

Journal of Plant Nutrition

ISSN: 0190-4167 (Print) 1532-4087 (Online) Journal homepage: https://www.tandfonline.com/loi/lpla20

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To cite this article: Cengiz Kaya, Muhammed Ashraf, Osman Sonmez, Tahir Polat & Atilla Levent Tuna (2019) RETRACTED ARTICLE: The Combined Effects of Nitric Oxide and Thiourea on Plant Growth and Mineral Nutrition of Salt-Stressed Plants of Two Maize Cultivars with Differential Salt Tolerance, Journal of Plant Nutrition, 42:1, i-viii, DOI: 10.1080/01904167.2016.1270314

To link to this article: https://doi.org/10.1080/01904167.2016.1270314

Accepted author version posted online: 19 Jul 2017.
Published online: 09 Jan 2019.

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JOURNAL OF PLANT NUTRITION
2019, VOL. 42, NO. 1, i–viii
https://doi.org/10.1080/01904167.2016.1270314

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RETRACTION

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RETRACTED ARTICLE: The combined effects of nitric oxide and thiourea on plant growth and mineral nutrition of salt-stressed plants of two maize cultivars with differential salt tolerance

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ABSTRACT

The combined effects of exogenously-applied nitric oxide (NO) and thiourea (TU) on plant growth and mineral nutrition of salt-stressed plants of two maize cultivars (DK 5783 and Apex 836) were studied under greenhouse conditions. The caryopses of the two cultivars were sown in pots containing soil salinized with 0 or 100 mM sodium chloride (NaCl) applied through irrigation water. In some other experiments, the effectiveness of NO and TU in growth regulation in salt-stressed plants was examined individually and both were found to be partially effective in mitigating the hazardous effects of salt on plants. So in the present study, of six NO and TU levels used in the initial germination experiment, 2 levels of combined NO and TU (3 + 400 or 6 + 500 mg L^{-1}) applied as seed soaking (pre-sowing) or as a spray to the leaves of 10-day old seedlings were chosen for subsequent studies. The experiment was placed in a randomized complete block design replicated thrice. Salinity stress resulted in high reductions in plant fresh and dry matters, total chlorophyll and maximum fluorescence yield (Fv/Fm), but increase in proline content and membrane permeability (MP) in both cultivars. The earlier mentioned reductions were greater in cv. Apex 836 than those in cv. DK 5783. In contrast, increase in proline contents under saline regime was higher in salt tolerant cultivar DK 5783 than that in salt sensitive cultivar Apex 836. Both treatments of combined NO and TU as seed soaking or foliar application were more effective in mitigating salt-induced shoot growth inhibition. Seed treatment with both levels of combined NO and TU was more effective in improving dry weights of cv. DK 5783 than that with foliar treatments. Salt stress enhanced leaf sodium (Na^+) contents, but reduced those of potassium (K^+) and calcium (Ca^{2+}) in both cultivars. Both modes of treatment of combined growth substances resulted in increased Ca^{2+} and K^+ contents, whereas decreased Na^+ in salt-stressed plants. From these findings it is evident thatexogenously-applied NO and TU caused growth improvement in maize plants which was ascribed to reduced MP under saline environment. It can be concluded that NO and TU may be involved in nutritional and physiological changes in plants subjected to high salinity.

ARTICLE HISTORY
Received 16 November 2015
Accepted 1 April 2016

KEYWORDS
maize; nitric oxide; thiourea; *Zea mays*

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Introduction

Salinization of irrigated land is one of the major environmental problems for agricultural production (Sreenivasulu et al. 2000). Reduced capacity of crop resistance to salinity is a major debacle in stabilization of crop performance in stress-prone environments (Chaudhry, Iqbal, and Subhani 2000).

