maximal chlorophyll fluorescence (*Fm*), fluorescence at steady state in light adapted leaf (*Fs*), maximum fluorescence at steady state in dark adapted leaves (*Fms*) and the maximum quantum yield of primary photochemical reaction in dark adapted leaves (*Fm/Fv*) decreased significantly in all four rice cultivars under salt stress (Fig. 2). Pre-sowing seed treatment with NO significantly increased the value of *Fm*, *Fs*, *Fms* and *Fv/Fm* under both control and salt stress in all four rice cultivars, the maximum values of all these parameters were observed at 0.2 mM of NO. Electron transport rate (*ETR*) value increased under salt stress in all four rice cultivars (Fig. 2). Pre-sowing seed treatment with NO decreased the *ETR* both under control and salt stress. The values of quantum yield of electron transport (*Y*) and leaf photochemical fluorescence quenching (*Qp*) decreased by root-zone salinity (Fig. 2). Pre-sowing seed treatment with NO increased the *Y* and *QP* value in all four rice cultivars under salt stress. Under control conditions values of *QP* decreased in cultivars Shaheen Basmati and Basmati PB-95 at 0.2 mM of NO. Values of non-photochemical quenching (*Qn*) and non-photochemical chlorophyll fluorescence quenching (*NPQ*) increased significantly with the root-zone salinity (Fig. 2). Pre-sowing seed treatment with NO significantly decreased the values of *Qn* and *NPQ* under salt stress, the minimum value *NPQ* was being observed at 0.2 mM level of NO in Shaheen basmati and Basmati PB-95 under both saline and non-saline conditions, however, in cvs. KS-282 and IRRI-6 the minimum value of *NPQ* was observed at 0.1 mM level of NO under both control and salt stress. But for *NPQ* the effect of both levels of NO was more prominent under salt stress.

