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SCREENING OF ZINC EFFICIENT AND INEFFICIENT RICE GENOTYPES IN LOW SOIL ZN STATUS

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ABSTRACT
Field experiment was conducted during thaladi season on 2013-2014 and 2014-2015 at wetlands of TNAU farm, Coimbatore to screen 18 rice cultivars for zinc efficiency using soil plus foliar zinc fertilization. The experiment was laid out in a split plot design with Zn treatment in main plot and rice genotypes in sub plot. The rice genotypes CORH4 recorded higher grain yield of 6674 and7559 kg ha^{-1}in no zinc and soil plus foliar applied Zn respectively. By using uptake and yield efficiency indices the Zn efficient and Zn inefficient rice genotypes were identified and found that higher uptake and yield efficiency index of 62.39 and 88.73 respectively. Zn efficient rice genotypes were identified as Co 50, Improved White Ponni, CORH4, ADT 46, TRY 1 and DRRH3 and the Zn inefficient rice genotypes were Co43, Swarna, Bhavani, BPT 5204 and TRY 3. The Zn efficient genotypes showed higher dry matter, root volume, shoot zinc content, grain zinc content

INTRODUCTION

The world's population is estimated to increase from 6 billion to about 10 billion by 2050. To meet the food demand of the growing world population, a large increase in food production is required (Byrnes and Bumb, 1998). More food production in available area leads to greater exploitation of the micronutrient soil reserves. Micronutrient deficiencies drastically affect the growth, metabolism and reproductive phase in plants, animal and human beings. Particularly, zinc deficiency in soils and plants is a global micronutrient deficiency problem reported in many countries and 30% of the world soils are deficient in available zinc (Alloway, 2008).

Zinc deficiency Symptoms in human include; growth retardation, susceptibility to infectious diseases, hypogonadism, iron deficiency anemia, and poor birth outcome in pregnant women; whereas in animal, Zn deficiency leads to Loss of hair, skin diseases, fall in milk production, loss of appetite, stiff and swollen joints. In India people consume rice as their main dietary food but during polishing Zn content is reduced which is not sufficient to meet the nutritional demand of human. Increasing the Zn content in the grains of cereal crops is considered a sustainable way to alleviate Zn deficiency in animals and human.

Biofortification has been defined as the process of increasing the bioavailable concentrations of essential elements in edible portions of crop plants through agronomic intervention or genetic selection. "Agronomic biofortification" can be done through the application of fertilizer (inorganic or organic), modification of cultivation systems, soil management and new irrigation strategies have proved effective in enriching micronutrients content in rice grain by controlling the availability of soil micronutrients for plant (White and Broadley,2009). Application of zinc fertilizer is essential in keeping sufficient amount of available Zn in soil solution, maintaining adequate Zn transport to the seeds during reproductive growth stage and increasing the yield. Zinc sulfate ($ZnSO_4$) is the most widely applied inorganic source of Zn due to its high solubility and low cost. Soil plus foliar application of Zn fertilizers under field conditions are highly effective and very practical way to maximize uptake and Zn accumulation in grains (Cakmak, 2008).

Timing of foliar Zn application is an important factor in determining the effectiveness of the foliar applied Zn fertilizers for increasing grain Zn concentration. More distinct increase in grain Zn by foliar Zn application was achieved when Zn was applied after flowering time, e.g., at early milk plus dough stages (Phattarakul *et al*., 2012). Besides the application of Zn fertilizers for alleviating Zn deficiency in animals and humans, a more efficient and sustainable solution is the development and use of Zn-efficient plant genotypes that can more effectively function under low soil Zn conditions, which would reduce fertilizer inputs and protect the environment as well. With this background a study was conducted to distinguish the Zn efficient and Zn inefficient rice genotypes were identified with soil plus foliar Zn application.