Although efforts have been made to improve salinity tolerance in plants by transferring salt tolerant genes either by advanced molecular biology approaches or classical selection and breeding (Purtyet al. 2008; Witcombe et al. 2008; Visarada et al. 2009), these approaches have yielded not so promising results in terms of generating highly salt tolerant crop varieties/lines. This has happened mainly due to the fact that salinity tolerance trait is multigenic and hence very complex (Flowers 2004). In this situation, use of growth substances provides a short-term solution to overcome environmental stresses. To date, a wide variety of substances/chemicals have been used to improve stress tolerance in plants (Ashraf and Foolad 2007; Nawaz and Ashraf 2010; Kaya, Ashraf, and Sonmez 2015). Thiourea is one of them, which is believed to play a key role in oxidative stress response and other related processes. For example, Srivastavaet al. (2011) found that thiourea treatment could alleviate the injurious effects of saline stress on *Brassica juncea* seeds by regulating a variety of signaling and effecter mechanisms.

Nitric oxide (NO) being a free radical is highly reactive. NO has been reported to be a universal signal in plants which has a key role in plant stress tolerance (Planchet and Kaiser 2006; Liuet al. 2014). NO has also been reported to alleviate the oxidative stress in plants caused by abiotic stresses (Chen et al. 2010; Mihailovic and Drazic 2011; Kaya et al. 2015).

The present investigation was carried out to appraise how far some key growth parameters regulated and mineral nutrients accumulated in two maize cultivars grown at high salinity with or without additional supply of combined nitric oxide and thiourea.

Materials and methods

Plant growth and treatments

The study was conducted in a glasshouse at the Research Station of the Agriculture Faculty, University of Harran (Turkey) during May and June 2013 using two maize cultivars DK5783 and Apex 836. Five seeds of each cultivar were planted in each pot which contained 10 kg of air-dried soil. The physicochemical properties of the soil used are as follows: soil texture loamy clay, electrical conductivity (EC: 1:2.5 water, v:v) 0.45 dS m^{-1}, pH 7.3, nitrogen (N) 1.25 g kg^{-1}, potassium (K) 1.40 gkg^{-1}, and. Nitrogen, phosphorus pentoxide (P_2O_5), and potassium oxide (K_2O) were added to the soil in the form of urea, triple superphosphate, and potassium sulfate at the rates of 100, 50, and 120 mg kg^{-1}, respectively.

Three seedlings were maintained in each pot after germination. All pots placed in a glasshouse for further 35 days wherein the mean temperature was 27 ± 2 °C and relative humidity (RH) 60–70%. The experiment was placed in a randomized complete block design replicated thrice. The volume of water applied daily toeach pot varied from 50 mL to 500 mL depending on the size of plants.

The sodium chloride (NaCl) levels(0, control, and 100 mM) were applied to the maize plants through irrigation water. Nitric oxide (3 and 6 mg L^{-1}) and thiourea (400 and 500 mg L^{-1}) were applied 10 days after seed germination in combination as seed treatment (soaking) or foliar spray. The source of NO was sodium nitroprusside (SNP). All seed samples before planting were surface sterilized with 1% sodium hypochlorite solution. For pretreatment of NO plus TU as seed soaking, the seeds were soaked for 24 hr either in 3 mg L^{-1} NO plus 400 mg L^{-1} TU or 6 mg L^{-1}NO plus 500 mg L^{-1} TU solution. Plants were sprayed once a week with NO and thiourea solution (50 mL pot^{-1}) prepared in a surfactant solution 0.01% tween-20 ($C_{58}H_{114}O_{26}$). The foliar spray was initiated 10 days after the seed germination took place and continued up to day 35. For the salt treatment 5.85 g kg^{-1} NaCl were added to the soil to bring the salt level to 100 mM. The EC of the soil was checked every week till the end of the experiment.

Just before ending the experiment, fresh, dry weights, inorganic nutrients, total chlorophyll, maximum fluorescence measurements, membrane permeability (MP) and free proline were measured.

Maximum fluorescence measurements

A portable chlorophyll fluorometer (Photosynthesis Yield Analyzer Mini-PAM, Walz, Germany) was used to measure chlorophyll fluorescence. The data on the following fluorescence attributes were recorded: minimum fluorescence (Fo), maximal fluorescence (Fm), and variable fluorescence (Fv). From these data, maximum quantum efficiency (Fv/Fm) of photosystem (PS) II was also worked out.