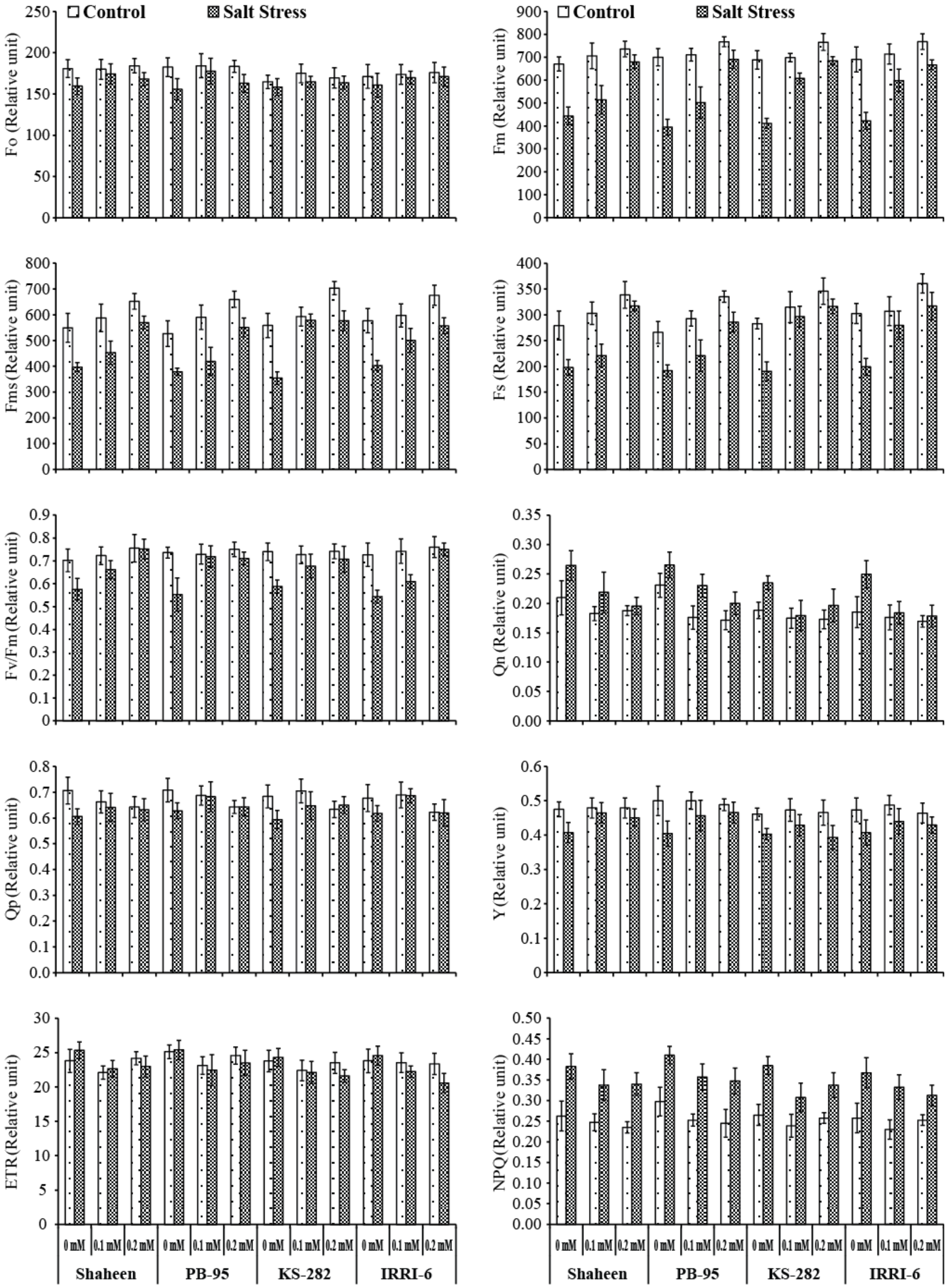
Discussion

Rice is generally considered salt sensitive. Poor growth and productivity of rice crop under saline stress could be due to salt induced osmotic stress and specific ion toxicity (Duan *et al*., 2004). In the present study, a significant decrease in chlorophyll content was observed in all four rice cultivars under salt stress. Salt-induced decrease in chlorophyll content has already been reported in various crops such as in sunflower (Akram *et al*., 2009), wheat (Arfan *et al*., 2007; Ashraf & Ashraf, 2012), and tomato (Doganlar *et al*., 2010). Breakdown of chlorophyll content under NaCl stress is generally attributed to increased Na^+ content because higher Na^+ concentrations are toxic for many bio-molecules (Ashraf *et al*., 2010a). However, chlorophyll biosynthesis has been reported to be affected more seriously as compared to chlorophyll degradation (Santos *et al*., 2001).



0, 0.1 and 0.2 mM = levels of nitric oxide applied exogenously.

Fig. 1. Chlorophyll pigments and gas exchange attributes of four rice (*Oryza sativa* L.) cultivars when different levels of nitric oxide (NO) were applied exogenously as pre-sowing seed treatment to salt-stressed and non-stressed plants.



0, 0.1 and 0.2 mM = levels of nitric oxide applied exogenously.

Fig. 2. Chlorophyll fluorescence attributes of four rice (*Oryza sativa* L.) cultivars when different levels of nitric oxide (NO) were applied exogenously as pre-sowing seed treatment to salt-stressed and non-stressed plants.

In the present study, nitric oxide application as a pre-sowing seed treatment caused a significant improvement in chlorophyll content of all four rice cultivars under both control and saline conditions. Increased chlorophyll content due to nitric oxide treatment has already been reported in salt stressed plants of tomato (Wu *et al*., 2010) and wheat (Ruan *et al*., 2002). This exhibits the protective role of nitric oxide against salt-induced damages to the rice plant.