MATERIALS AND METHODS

A field experiment was conducted during the two consecutive years 2013-14 and 2014-15 in Thaladi season at two different Zn deficient sites at the wetlands of TNAU farm, Coimbatore to screen various rice cultivars for zinc efficiency using soil plus foliar zinc fertilization. The genotypes included in this study were Co43, Co49, Co50, Improved white Ponni, IR 20, CoRH4, Swarna, Bhavani, TPS 3, ADT 38, ADT 39, ADT 46, ADT 49, BPT 5204, TRY I, TRY III, PYR I and DRRH3. The soil of the experimental site was sandy clay loam in texture and had the following chemical properties: pH - 7.85 (1:2.5 soil water ratio), EC - 0.22 dSm^{-1}, Available N- 217 kg ha^{-1}, Available P - 29.7 kg ha^{-1}, Available K - 324 $kgha^{-1}$, Organic carbon - 0.24 per cent, DTPA Cu -1.42 mg kg^{-1}, DTPA Fe- 5.47 mg kg^{-1}, DTPA Mn 15.4 mg kg^{-1} and DTPA Zn 1.09 mg kg^{-1}, the soil was deficient in available zinc (< 1.22 mg kg^{-1}). Rice seeds were obtained from the different Research stations of Tamil Nadu Agricultural University. The experiment was laid out in a split plot design, replicated which was three times. Main plot treatments were Zn at two levels (-Zn and +Zn, 100 kg $ZnSO_4.7H_2O$ ha^{-1} at basal and 0.5 per cent $ZnSO_4.7H_2O$ foliar spray thrice at flowering, milk and dough stages of rice plant) and sub plot treatments were rice genotypes (18 Nos.) with a plant spacing of 20 X 15 cm.

Recommended dose of fertilizer @ 150: 50: 50 NPK kg ha^{-1}, in case of varieties, 175: 60:60 NPK kg ha^{-1} for hybrid and 75: 50: 50 NPK kg ha^{-1} for improved white ponni. Full dose of P was applied basally and N and K were applied at four equal splits at basal, active tillering, panicle initiation and fifty percent flowering stages. Zinc was applied at basal in the form of ZnSO4. $7H_2O$ (100 kg ha^{-1}) as per treatment plots. At harvest observation taken to screen the Zn efficient and inefficient rice genotypes were grain yield (kg/ha), grain Zn content (mg/kg), grain dry matter production (kg/ha) and grain Zn uptake (g/ha). To compare the Zn efficient and inefficient rice genotypes in some parameters observations like dry matter production, shoot zinc concentration, total plant Zn uptake and phytic acid content were recorded at harvest stage and also at 50 % flowering stage root volume, Super oxide dismutase and Carbonic anhydrase enzyme activity were recorded.

Superoxide dismutase (SOD)

Fresh leaf samples were macerated with 10 ml of 0.2 M Citrate Phosphate buffer (pH 6.5) at 4°C. The homogenate was centrifuged at 10000 rpm for 30 minutes. SOD activity was estimated by recording the decrease in optical density of form zone made by superoxide radical and nitro-blue tetrazolium chloride dye by the enzyme (Dhindsa *et al.*, 1981). 3 ml of the reaction mixture contained 13.33 mM Methionine (0.2 ml), 75µM nitro blue tetrazolium (NBT) (0.1 ml), 0.1 mM EDTA (0.1 ml), 50 mM Sodium Phosphate buffer (pH 7.8) (1.5 ml), 50 mM sodium carbonate (0.1 ml), 0.05-0.1 ml enzyme extract and 0.9-0.95 ml of water (to make a final volume of 3.0 ml). The reaction was initiated by the addition of 2µM riboflavin (0.1 ml) and placing the tubes under 15 W fluorescent lamps for 15 min. A complete blank reaction mixture, which gave the maximal color served as control. Transferring the tubes to dark stopped the reaction. A non- irradiated reaction mixture served as blank. The change in absorbance was measured calorimetrically at 560 nm. The decrease in NBT reduction was calculated from the blank and sample absorbance values and 50 % decrease in NMT reduction was reported as one unit of SOD.

Carbonic anhydrase

Carbonic anhydrase was estimated by the method of Gibson and Leece (1981).

It was extracted from triplicate 1 g sample of fresh leaf tissue with 5 ml of 100 mM Tris-SO_4 pH 8.3, containing 1 Mm EDTA and 100 mM 2-morcaptoethanol, using a chilled mortar and pestle. Acid washed sand (1 g) was added to aid grinding. The extract was filtered through moist Miracloth, and the Carbonic anhydrase activity of 0.1 ml was measured at 0°C by the vernol-indicator method. Extracts with a reaction time of less than 10 seconds were diluted with extraction buffer and re-assayed. Controls which consists of 0.1 ml buffer in place of enzyme extract, generally completed reaction in 100-110 seconds. Each extract was assayed three times. Extracts with a reaction time of less than ten seconds were diluted with extraction buffer and re-assayed. Carbonic anhydrase activity was expressed on a fresh weight basis using the formula: EU/g= (10(Tb-Te)-1)/g, where Tb = Time for the uncatalysed reaction and Te = Time for the catalysed reaction .