Electrolyte leakage

The protocol described by Dionisio-Sese and Tobita (1998) was followed for appraising electrolyte leakage of the maize plants. Fresh leaves were cut into pieces of about 5 mm size and 200 mg of the subsamples were placed in each test tube containing 10 mL distilled deionized water. All containing leaf pieces and water were placed in a water bath at 32°C, and after 2 hr the initial electrical conductivity of the medium (EC1) was measured. After that, in order to get all electrolytes released, the same samples were autoclaved at 121°C for 20 min. After cooling the samples, the final electrical conductivity (EC2) was measured. For working out the electrolyte leakage following formula was employed:

$$(\text{EL } \% \ = \ \text{EC1} \ / \text{EC2} \times 100)$$

Chlorophyll content

One gram of fully expanded youngest leaves was triturated in acetone solution (90%). After measuring the optical density of the samples using a UV–visible spectrophotometer, the values were subjected to the formulae given by Strain and Svec (1966) to calculate chlorophyll concentrations.

Free proline content

The protocol described by Bates, Waldren, and Teare (1973) was employed to determine free proline in fresh leaves. Half-gram of fresh leaf material was triturated in 10 mL of 3% aqueous sulfosalicylic acid. After reacting the filtrate with acid-ninhydrin solution and glacial acetic acid, the mixture was heated for 1 hr at 100°C in a water bath. Then it was extracted with 4 mL toluene. The optical density of the colored mixture was read at 520 nm.

Nutrient analysis and dry weight measurement

For measuring dry weights, the plants were dried in an oven up to constant weight. For determining the amount of mineral nutrients in plant samples, the samples were subjected to a muffle furnace at 550°C for 6 hr to get ash. To the ash, 5 mL of 2 M hot hydrochloric acid (HCl) were added, and final volume was raised to 50 mL with distilled water. Sodium (Na), calcium (Ca), and potassium (K) were determined using an inductively coupled plasma (ICP) (Chapman and Pratt 1982).

Statistical analysis

The statistical package SAS version 9.1 (SAS, Cary, NC) was used to work out analysis of variance of data for all parameters.The least significant difference (LSD) test at $p < 0.05$ probability level was used to appraise the differences among mean values within each parameter.

Results

Based on the results of unpublished germination experiment, of nine cultivars, cv. DK 57 83 (salt tolerant) and cv. Apex 836 (salt sensitive) and of six NO and TU doses, two levels each of NO (3 and 6 mg L^{-1}) and TU (400 and 500 mg L^{-1}) were selected and combined for the glasshouse experiment.

Table 1. Fresh (FW), dry weights (DW) and total chlorophyll (mg kg^{-1}) of different cultivars of maize grown in salt with or without different levels of combined nitric oxide (NO) and thiourea (TU) (mg L^{-1}) applied as different modes. (Within each column, means with different letters are significantly different ($p \leq 0.05$). *LSD test: Shows significant differences between treatments and cultivars ($p < 0.05$). ns: not significant.

Cultivars	Treatments	FW (g $plant^{-1}$)	DW (g $plant^{-1}$)	Chl a +Chl b
	C	16.3 a	1.86 a	1256 a
	S	9.7d	1.11c	1056 c
	sNO+TU3+400	12.3 b	1.23 b	1132 b
DK 5783	sNO+TU6+500	12.3 b	1.21 b	1136 b
	fNO+TU3+400	10.7 c	1.12 c	1136 b
	fNO+TU6+500	11.4 c	1.16 bc	1139 b
	C	12.3 a	1.29 a	1198 a
	S	6.7 c	0.71c	1005 d
Apex 836	sNO+TU3+400	7.2 b	0.81b	1074 b
	sNO+TU6+500	7.3 b	0.84 b	1082 b
	fNO+TU3+400	7.2 b	0.79 b	1046 c
	fNO+TU6+500	7.3 b	0.82 b	1036 c
Cvs × treatments		*	*	ns

C: control; S: 100 mM NaCl; s: seed application; f: foliar application.

Some key growth parameters

Salinity stress reduced fresh and dry weights, total chlorophyll and maximum fluorescence yield (Fv/Fm) of both cultivars (Tables 1 and 2). However, cv. Apex 836 was more affected by salinity than cv. DK 5783. Foliar and seed applications of NO and TU in combination at both doses increased these key parameters in both cultivars grown under saline regime, though the values were still significantly lower than those of the control plants. The effect of seed application of combined NO and TU was slightly higher than that of foliar application in increasing dry weight in the salt-stressed maize plants.

