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Impact of Salinity Stress on Morpho-physiology of Four Rice (*Oryza sativa* L.) Varieties

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Abiotic stress, especially salinity, is one of the major restraints for attaining self-sufficiency in the food grain production. The saline soils affect the crop growth both directly and indirectly by interfering with plant metabolism resulting in reduction in yield potential of various crops. Rice (*Oryza sativa* L.), the staple food of much of the world's population, is categorized as a salt-susceptible crop. Improving the salt tolerance of rice would increase the potential of saline-alkali land and ensure food security. To investigate the effect of different levels of salinity on morpho-physiological characters and yield of four rice variety *viz*. Pokkali, Narendra Ushar Dhan 3, IR 28 and IR 29. A pot experiment was conducted during *Kharif* 2011 and 2012 at the Department of Crop Physiology, Narendra Deva University of Agriculture and Technology, Kumarganj, Faizabad (U.P.) under normal soil and saline conditions with EC 6.0 and EC 10.0 dS/m. Gradual increase on

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plant height as well as biomass with the advancement in the age of crop up to dough grain in all the varities under both normal and salinity treatment. Maximum grain yield recorded in tolerant varieties Narendra Usar Dhan 3 followed by Pokkali, whereas minimum in IR 28. Under saline conditions regarding sink potential, the tolerant varieties recorded less reduction in yield attributes like length of panicle (cm), number of panicle per plant, number grain panicle^{-1} and grain yield plant^{-1} as compared to normal condition. The salinity tolerance capacity of tolerance varieties was associated with increased the activity of catalase and superoxide dismutase enzyme batter accumulation of proline and total carbohydrate as compared to normal condition.

Keywords: Antioxidant enzyme; SOD; salinity; grain yield; rice

1. INTRODUCTION

Rice is one of the important staple food crops and is consumed by approximately 50% of the global population as their main source of energy. The world population is increasing and will reach 9.5 billion by year 2050 and world food production will need to increase by 70% (FAO 2013). Salinity stress is one of the most vital abiotic stresses which results in significant damages of agricultural production, particularly in arid and semi-arid areas of the world. Salinity causes by high accumulation of soluble salt, especially NaCl in soil and water (Zhao et al. 2007). According to the FAO Land and Nutrition Management Service, (2008), over 6% of the world’s land is affected by either salinity or sodicity which accounts for more than 800 million ha of land (FAO 2008). Saline soils are defined as those contain sufficient salt in the root zone to impose the growth of crop plants (Ponnamperuma 1984). However, since salt injury depends on species, variety, growth stage, environmental factors, and nature of the salts, it is difficult to define saline soils precisely. The USDA Salinity Laboratory defines a saline soil as having an electrical conductivity of the saturation extract (EC) of 4 dS/m or more. EC is the electrical conductivity of the ‘saturated paste extract’, that is, of the solution extracted from a soil sample after being mixed with sufficient water to produce a saturated paste. The most widely accepted definition of a saline soil has been adopted from as one that has an EC of 4 dS/m or more and soils with EC exceeding 15 dS m^{-1} are considered strongly saline (Yadav et al. 2011).

Soil salinity, particularly due to NaCl, can be considered the single most widespread soil toxicity problem that global rice production faces at present. Salinity influences a number of physiological processes like photosynthesis, nutrient uptake, water absorption, root growth, and cellular metabolism (Hasegawa et al. 2000, Lin et al. 2000 and Netondo et al. 2004). Rice plants are relatively susceptible to soil salinity, and NaCl is a major salt that causes this problem (Flowers 2004). In general, electrical conductivity of saturated paste extract (EC) of 4.0 deciSiemens per meter (dS/m) is considered a lower limit to define saline soils (Flowers 2004).

Salinity affects at all growth stages, yield and metabolism of rice crop responses to salinity varies with these stages and concentration and duration of exposure to salinity. In the most commonly cultivated rice young seedlings were very sensitive to salinity (Lutts et al. 2005 and Ashrafuzzaman et al. 2002).

The detrimental effect of salinity can be attributed to the decrease in osmotic potential of the medium and disturbance of the ion balance on plant growth and metabolism (Ram, 1979). Salinity in the growth medium causes significant impacts on plant growth parameters like leaf area, leaf length, root and shoot dry weight, decrease carotenoid and induce reduction in chlorophyll and photosynthetic activity (Rechards 1954 and Levitt 1980).