Phytic acid

Phytic acid from the rice grain samples was determined by the method described by Wei *et al.* (2012). Briefly, 0.5 g of rice flour was extracted with 10 mL of 0.2 M HCl for 2 h by a rotary shaker and then centrifuged at 10000 g for 10 min. The clear supernatant was collected, and 2 mL of 0.2% $FeCl_3$ was added to 2.5 mL of supernatant. The resulting solution was mixed thoroughly, heated in a boiling water bath for 30 min, cooled in room temperature, and centrifuged at 10000 g for 15 min. Then supernatant was discarded and the residue in the tube washed three times with 5 mL of deionized water. The tube was then centrifuged again at 10000 g for 10 min after adding 3 mL of 1.5 M NaOH to it. The supernatant was discarded again, and 3 mL of 0.5 M HCl was added to the tube to dissolve the residue. Finally, deionized water was added to the solution made up to the volume of 10 mL. The Fe concentration in the solution was measured by Atomic Absorption Spectrophotometer. The phytic acid content was calculated by multiplying Fe content by the factor 4.2.

RESULTS AND DISCUSSION

The results obtained from the present investigations as well as relevant discussion based on the data pooled over two consecutive years (2013-2014 and 2014-2015) have been presented under following heads. Based on the pooled data the grain yield was significantly influenced by the zinc application and genotypes, which ranged from 4553 kg ha^{-1} in control of Bhavani to 7559 kg ha^{-1} in Zn applied plot of CORH4 (Table 2) and it was found that the application of NPK with zinc increased the grain yield considerably than NPK alone in all the genotypes. This finding is in agreement with Nawaz *et al.* (2015) and Painkra *et al.* (2015). The genotype CORH4 registered the highest grain yield in both No zinc (6674 kg ha^{-1}) and zinc applied (7559 kg ha^{-1}) while the lowest grain yield was recorded in Bhavani for both control (4553 kg ha^{-1}) and zinc applied treatments (5271 kg ha^{-1}).Pedda Babu *et al.* (2007) also reported that the yield increase may also be due to enhanced synthesis of carbohydrates and their transport

Table 1: Details of analytical procedures employed in analysis

Estimations	Procedure	Reference
Soil reaction (pH)	1:2.5 soil water suspension	Jackson (1973)
Electrical conductivity (EC)	1:2.5 soil water suspension	Jackson (1973)
Organic carbon	Chromic acid wet digestion	Walkley and Black (1934)
Available nitrogen	Alkaline permanganate method	Subbiah and Asija (1956)
Available phosphorus	0.5 M $NaHCO_3$ (pH-8.5)	Olsen *et al*. (1954)
Available potassium	Neutral N NH_4OAc	Stanford and English (1949)
DTPA micronutrients	DTPA extraction and AAS method	Lindsay and Norvell (1978)
Grain and Shoot Zn	Triple acid extraction- AAS method	Lindsay and Norvell (1978)