Salinity stress increased MP and proline content in both cultivars. MP was slightly higher in cv. Apex 836, but proline was higher in cv. DK 5783 (Table 2). Both seed and foliar applications of NO and TU in combination at both doses reduced MP and proline content to the levels being significantly higher than those at control conditions.

Mineral elements

As expected, Na^+ concentrations increased in the salt-stressed plants of both maize cultivars. The salt sensitive cultivar Apex 836 had higher Na^+ concentration than the salt tolerant cultivar DK5783

Table 2. Maximum fluorescence yield (Fv/Fm), membrane permeability (MP) and proline (pro, μmol g^{-1}) of different cultivars of maize grown in salt with or without different levels of combined nitric oxide (NO) and thiourea (TU) (mg L^{-1}) applied as different modes. (Within each column, means with different letters are significantly different ($p \leq 0.05$). *LSD test: Shows significant differences between treatments and cultivars ($p < 0.05$). ns: not significant

Cultivars	Treatments	Fv/Fm	MP (%)	Pro
DK 5783	**C**	0,62 a	16 c	1.09 d
	S	0,58 c	24 a	2.89 a
	sNO+TU3+400	0,59 bc	21 b	2.45 b
	sNO+TU6+500	0,59 bc	21 b	2.36 bc
	fNO+TU3+400	0,60 abc	21 b	2.32 c
	fNO+TU6+500	0,60 abc	21 b	2.43 b
Apex 836	C	0,60 a	19c	1.12 c
	S	0,54 c	29a	2.62 a
	sNO+TU3+400	0,56 bc	26ab	2.38 b
	sNO+TU6+500	0,56 bc	25b	2.41 b
	fNO+TU3+400	0,57 b	25b	2.29 b
	fNO+TU6+500	0,56 bc	26ab	2.26 b
Cvs × treatments		ns	*	*

C: control; S: 100mM NaCl; s: seed application; f: foliar application.

Table 3. Sodium, calcium, and potassium concentrations (mmol kg^{-1} dry weight) in the leaves of different cultivars of maize grown in salt with or without different levels of combined nitric oxide (NO) and thiourea (TU)(mg L^{-1}) applied as different modes. (Within each column, means with different letters are significantly different ($p \leq 0.05$). *LSD test: Shows significant differences between treatments and cultivars ($p < 0.05$).

Cultivars	Treatments	Na	Ca	K
DK 5783	C	36 d*	172 a	355 a
	S	322 a	110 c	254 d
	sNO+TU3+400	262 c	126 b	284 c
	sNO+TU6+500	273bc	132 b	289 c
	fNO+TU3+400	283 b	132 b	295 bc
	fNO+TU6+500	283b	130 b	305 b
Apex 836	C	30 d	165 a	341 a
	S	393 a	95 c	221 d
	sNO+TU3+400	333 c	122 b	282 b
	sNO+TU6+500	330 c	131 b	284 b
	fNO+TU3+400	356 b	125 b	253 c
	fNO+TU6+500	353 b	124 b	278 b
Cvs x treatments		*	*	*

C: control; S: 100mM NaCl; s: seed application; f: foliar application.

(Table 3). Both modes of NO and TU in combination at both doses reduced Na^+ content, but it was still much higher than that under control conditions. Furthermore, salinity reduced Ca^{2+} and K^+ concentrations in the leaves of both cultivars, but these reductions were slightly higher in the salt sensitive cultivar Apex 836. In most cases, seed application of combined NO and TU was more effective in reducing Na^+ and increasing Ca^{2+} and K^+ contents compared to the other mode of application.