Therefore, this study aims to compare growth and physiological responses, among four rice cultivars differing in salinity tolerance ability in order to gain more understanding of the mechanisms of salinity tolerant and salinity sensitive varieties are expected to be useful as potential targets for improvement of salinity tolerant rice.

2. MATERIALS AND METHODS

A Pot experiment was conducted during Kharif 2011 and 2012 at the Department of Crop Physiology, Narendra Deva University of Agriculture and Technology, Kumarganj, Faizabad (U.P.) under normal soil and saline conditions with Electrical Conductivity (EC) 6.0

and 10.0 dS/m and two tolerant varieties (Pokkali and Narendra Ushar Dhan 3) two susceptible varieties IR 28 and IR 29 were taken for this experimentation. Before preparation of soil.

The soil was silty loam in nature with having pH 8.7, organic carbon 0.22%, EC 3.6 dS/m and ESP 71 % concentration in soil solution and normal was sandy loam in nature soil having pH 7.8, organic carbon 0.48%, EC 1.9 dS/m and ESP 13 %. Pots were arranged in a completely randomized design under the sun with three replicates per treatment EC 6.0 and 10 dS/m maintained the amount of NaCl for 30 liters of water. Soil saturation being 30%, NaCl 44.86 and 119.61 g, dissolved in demineralized water respectively. Spread 100 Kg soil on a thick polyethylene sheet and spray NaCl solution so as to saturate it similar to that mentioned in the preparation of alkali soil. After completion of spraying, leave this soil for a few days for equilibration. Finally mix the soil and use or filling in pots or trays for experiment. Before filling in the pots check for the salinity level in the soil as per standard procedure (Strogonov 1973).

The total chlorophyll content was describe by Arnon, (1949) and expressed as mg per g fresh weight. The membrane stability index (MSI) and total carbohydrate (mg per g dry weight) were determined according to the specified methods described by Saadalla *et al*, (1990) and Yemm and Willis (1954). Catalase activity (unit per g Fr. Wt.) was assayed by method of Sinha (1972). SOD was assayed method of Asada *et al* (1992) and expressed as enzyme unit per g fresh weight. Free proline content (mg per g fresh weight) in embryo axis was estimated spectrophotometrically according to the methods of Bates *et al.* (1973). Observation on yield and yield components were taken at the time of harvesting on three plants per replicate already tagged for this purpose.

3. RESULTS AND DISCUSSION

The growth parameters like plant height and dry biomass (Table 1 and Fig. 1) salinity enhance both susceptible and tolerant varieties. Minimum reduction in plant height and dry biomass was observed in Pokkali and Narender Usar Dhan- 3 (tolerant varieties) and maximum observed in IR 28 and IR 29 (susceptible varieties) in both salinity levels at EC 6.0 and 10.0 dS/m as compared to control. High concentrations of salinity caused osmotic stress (Bhowmik et al. 2009) around the plant root zone. Under salinity stress, especially NaCl stress reduces the plant cell turgor pressure, uptake of water and nutrients, closure of stomata took place. Due to competition of sodium (Na+) an imbalance of mineral and water uptake the activity of photosynthesis decreased and growth was inhibited (Bhowmik et al. 2009).

Table 1. Impact of salinity stress on different growth and biochemical parameters four rice varieties

S. No.	Variety	Plant Height (cm) at maturity	Dry biomass per plant	Superoxide dismutase (unit g per g fresh weight per min)	Proline content
1	Pokkali	131.13	30.36	493.55	475.69
2	Narendra Ushar Dhan 3	68.93	18.95	488.8	456.58
3	IR 28	63.50	16.61	402.37	404.60
4	IR 29	68.35	18.81	414.15	402.71
1	Normal	100.54	24.82	385.4	365.22
2	EC 6.0	84.02	21.81	457.1	445.81
3	EC 10.0	64.37	16.92	506.7	493.66
Sem±		V= 1.83 T=1.58 VXT= 3.16	V= 7.38 T=6.39 VXT=12.8	V= 7.45 T=6.46 VXT=12.9	V= 12.36 T=10.7 VXT=21.41
CD at 5%		V= 5.36 T=4.64 VXT=NS	V= 7.38 T=6.39 VXT=12.79	V= 21.88 T=18.95 VXT=NS	V=36.29 T=3143 VXT=NS