Table 2: Zinc efficiency index of rice genotypes

Cultivars	Grain yield (kg ha^{-1})		Grain Zn content (mg kg^{-1})		Grain DMP (kg ha^{-1})		Uptake (g ha^{-1})		Uptake	Yield
	No Zn	Zinc	No Zn	Zinc	No Zn	Zinc	No Zn	Zinc	index	index
V_1- CO 43	4862	5777	15.6	37.2	4327	5142	67.5	191.0	35.34	84.16
V_2- CO49	5809	6682	17.4	33.7	5149	5947	89.6	194.2	46.14	86.93
V_3- CO50	5936	6736	19.5	28.7	5283	5995	102.8	171.8	59.83	88.12
V_4- I.W.Ponni	4804	5467	25.2	37.4	4275	4866	107.7	182.0	59.20	87.86
V_5-IR 20	5106	5827	17.1	29.6	4545	5186	74.3	150.7	49.33	87.63
V_6- CORH4	6674	7559	20.9	31.4	5940	6727	123.9	211.2	58.63	88.30
V_7- Swarna	5414	6344	16.2	30.0	4818	5646	78.1	162.0	48.17	85.34
V_8- Bhavani	4553	5271	16.1	32.1	4052	4691	65.0	150.6	43.18	86.37
V_9- TPS 3	4798	5644	19.7	31.2	4270	5023	83.9	156.7	53.54	85.00
V_{10}- ADT 38	6093	6922	19.0	37.8	5423	6161	102.8	232.9	44.13	88.02
V_{11}- ADT 39	5088	5787	16.2	37.5	4529	5150	73.4	193.1	37.99	87.93
V_{12}- ADT 46	6198	7083	21.3	29.4	5512	6304	117.4	188.2	62.39	87.50
V_{13}- ADT 49	5619	6534	18.3	29.5	5001	5815	91.3	171.5	53.20	86.00
V_{14}-BPT 5204	5043	5931	14.6	27.6	4488	5278	65.5	145.4	45.06	85.03
V_{15}- TRY 1	5269	5939	22.7	37.7	4689	5285	106.2	199.0	53.38	88.73
V_{16}- TRY 3	5114	5982	17.1	35.4	4551	5324	77.6	188.2	41.23	85.48
V_{17}-PYR 1	5475	6327	17.2	29.0	4873	5631	83.8	163.3	51.33	86.54
V_{18}- DRRH3	6142	6969	18.5	29.2	5462	6202	100.8	181.1	55.65	88.13
Mean	5444	6265	18.5	32.4	4844	5576	89.5	179.6	49.87	86.84
	SEd	CD(0.05)	SEd	CD(0.05)	SEd	CD(0.05)	SEd	CD(0.05)		
M	47	201	0.5	2.3	38	162	3.9	16.9		
V	35	69	0.5	1.0	28	55	2.6	5.1		
M x V	67	209	0.8	2.5	54	168	5.3	17.3		
VxM	49	98	0.7	1.3	39	78	3.6	7.2		

to the site of grain production. The foliar spraying of zinc resulted in better absorption of zinc and in turn helping in the photosynthetic activities and effective translocation to storage organs which might have contributed for increased yield. This was in accordance with the earlier findings of Datta and Dhiman (2001).

The zinc concentration in rice grains was significantly influenced by zinc and genotypes (Painkra *et al*., 2015). Zinc concentration in whole rice grains ranged from 14.6 to 37.8 mg kg^{-1}. The genotype ADT 38 (37.8 mg kg^{-1}) had markedly higher zinc in zinc applied treatment; however it was statistically on par with Improved white ponni (37.4 mg kg^{-1}) which also had higher zinc concentration in control (25.2 mg kg^{-1}). The genotype BPT 5204 recorded lower zinc concentration in both control (14.6 mg kg^{-1}) and zinc applied plot (27.6 mg kg^{-1}). Boonchuay *et al.* (2013) noted that increase in zinc concentration in grains may be due to two sources of grain Zn loading a) xylem transport of Zn from root b) absorption of foliar applied Zn by leaf epidermis, remobilization and translocation into the developing rice grains through the phloem by several members of the Zn- regulated transporters.

The genotypes were significantly different in grain DMP and also responded well to external zinc application. This may be due to zinc application had improvement in metabolic activities of plant. Those results were supported by Cheema *et al*. (2006). Based on the pooled data the grain DMP ranged from 4052 to 6727 kg ha^{-1}, with a mean grain DMP of 4844 kg ha^{-1} in adequate zinc supply; whereas in control the mean value was 5576 kg ha^{-1}.

Zinc application had a positive influence on the zinc uptake by grains. The result was in accordance with the findings of Khan *et al*. (2012) and Suvarna*et al*. (2015). This may be due to increased availability of zinc in soil solution. In main plots, the uptake varied from 65.0 in control to 232.9 g ha^{-1} in adequate zinc supply (Table 2). Genotypes and their interaction with zinc exerted their prominent influence on the Zn uptake. The highest zinc uptake was observed in CORH4 in control (123.9 g ha^{-1}) and ADT 38 in adequate zinc supply (232.9 g ha^{-1}).

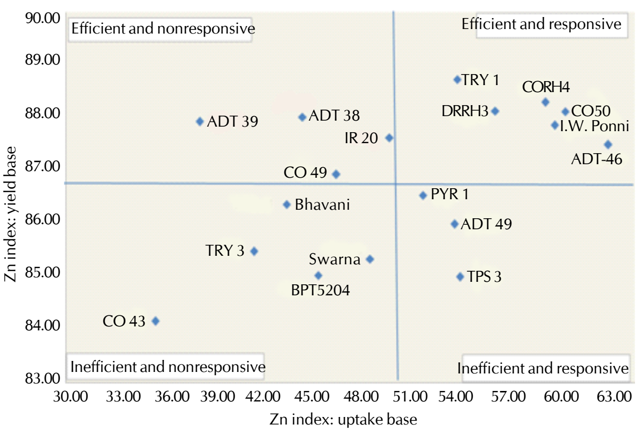

Figure 1: Screening of Zn efficient and Zn inefficient rice genotypes for pooled data