Discussion

Exogenous application of a variety of growth promoting substances is contemplated as an effective means of eliminating the negative effects of abiotic stresses including salinity on plants (Ashraf et al. 2010; Akram and Ashraf 2013; Habib and Ashraf 2014). Of such growth substances, application of thiourea (TU) and nitric oxide (NO) has been found beneficial for mitigating the inhibitory effects of salt stress on different crops, e.g., chickpea (Sheokand, Bhankar, and Sawhney 2010), maize (Yildiztugay et al. 2014), wheat (Asthir et al.2013), Phragmites karka (Zehra et al. 2013), cucumber (Cui et al. 2011), and rice (Habib and Ashraf 2014). In the present study, although saline stress (100 mM sodium chloride) suppressed growth in terms of plant fresh and dry weight of two maize cultivars, DK 5783 and Apex 836; however, exogenous application as seed priming or foliar-spray improved the growth of maize plants under saline conditions. Our results are in agreement with an earlier study by Habib, Ashraf, and Aqeel Ahmad (2010) in which varying levels of NO as pre-sowing seed treatment showed stimulating effects on seedling growth as well as on seed germination of rice plants at 80 mM NaCl. In extension to this report, Habib and Ashraf (2014) attributed this improved seedling growth to NO-induced improvement in leaf water relations and reduction in the accumulation of toxic ions such as Na^+ and Cl^-. Similarly, using thiourea (10 mM) as a foliar spray, Anjum et al. (2011) also observed improved growth of two differentially salt responsive wheat cultivars supplied with salinity (120 mM NaCl) stress. They ascribed this thiourea-induced increase in growth to triggering of a variety of physio-biochemical processes as recently reported by Pandey et al. (2013).

A number of studies have shown that saline stress can cause alterations in leaf fluorescence of different crops such as sunflower (Akram, Ashraf, and Akram 2009), okra (Saleem, Ashraf, and Akram 2011), wheat (Habib, Ashraf, and Shahbaz2013; Perveen, Shahbaz, and Ashraf, 2013), and eggplant (Shaheen et al. 2012), etc. In the present study, maximum fluorescence yield (F_v/F_m) of both maize cultivars was enhanced due to exogenously-applied combined NO and TU under saline conditions which is parallel to the findings of Habib, Ashraf, and Shahbaz (2013), who documented improved chlorophyll fluorescence in salt-stressed rice plants due to foliar-applied NO. In another study, Pandeyet al. (2013) have found improvement in the vegetative growth of Indian mustard (*B. juncea*)plants and they

attributed this growth improvement to high efficiency of PSI and PSII due to exogenous application of varying levels of TU. About two decades ago, Sahu, Solanki, and Dashora (1993) observed that exogenously-applied TU enhanced the photosynthetically active leaf area as well as rate of photosynthesis in maize plants that was ascribed to TU-induced improvement in the efficiency of photosystems (Sahu, Solanki, and Dashora 1993). Up till now, a number of experiments have been carried-out on TU- and/or NO-induced changes/improvement in the rate of photosynthesis under stress in different crops, e.g., tall fescue (Chen et al. 2013), clusterbean (Burman, Garg, and Kathju 2004), wheat (Nathawat et al. 2007; Kausar and shahbaz 2013), maize (Sahu, Solanki, and Dashora 1993), and tomato (Xue-Xia et al. 2007), but exploration of the role of TU or NO on efficiency of photosystems has been ignored. As it is well known that the efficiency of photosytems and rate of photosynthesis is closely interlinked (Misra, Latowski, and Strzalka 2006; Geissler, Hussin, and Koyro 2009; Ashraf and Harris 2013), but the gap between TU- or NO-induced changes in the photosynthesis either linked to PSI or PSII still needs to be elucidated. Recently, Chen et al. (2013), while examining the protective role of NO in the recovery of PSII in tall fescue under stress, have reported that the improved behavior of PSII under stress conditions was due to chlorophyll a fluorescence transients induced by overexpression of genes encoding PSII core proteins.

In the present study, both modes of NO and TU in combination at both doses reduced Na^+ contents, while increased Ca^{2+} and K^+ contents in both maize cultivars under saline conditions. Similarly, Habib and Ashraf (2014) while working with rice have observed that pre-sowing seed treatment with NO significantly decreased $Na^+$and Cl^-, while it improved $Ca^{2+}$and K^+ contents in both shoots and roots of salt-stressed rice plants. A significant reduction observed in Na^+uptake shows that TU induced tolerance is due to salt avoidance strategy (Srivastava et al. 2011). Recently, while working with cotton, Liu et al. (2014) have observed that foliar-applied NO (0.09 mM) improved seedling growth and they ascribed this growth improvement to low uptake of Na^+ and enhanced accumulation of some essential nutrients such as Ca^{2+}, K^+, and magnesium (Mg^{2+}). Furthermore, exogenously-applied 0.1 mM NO improved K^+ uptake thereby decreasing Na^+/K^+, which resulted in improved antioxidant defense system in salt-stressed cotton plants (Dong et al. 2014). Although many reports are available in the literature on the differential uptake of different inorganic nutrients, a detailed study needs to be carried out to uncover the integral role of TU or NO in accumulation of these nutrients in plants under saline stress.