When increase of salinity in soil, the osmotic stress induces stomata closure and less uptake of water and minerals ((Bhowmik et al. 2009 and Gale and Zeroni 1984). The activity of stomata closure restricts the supply of CO_2 fixation in plants. The activity of ROS, lipids, nucleic acids and some photosynthetic enzymes is affected. The slower plant growth and consequently low crop yields due to the week binding between chlorophyll and chloroplast protein under salinity stress (Afria et al. 1999 and Makino and Mae 1999). The less reduction of total chlorophyll content was noticed in Pokkali and Narender Usar Dhan-3 and the minimum reduction was observed in IR 28 and IR 29 under both salinity levels in comparison to the control.

Salinity significantly reduced sugar content in leaves, but maximum reduction was noticed at EC 10.0 dSm^{-1} in both the tolerant and susceptible varieties. The highest total carbohydrate (Table 1) was observed in tolerant varieties, where the lowest was observed in susceptible varieties. At both the levels of EC (6.0 and 10.0), IR 29 showed the minimum reduction in total carbohydrate, where the maximum reduction was observed in Pokkali. With an increase in CO_2 fixation in plants, the rate of carbohydrate accumulation and photosynthetic rates are also increasing, to show a better relation between source and sink. The negative effect on plant growth, phloem transport and carbohydrate production under salinity stress (Kong-ngern et al. 2012) Salinity may cause hydrolysis of reserve polysaccharides or rapid utilization of total soluble sugars, the level of carbohydrate is decreased (Prasad 1990).