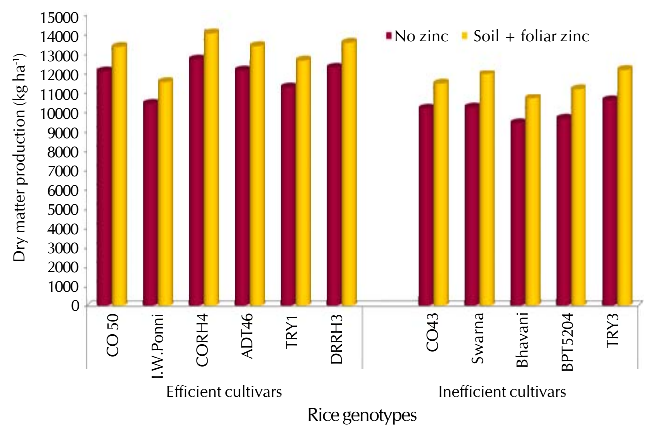

Figure 2: Total plant dry matter production (kg ha^{-1}) of Zn efficient and inefficient rice cultivars at harvest

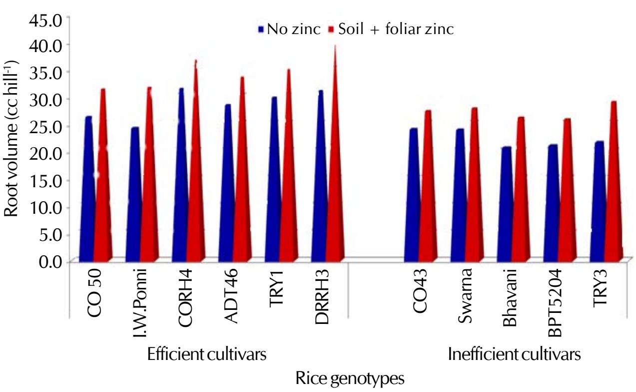

Figure 3: Root volume (cc hill^{-1}) of zinc efficient and inefficient rice cultivars sat 50% flowering stage

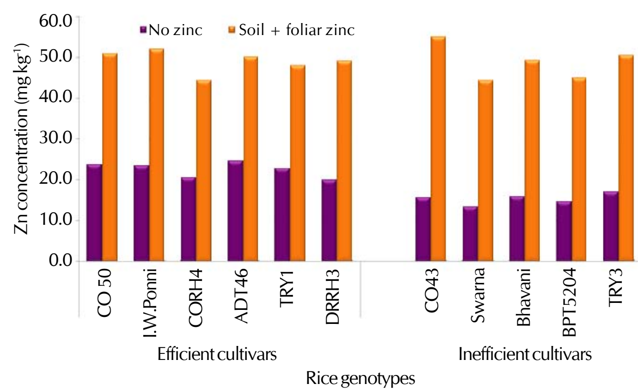

Figure 4: Shoot zinc concentration (mg kg^{-1}) of zinc efficient and inefficient rice cultivars at harvest stage

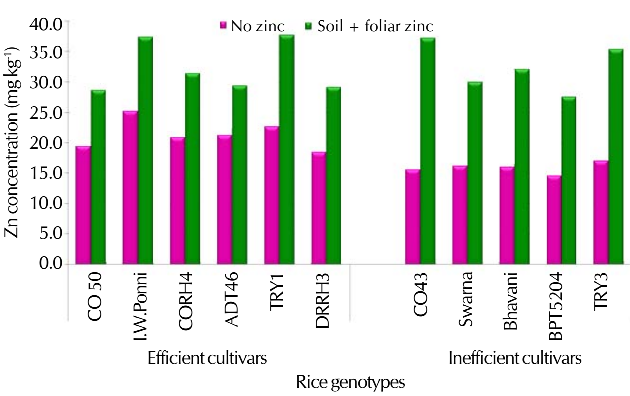

Figure 5: Grain zinc concentration (mg kg^{-1}) of zinc efficient and inefficient rice cultivars