Conclusions

In conclusion, salinity stress induced decrease in plant fresh, dry matter, and F_v/F_m, but increase in MP and proline content in both maize cultivars. The aforementioned reductions were higher in Apex 836 than those in DK 5783. Both treatments of combined NO and TU as seed soaking or foliar application were effective in mitigating salt-induced inhibition more in shoot growth than on other processes. Both modes of treatment of combined growth substances resulted in increased Ca^{2+} and K^+ contents, and decreased that of Na^+ in salt-stressed maize plants. Overall, externally-applied combined NO and TU induced growth improvement in maize was ascribed to reduced leaf Na^+ andMP and increased Ca^{2+} and K^+as well as increased maximum fluorescence yield under saline regime.

Funding

This research was supported by The Scientific and Technical Research Council of Turkey (TUBITAK-TOVAG-112O375).

References

Akram, M. S., M. Ashraf, and N. A. Akram. 2009. Effectiveness of potassium sulfate in mitigating salt-induced adverse effects on different physio-biochemical attributes in sunflower (*Helianthus annuus* L.). *Flora* 204:471–483.

Akram, N. A., and M. Ashraf. 2013. Regulation in plant stress tolerance by a potential plant growth regulator, 5-aminolevulinic acid. *Journal of Plant Growth Regulation* 32:63–79.
Anjum, F., A. Wahid, M. Farooq, and F. Javed. 2011. Potential of foliar applied thiourea in improving salt and high temperature tolerance of bread wheat (*Triticum aestivum*). *International Journal of Agricultural Biology* 13:251–256.
Ashraf, M., N. A. Akram, R. N. Arteca, and M. R. Foolad. 2010. The physiological, biochemical and molecular roles of brassinosteroids and salicylic acid in plant processes and salt tolerance. *Critical Reviews in Plant Science* 29:162–190.
Ashraf, M., and M. R. Foolad. 2007. Roles of glycine betaine and proline in improving plant abiotic stress resistance. *Environmental and Experimental Botany* 59:206–216.
Ashraf, M., and P. J. C. Harris. 2013. Photosynthesis under stressful environments: An overview. *Photosynthetica* 51:163–190.
Asthir, B., R. Thapar, M. Farooq, and N. S. Bains. 2013. Exogenous application of thiourea improves the performance of late sown wheat by inducing terminal heat resistance. *International Journal of Agricultural Biology* 15:1337–1342.
Bates, L. S., R. P. Waldren, and I. D. Teare. 1973. Rapid determination of free proline for water stress studies. *Plant and Soil* 39:205–207.
Burman, U., B. K. Garg, and S. Kathju. 2004. Interactive effects of thiourea and phosphorus on clusterbean under water stress. *Biologia Plantarum* 48:61–65.
Chapman, H. D., and P. F. Pratt. 1982. *Methods of plant analysis, I. Methods of analysis for soils, plants and water*. Riverside, California: Chapman Publishers.
Chaudhry, M. R., M. Iqbal, and K. M. Subhani. 2000. Economic use of degraded land and brackish water by growing salt tolerant trees. In: *Prospects for saline agriculture*, eds. R. Ahmed, and K. A. Malik, pp. 287–295. The Netherlands: Kluwer Academic Publisher.
Chen, F., F. Wang, H. Y. Sun, Y. Cai, W. H. Mao, G. P. Zhang, E. Vincze, and F. B. Wu. 2010. Genotype-dependent effect of exogenous nitric oxide on Cd-induced changes in antioxidative metabolism, ultrastructure, and photosynthetic performance in barley seedlings (*Hordeum vulgare*). *Journal of Plant Growth Regulation* 29:394–408.
Chen, K., L. Chen, J. Fan, and J. Fu. 2013. Alleviation of heat damage to photosystem II by nitric oxide in tall fescue. *Photosynthesis Researches* 116:21–31.