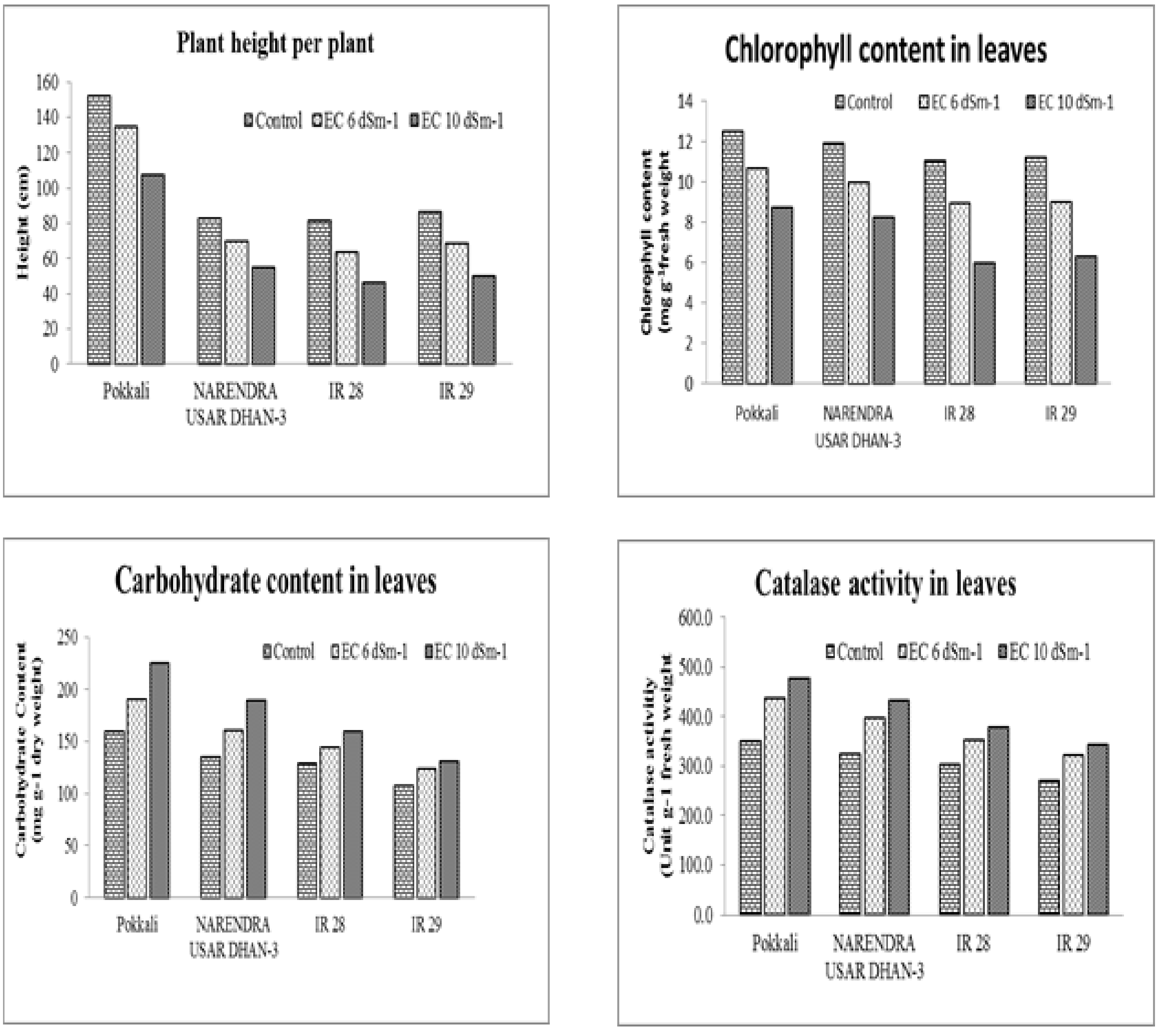

Fig. 1. Impact of salinity stress on plant height, chlorophyll, carbohydrate and catalase activity of four rice varieties

The minimum accumulation of proline content (Table 1) was observed by IR 29, where, as maximum accumulation in Pokkali at both the EC 6.0 and 10.0 dS/m with comparison to control. Under both abiotic and biotic stress conditions, plants increase the accumulation of free proline. Stabilizing reactive oxygen species (ROS) scavenging enzyme and active alternative detoxification pathway the proline accumulated (Amar, 1999 and Pandey & Srivastava 1985).

Under abiotic stress, stimulate the synthesis of hydrogen peroxides (H_2O_2), hydroxyl anion (OH^-) and super oxide anion (O_2^-) in chloroplasts and mitochondria (Hanson & Hits 1982). Formation of ROS in plant cell with increase of level of salinity, Accumulation of high level of ROS causes oxidative damage, non-enzymatic and enzymatic system are involve to prevent the oxidative damage (Hanson & Hits 1982 and Mittler 2002). Plants release a number of antioxidant enzymes like SOD, APX, and CAT to protect against the damaging effect of ROS (Trotel et al. 1989). The activity of catalase and superoxide dismutase increases with an increase in salinity in both tolerant and susceptible varities. In this study also, SOD activity (Table 1) increased under both saline soils in both tolerant varieties, Pokkali and Narendra Usar Dhan 3, while decreasing in sensitive varieties, IR 28 and IR 29. The minimum decrease of SOD, at both salinity treatments (EC 6 and 10 dS/m) were observed by IR 29, where, the maximum reduction was observed by Pokkali. The minimum reduction CAT, at both salinity treatment (EC 6 and 10 dSm^{-1}) were observed by IR 29, where, as maximum reduction was observed by Pokkali.

Salinity negative effect on number of panicles per plant, number of grains per panicle, panicle length, and grain yield per plant in IR 28 and IR 29 indicated that these varieties were more susceptible to salinity than Pokkali and Narendra Usar Dhan 3. The inhibition of growth of a rice plant is due to the high salinity concentration in the soil solution (*i.e.,* higher osmotic pressure and consequently low soil water potential) and high concentration of potentially toxic ions such as Cl^- and Na^+, which might lead to ion toxicity and nutrition imbalance, consequently growth inhibition. The other possible causes could be the shrinkage of cell contents, reduced development and differentiation of tissues, imbalanced nutrition, damage of membranes and disturbed avoidance mechanisms (Apel et al. 2004 and Ali et al. 2004). The grain yield plant-1 of rice genotypes was significantly reduced under salinity stress (Ali et al. 2004), where the grain yield of rice was significantly decreased with increasing salinity levels (Nejad et al. 2010).