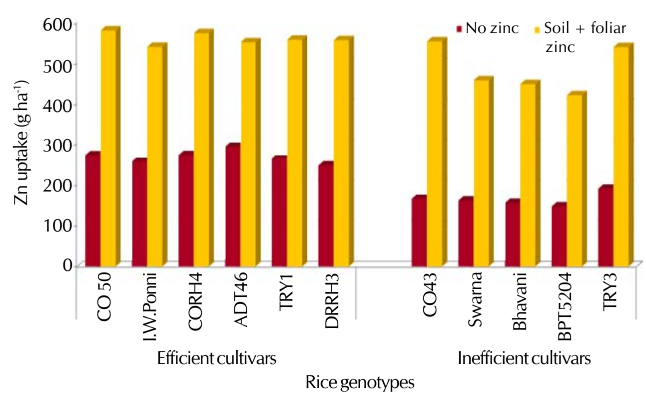

Figure 6: Total plant Zn uptake (g ha^{-1}) of Zn efficient and inefficient rice cultivars at harvest

The Zinc efficient and inefficient rice genotypes were identified based on the screening of cultivars by drawing a scattered diagram using uptake and yield efficiency indices on X and Y axis, respectively.

From the pooled data of two field experiment (2013-14) and (2014-2015), the uptake index varied between 35.34 and 62.39, with a mean uptake index of 49.87, whereas the yield index differed from 84.16 to 88.73 with a mean value of 86.84 (Table 2). Among the genotypes studied Co 50, Improved White Ponni, CORH4, ADT 46, TRY 1 and DRRH3 were grouped under Zn efficient genotypes; whereas CO 43, Swarna, Bhavani, BPT 5204 and TRY 3 were Zn inefficient genotypes (Fig 1).

The Zn efficient and inefficient genotypes identified in the present study are linked with the following parameters:

The identified efficient genotypes could be grown under Zn

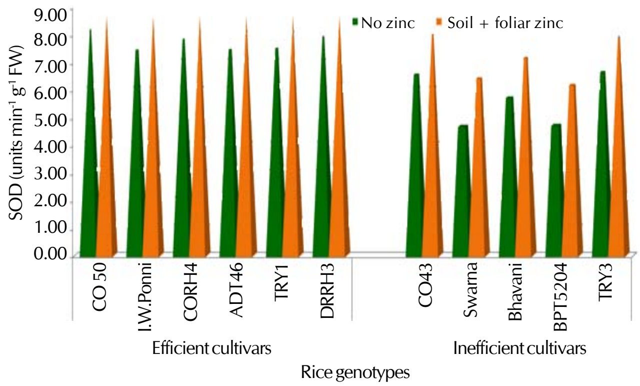

Figure 7: Super oxide dismutase (Units min^{-1} g^{-1} FW) activity in leaves of zinc efficient and inefficient rice cultivars at 50 % flowering stage

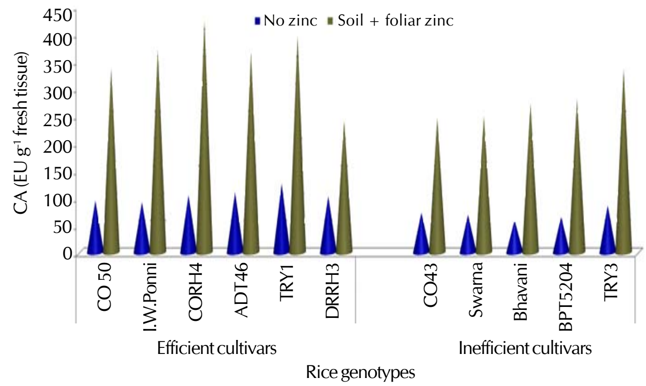

Figure 8: Carbonic anhydrase (EUg^{-1} Fresh tissue) activity in leaves of zinc efficient and inefficient rice cultivars at 50 % flowering stage

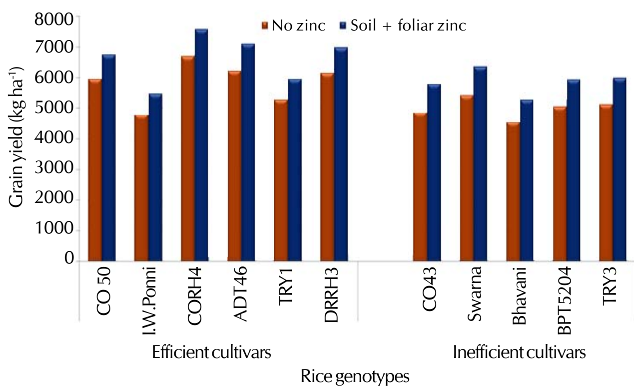

Figure 9: Grain yield (kg ha^{-1}) of zinc efficient and inefficient rice cultivars