Cui, I. X., Y. H. Zhou, J. G. Ding, X. J. Xia, K. Shi, S. C. Chen, T. Asami, Z. Chen, and J. Q. Yu. 2011. Role of nitric oxide in hydrogen peroxide−dependent induction of abiotic stress tolerance by brassinosteroids in cucumber. *Plant, Cell and Environment* 34:347–358.
Dionisio-Sese, M. L., and S. Tobita. 1998. Antioxidant responses of rice seedlings to salinity stress. *Plant Science* 135:1–9.
Dong, Y. J., S. S. Jinc, S. Liu, L. L. Xu, and J. Kong. 2014. Effects of exogenous nitric oxide on growth of cotton seedlings under NaCl stress. *Journal of Soil Science and Plant Nutrition* 14:1–13.
Flowers, T. J. 2004. Improving crop salt tolerance. *Journal of Experimental Botany* 55:307–319.
Geissler, N., S. Hussin, and H. W. Koyro. 2009. Interactive effects of NaCl salinity and elevated atmospheric CO_2 concentration on growth, photosynthesis, water relations and chemical composition of the potential cash crop halophyte *Aster tripolium* L. *Environmental and Experimental Botany* 65:220–231.
Habib, N., M. Ashraf, and M. S. Aqeel Ahmad. 2010. Enhancement in seed germinability of rice (*Oryza sativa* L.) by presowing seed treatment with nitric oxide (NO) under salt stress. *Pakistan Journal of Botany* 42:4071–4078.
Habib, N., M. Ashraf, and M. Shahbaz. 2013. Effect of exogenously applied nitric oxide on some key physiological attributes of rice (*Oryza sativa* L.) plants under salt stress. *Pakistan Journal of Botany* 45:1563–1569.
Habib, N., and M. Ashraf. 2014. Effect of exogenously applied nitric oxide on water relations and ionic composition of rice (*Oryzya Sativa* L.) plants under salt stress. *Pakistan Journal of Botany* 46:111–116.
Kausar, F., and M. Shahbaz. 2013. İnteractive effect of foliar application of nitric oxide (NO) and salinity on wheat (*Triticum aestivum* L.). *Pakistan Journal of Botany* 45:67–73.
Kaya, C., M. Ashraf, and O. Sonmez. 2015. Promotive effect of exogenously applied thiourea on key physiological parameters and oxidative defense mechanism in salt-stressed *Zea mays* L. plants. *Turkish Journal of Botany* 39:786–795.
Kaya, C., M. Ashraf, O. Sonmez, A. L. Tuna, and S. Aydemir. 2015. Exogenously applied nitric oxide confers tolerance to salinity-induced oxidative stress in two maize (*Zea mays* L.) cultivars differing in salinity tolerance. *Turkish Journal of Agriculture and Forestry* 39:909–919.
Liu, S., Y. Dong, L. Xu, and J. Kong. 2014. Effects of foliar applications of nitric oxide and salicylic acid on salt-induced changes in photosynthesis and antioxidative metabolism of cotton seedlings. *Plant Growth Regulators* 73:67–78.
Mihailovic, N., and G. Drazic. 2011. Incomplete alleviation of nickel toxicity in bean by nitric oxide supplementation. *Plant Soil and Environment* 57:396–401.
Misra, A. N., D. Latowski, and K. Strzalka. 2006. The xanthophyll cycle activity in kidney bean and cabbage leaves under salinity stress. *Russian Journal of Plant Physiology* 53:113–121.
Nathawat, N. S., J. S. Nair, S. M. Kumawat, N. S. Yadava, G. Singh, N. K. Ramaswamy, M. P. Sahu, and S. F. D'souza. 2007. Effect of seed soaking with thiols on the antioxidant enzymes and photosystem activities in wheat subjected to water stress. *Biologia Plantarum* 51:93–97.
Nawaz, K., and M. Ashraf. 2010. Exogenous application of glycinebetaine modulates activities of antioxidants in maize plants subjected to salt stress. *Journal of Agronomy and Crop Science* 196:28–37.
Pandey, M., A. K. Srivastava, S. F. D'Souza, and S. Penna. 2013. Thiourea, a ROS scavenger, regulates source-to-sink relationship to enhance crop yield and oil content in *Brassica juncea* (L.). *PLoS ONE* 8:e73921.