The severe inhibitory effects of salinity on fertility may be due to the differential competition in carbohydrates supply between vegetative growth and constrained its distribution to the developing panicles, whereas the other is probably linked to reduced viability of pollen under stress conditions, thus resulting in failure of seed set (Mahmood et al. 2009).

The decreased harvest index with the increase in salinity was consistent with this hypothesis. The reduction in yield and yield components under saline conditions might be due to reduced cell division and differentiations leading to poor sink development. In addition, adverse effects of salinity stress on photosynthesis and translocation of metabolites to the reproductive sink could be some of the possible reasons for lower yield (Singh and Mishra 2003 and Abdullah et al. 2001).

Table 2. Impact of salinity stress on yield component of four rice varieties

S. No.	Variety	length of panicle (cm)	No. of panicle /plant	No. grain / panicle
1	Pokkali	18.72	3.76	156.49
2	Narendra Ushar Dhan 3	17.3	3.75	157.2
3	IR 28	14.73	3.41	141.73
4	IR 29	15.95	3.4	145.21
1	Normal	19.19	4.07	180.4
2	EC 6.0	16.79	3.66	145.63
3	EC 10.0	14.04	3.02	124.45
Sem±		V= 0.37 T=0.32 VXT= NS	V= 0.09 T=0.08 VXT= 0.16	V= 3.33 T= 2.88 VXT=5.76
CD at 5%		V= 1.08 T=0.94 VXT= NS	V= 0.27 T=0.23 VXT=NS	V=9.77 T=8.46 VXT=NS

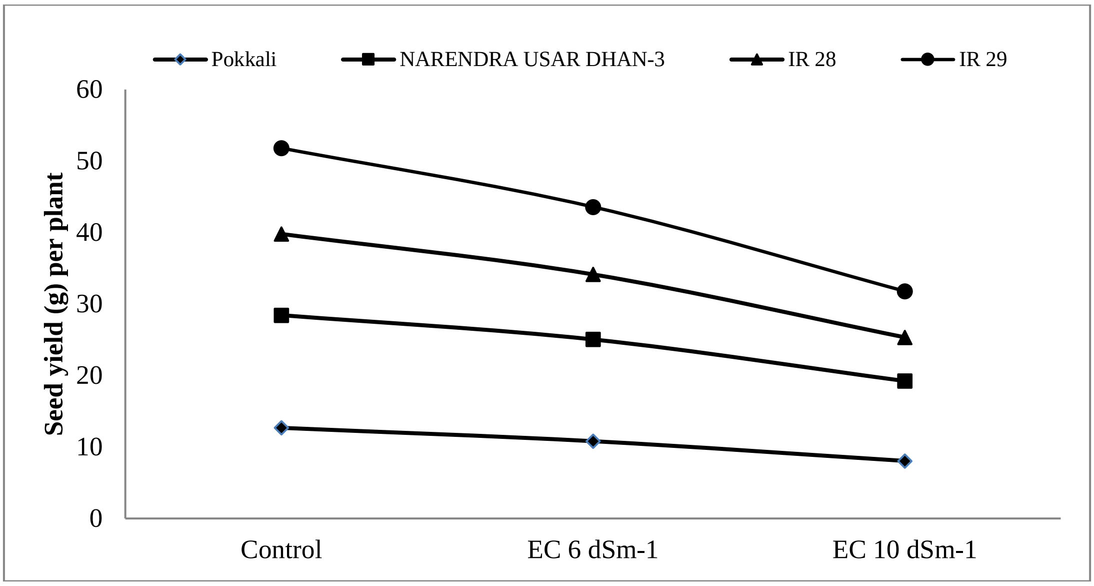

Fig. 2. Impact of salinity stress on seed yield per plant of four rice varieties

4. CONCLUSION

Up-regulation of the anti-oxidant system appears to play a role in salinity tolerance of rice, with tolerant genotypes also maintaining relatively higher relative water content, membrane stability index, chlorophyll content, carbohydrate, proline, catalase, superoxide dismutase during all the stages in tolerant varieties than susceptible. Pokkali and Narendra Ushar Dhan 3 have desirable yield traits for saline condition and these varieties may be used in breeding programme and can be helpful in boosting up rice production in saline soil.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (Chat GPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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