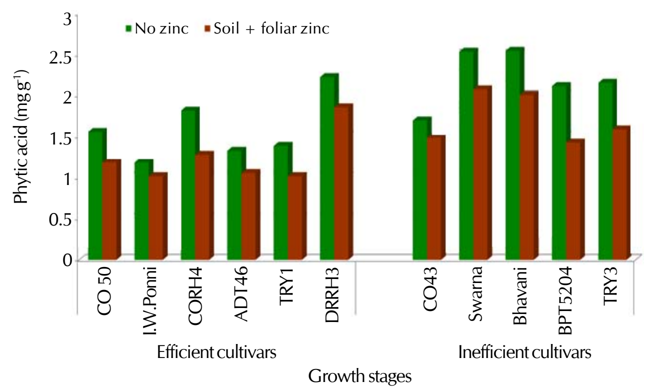

Figure 10: Phytic acid concentration (mg g^{-1}) of zinc efficient and inefficient rice cultivars

stress condition due to their efficiency of Zn utilization from native Zn source in the soil. The mechanisms responsible for this tolerance of genotypes in zinc stress condition include multi-various reasons: a) increased Zn bioavailability in the rhizosphere due to release of root exudates, higher Zn uptake by roots, and efficient utilization and (re)-translocation of Zn (Hajiboland *et al*., 2001;) b) Recently uptake has been considered as the major mechanism responsible for Zn efficiency (ZE) (Genc *et al*., 2006). The agronomic biofortification through soil and foliar Zn application could be a better approach for enhancement of grain Zn concentration of Zn inefficient genotypes.

The genotypes CORH4 recorded the highest total plant dry matter of 12721 and 14073 kg ha^{-1}in no zinc and zinc supply respectively. The Zinc efficient genotypes produce higher dry matter production under deficient and adequate Zn supply, due to their ability to absorb higher zinc from the soil and to utilize for higher DMP as stated by Chaab *et al.* (2011). From this statement the highest DMP was produced in CORH4 and DRRH3 followed by CO 50, ADT 46 and ADT 38, which are the efficient genotypes; whereas the lowest DMP was produced in BPT 5204 (Fig. 2). This may be due to higher Zn uptake by efficient genotypes and enhanced SOD and CA activity in rice leaves of efficient genotypes under Zn stress condition.

The another key attributes in a plant that can play a significant role in determining zinc efficiency or zinc deficiency tolerance of crops was root characteristics like root volume, which can influence the bioavailability of Zn from soil, Zn uptake by root. In this study the higher root volume was observed in DRRH3 (40.4 cc hill^{-1}) followed by CORH4 (36.6cc hill^{-1}), TRY 1(34.9cc hill^{-1}) and ADT46 (33.5cc hill^{-1})(Fig. 3) which could more efficiently scavenge off the small amounts of immobile Zn ion, than plants that produce thicker roots (Rengel *et al.,* 1998). The difference in the root volume of genotypes may be due to the presence of many swollen mitochondria in the root tip cells of efficient genotypes under Zn deficient conditions, whereas most root cells in inefficient genotypes remained intact (Dong *et al.,* 1995). The study indicates that ability of the Zn efficient genotype to produce more fine roots and maintain a relatively efficient antioxidative system and intact root tip cell and functions were the contributing factors responsible for its Zn deficiency tolerance characteristics. These results are confirmed by Chen *et al*. (2009).

Cakmak *et al*. (1999) stated that the zinc efficiency was related to the shoot zinc concentration. In this study under Zn stress condition, ADT 46 recorded higher shoot zinc concentration followed by Improved White ponni, CO 50, TRY 1 (Fig. 4) and this might be due to an efficient ion-transport system within the plant (Khan *et al*., 1998) and the lower shoot zinc concentration was noted in Bhavani and Swarna.

Rengel and Graham (1995) and Khan *et al*. (1998) suggested that high Zn efficiency is a reflection of the high concentration of Zn in seeds. However, Cakmak *et al*. (1997) and Yilmaz *et al*. (1998) reported that the Zn efficiency is usually not accompanied by higher Zn concentrations in grains, in fact Zn inefficient genotypes have higher Zn concentration in grain than Zn efficient one. However, in the present investigation, it was observed that Zn efficient genotypes like Improved White Ponni, TRY-1, ADT 46 and CORH 4 had higher zinc concentration in grains (Fig. 5), which may be to higher yield and uptake efficiency indices found in those genotypes.