Perveen, S., M. Shahbaz, and M. Ashraf. 2013. Influence of foliar-applied triacontanol on growth, gas exchange characteristics, and chlorophyll fluorescence at different growth stages in wheat under saline conditions. *Photosynthetica* 51:541–51.

Planchet, E., and W. M. Kaiser. 2006. Nitric oxide (NO) detection by DAF fluorescence and chemiluminescence: A comparison using abiotic and biotic NO sources. *Journal of Experimental Botany* 57:3043–3055.

Purty, R. S., G. Kumar, S. L. Singla-Pareek, and A. Pareek. 2008. Towards salinity tolerance in Brassica: An overview. *Physiology and Molecular Biology of Plants* 14:39–49.

Sahu, M. P., N. S. Solanki, and L. N. Dashora. 1993. Effects of thiourea, thiamine and ascorbic acid on growth and yield of maize (*Zea mays* L.). *Journal of Agronomy and Crop Science* 171:65–69.

Saleem, M., M. Ashraf, and N. A. Akram. 2011. Salt (NaCl)-induced modulation in some key physio-biochemical attributes in okra (*Abelmoschus esculentus* L.). *Journal of Agronomy and Crop Science* 197:202–213.

Shaheen, S., S. Naseer, M. Ashraf, and N. A. Akram. 2012. Salt stress affects water relations, photosynthesis and oxidative defense mechanisms in *Solanum melongena* L. *Journal of Plant Interaction* 8:85–96.

Sheokand, S., V. Bhankar, and V. Sawhney. 2010. Ameliorative effect of exogenous nitric oxide on oxidative metabolism in NaCl treated chickpea plants. *Brazilian Journal of Plant Physiology* 22:81–90.

Sreenivasulu, N., B. Grimm, U. Wobus, and W. Weschke. 2000. Differential response of antioxidant compounds to salinity stress in salt-tolerant and salt-sensitive seedlings of foxtail millet (*Setaria italica*). *Physiologia Plantarum* 109:435–442.

Srivastava, A. K., S. Srivastava, S. Penna, and S. F. D'Souza. 2011. Thiourea orchestrates regulation of redox state and antioxidant responses to reduce the NaCl-induced oxidative damage in Indian mustard (*Brassica juncea* L. Czern). *Plant Physiology and Biochemistry* 49:676–686.

Strain, H. H., and W. A. Svec. 1966. Extraction, separation, estimation and isolation of the Chlorophylls. In: *The chlorophylls*, eds. L. P. Vernon, and G. R. Seely, pp 21–65. New York, NY: Academic Press.

Visarada, K. B. R. S., K. Meena, C. Aruna, S. Srujana, N. Saikishore, and N. Seetharama. 2009. Transgenic breeding: Perspectives and prospects. *Crop Science* 49:1555–1563.

Witcombe, J. R., P. A. Hollington, C. J. Howarth, S. Reader, and K. A. Steele. 2008. Breeding for abiotic stresses for sustainable agriculture. *Philosophical Transactions of the Royal Society B* 363:703–716.

Xue-Xia, W., D. Hai-Dong, C. Jian- Lin, Z. Hong-Juan, and Z. Wei-Min. 2007. Attenuation of salt-induced changes in photosynthesis by exogenous nitric oxide in tomato (*Lycopersicon esculentum* Mill. L.) seedlings. *African Journal of Biotechnology* 9:7837–7846.

Yıldıztugay E., C. Özfidan Konakçı, M. Küçüködük, and Y. Duran. 2014. Modulation of osmotic adjustment and enzymatic antioxidant profiling in Apera intermedia exposed to salt stress. *Turkish Journal of Botany* 38:99–111.

Zehra, A., B. Gul, R. Ansari, A. R. A. Alatar, A. K. Hegazy, and M. Ajmal Khan. 2013. Action of plant growth regulators in alleviating salinity and temperature effects on the germination of Phragmites karka. *Pakistan Journal of Botany* 45:1919–1924.