Plant gas exchange attributes are very important for biomass production. Salt stress has an inhibitory effect on these gas exchange attributes (Ashraf & Ali, 2008; Ashraf *et al*., 2010b). In the present study, photosynthetic rate (*A*), transpiration rate (*E*), sub-stomatal CO_2 concentration (C_i) and stomatal conductance (g_s) were markedly decreased due to salt stress in all four rice cultivars. According to Ashraf (2009) reduced photosynthetic rate under moderate to severe salt stress could be due to stomatal closure. Stomatal closure is resulted due to higher levels of ABA under salt stress which ultimately decreases stomatal conductance (Zheng *et al*., 2001; Parida & Das, 2005; Etehadnia *et al*., 2010). This decrease in stomatal conductance leads to a marked reduction in other gas exchange parameters such as internal CO_2 concentration, transpiration rate and photosynthetic rate (Ashraf, 2004). In the present study, pre-sowing seed treatment with nitric oxide significantly improved the gas exchange attributes in salt-stressed and non-stressed plants of all four rice cultivars. Nitric oxide-induced improvement in gas exchange attributes has already been reported in salt stressed tomato plants (Wu *et al*., 2010). Endogenous NO level is important for stomatal closure (Kolla & Raghavendra, 2007), because NO acts as a mediator in ABA-induced stomatal closure (Desikan *et al.,* 2004).

Activity of photosystem II is measured through chlorophyll fluorescence (Saleem *et al*., 2011). In the present study, various chlorophyll fluorescence attributes were altered in all four rice cultivars under salt stress. Root-zone salinity markedly decreased the valu es of *Ft*, *Fo*, leaf *Fm*, *Fs*, *Fms*, Qp, *Y* and *Fv*/*Fm* under salt stress in all four rice cultivars. Decrease in the value of *Fo* under salt stress indicates the loss of energy transfer from antenna complex to reaction centers (Lutts *et al*., 1996; Baker, 2008). Similarly, a decrease in the value of *Y* shows that plant's ability to repair the salt-induced damage to photosystem II has been impaired (Allokhverdiev *et al*., 2002; Amirjani, 2010). Decreased value of *Fv/Fm* under salt stress is related to decrease in *Fm* value indicating the disruption of antenna complex of PS II and increased dissipated energy and destruction of reaction center at photosystem II (Lutts *et al*., 1996; Santos *et al.*, 2001). Salt-induced decrease in *Fv*/*Fm* also indicates that RUBP regeneration ability has also been impaired (Kafi, 2009). *Qp* value indicates the proportion of inactivated PS II reaction centers (Moradi & Ismail, 2007). Decrease in *Qp* value could be due to the separation of light harvesting complex II from PS II reaction center under salinity stress (Wu *et al*., 2010). In the present study, root-zone salinity significantly increased the *ETR* and *NPQ* values in all four rice cultivars. Increase in electron transport rate is due to increase in photorespiration under salt stress in C_3 plants such as wheat (Megdich *et al*., 2008). Similarly, Netondo *et al*. (2004) have reported that increase in *NPQ* indicates an adaptive energy dissipation process protecting the photosynthetic apparatus against photo-damage under salt stress.

Salt-induced impairment in the activity of PS-II has already been reported in wheat (Mehta *et al*., 2010; Ashraf & Ashraf, 2012) and rice (Moradi & Ismail, 2007). In the present investigation, pre-sowing seed treatment with nitric oxide considerably improved different chlorophyll fluorescence attributes in all four rice cultivars under control and saline conditions. As exogenous nitric oxide could keep more proportion of PSII reaction centers in an open state, so that more excitation energy can be used for electron transport (Wu *et al*., 2010). Nitric oxide treatment slowed down the electron transport rate and inhibited the steady-state photochemical and nonphotochemical quenching processes. It also appears to modulate reaction center-associated nonphotochemical quenching (Wodala *et al*., 2008).

Conclusion

Overall, in the present study imposition of salt stress significantly reduced chlorophyll content, photosynthetic rate (*A*), transpiration rate (*E*), and altered different chlorophyll fluorescence attributes in plants of all four rice cultivars. Pre-sowing seed treatment with nitric oxide was effective in improving chlorophyll content, gas exchange and chlorophyll fluorescence attributes. Both nitric oxide levels (0.1 and 0.2 mM) were equally effective under control conditions, however, 0.1 mM was more effective under salt stress conditions. Of rice cultivars Shaheen Basmati and IRRI-6 performed better as compared to Basmati PB-95 and KS-282.

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