Zinc uptake is the most important factor statistically explaining variation in Zn efficiency among the rice genotypes considered (Hajiboland and Salehi, 2006).

The higher Zn uptake was found in CO 50, Improved white ponni, CORH4, TRY 1, ADT 46 and DRRH3, under Zn stress condition, which was higher than the average value (Fig. 6). The higher Zn uptake capacity of Zn efficient genotypes might be attributable to a greater amount of sulfhydryl groups in root-cell plasma membranes, particularly in ion transport-related proteins (Rengel *et al*., 1998).

Gokhan *et al*. (2003) reported that, utilization efficiency in termsof dry matter production per unit of zinc present in the dry matter may be linked to differences in the ability of a genotype to maintain an optimal activity of the important zinc-regulated enzymes, viz. super oxide dismutase (SOD) and carbonic anhydrase (CA). There are also a large number of enzymes in which zinc is an integral component of the enzyme structure (zinc enzymes). Activity of these enzymes has been correlated with zinc availability to the plants. Differences in internal utilization or mobility of Zn have been shown to be involved in expression of Zn efficiency. Gibson and Leece (1981) and Cakmak *et al*. (1997) stated that the activity of SOD and CA was suggested to be a suitable indicator for the levels of physiologically active Zn in the leaf tissue and related with the sensitivity of genotypes to Zn deficiency. In this study, the genotypes CO 50, Improved white ponni, CORH4, TRY 1, ADT 46 and DRRH3 recorded higher SOD and CA than average values under zinc stress conditions and there was twofold higher CA activity in zinc-efficient than zinc inefficient genotypes, which may be due to a higher level of physiologically active Zn pool in leaves of Zn-efficient genotypes (Fig.7 and 8).

Rengel (1995) stated that upon supply of zinc to zinc-deficient plants, zinc-inefficient genotypes showed moderate increase in CA activity, while zinc-efficient genotype showed a marked increase in the CA activity, indicating a positive relationship between CA activity and Zn efficiency. In this study, the percent increase of CA activity among all genotypes was found to be higher in CO 50, CO 49, Improved white ponni, CORH4, TRY 1, ADT 46 and ADT 49 over control. Likewise SOD also related to Zn efficiency, which utilizes physiologically active Zn and prevents lipid peroxidation through its role in superoxide radical metabolism, as noted by Hajiboland and Salehi, (2006).

Zinc efficiency (ZE), mainly defined as the ability of a plant to grow and yield well under Zn deficiency.Hafeez *et al*. (2013) reported that efficient genotypes are those with high ability to absorb nutrients from soil and fertilizer, produce high grain yield per unit of absorbed nutrient and store relatively little nutrients. In this study CO 50, CORH4, ADT 38, ADT 46 and DRRH3 produced higher grain yield under Zn stress conditions (Fig. 9). High Zn-accumulating types were also efficient to transport more assimilates, along with Zn, to the grains, which resulted in higher grain yield under stress condition, as reported by Fageria *et al*. (2011). Genc and McDonald (2008) found that the genotypes which are high yielding under Zn stress conditions and also responsive to Zn fertilizer. Hybrids give more encouraging response as compared to varieties and their levels of Zn response were different from each other (Kanwal *et al*., 2010) which coincide with our results indicating CORH4 and DRRH3 showing higher grain yields.

Depar *et al*. (2013) reported that Zinc efficient genotypes are the less accumulator of phytic acid.He further revealed that Zn efficient rice genotypes showed lower concentration of phytic acid in rice grains under Zn deficient conditions, while Zn inefficient genotypes illustrated high phytic acid concentration. He also stated that the reduction of phytic acid was more in Zn inefficient genotypes than Zn efficient genotypes upon zinc application. In this study, the genotypes, like CO 50, Improved white ponni, CORH4, ADT 46, TRY 1 and DRRH3 contained lesser phytic acid and the genotypes like BPT 5204, Swarna and Bhavani contained higher phytic acid under Zn stress conditions (Fig. 10). The reduction of phytic acid upon zinc application was more pronounced in BPT 5204, Swarna and Bhavani.

From these above said parameters studied in the present investigation, CO 50, Improved white Ponni, CORH4, ADT 46, TRY 1 and DRRH3 were identified as zinc efficient rice genotypes ; whereas BPT 5204, TRY 3, Swarna and Bhavani were categorized as zinc inefficient genotypes.

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