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SCREENING OF HIGH YIELDING ZINC EFFICIENT AND INEFFICIENT RICE GENOTYPE USING STRESS INDICES IN ZINC DEFICIENT SOIL

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Abstract

A pot experiment was conducted during *Kharif* 2011 in glass house of experimental farm of Annamalai University to study the screening of high yielding zinc efficient and inefficient rice genotype using stress indices in zinc deficient soil. The experimental soil belonged to Kondal series (Typic Haplusterts). The experiment was conducted in FCRD with ten rice genotypes (ADT 36, ADT 37, ADT 45, ADT38, CO 45, ADT 43, ADT 46, ADT 39, CO 43, ADT 48) and two Zn levels(0 and 5 ppm) with 3 replications in zinc deficient Vertisol. Genotypes differed significantly in grain and straw yield due to zinc addition. The percent increase in grain yield ranged from 4.2 to 13.5 among rice genotypes on addition of 5 ppm Zn over control. Overall there was 5.75% increase in grain yield when 5 ppm Zn was applied. Similar effect was also noticed with respect to Straw. Accordingly in the present study, genotypes ADT 48, CO 43, ADT 39, ADT 45, ADT 36 and ADT 46 were considered zinc inefficient while genotypes ADT 37, ADT 36, CO 45 and ADT 43 were considered Zn efficient.

Key words: yield, zinc, genotypes

Introduction

The world's population is essential 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. It has been estimated that to supply enough food for world population in 2020, annual cereal production needs to increase by 40 per cent from 1773 billion tonnes in 1993 to nearly 2500 billion tonnes by 2020 (Rosegrant *et al.*, 2001). About 85 per cent of the increase in total cereal demand will occur in developing countries. Rice is the staple food for about 50 per cent of the world's population (72.7 billion) that resides in Asia where 90 per cent of the world's rice is grown and consumed. It is an important staple food that provides 66 to 70 per cent body calorie intake of the consumers (Barah and Pandey, 2005). Zinc deficiency is the most widespread micronutrient deficiency in the world and in India. Plant available Zn concentration is as low as 50 percent of arable soils in the world and zinc deficiency is the most prevalent in rice growing area (Fageria *et al.*, 2002). Rice is the main dietary source for 5% of the human population in the world (Liang *et al.* 2007). Developing rice cultivars with high zinc efficiency depends on the capacity of a genotype to grow and yield well on low Zn levels and offers a sustainable and cost effective way to overcome zinc deficiency problem (Graham *et al.* 1992). Variation in Zn efficiency is mainly related to variation in Zn uptake rather than to differences in the internal Zn efficiency (Gao *et al.*, 2005). In most soils, total Zn is much larger than the amount of removed by a crop (Hacisalihoglu and Kochian, 2003) but the ability to absorb sufficient Zn from soil is a concern. High costs of Zn fertilizers and its repeated and relatively low- efficient application may be sufficient justification for use of efficient rice genotypes that can grow well on soils with loe amount of available Zn (Graham *et al.*, 1992). Productivity of rice depends upon balance application of nutrients. Farmer's of state having the apathy to use micronutrients in their farming system resulting into poor micronutrients soils (Mahata *et al.*, 2013). Biofertication of staple food crops is a feasible, sustainable and economical approach to defeat zinc malnutrition in the

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population depending on the origin of plant in the diet. Realizing the importance of zinc efficient genotypes and biofertication to increases the zinc density in plant grain and at the same time seriousness of its deficiency in soils and plants, the present study was undertaken.

Materials and Methods

A pot experiment was conducted in glass house of experimental farm of Annamalai University to study the response of rice genotypes to zinc application. The experimental soil belonged to Kondal series (Typic Haplusterts). The physicochemical characterization of the soil was clay loam with pH- 8.02, EC-0.72 dSm^{-1}, organic carbon- 6.74 g kg^{-1}, $CaCO_3$- 2.27%, $KMnO_4$-N- 283 kg ha^{-1}, Olsen P- 26 kg ha^{-1}, NH_4OAc- K- 320 kg ha^{-1} and DTPA Zn- 0.70 mg kg^{-1}. The experimental soil was deficient in Zn (critical limit of Zn–0.84 mg kg^{-1}, Muthukumararaja and Sriramachandrasekharan, 2012). The treatments consisted of ten rice genotypes (ADT 36, ADT 37, ADT 45, ADT38, CO 45,ADT 43, ADT 46, ADT 39, CO 43, ADT 48) and two Zn levels(0 and 5 ppm) applied through zinc sulfate. Each pot was filled with 10 kg of processed soil sample. All the pots received uniform dose of 100: 50:50 kg N, P_2O_5 and K_2O applied through urea, superphosphate and muriate of potash respectively. The experiment was conducted in FCRD with three replications. To determine grain, straw yield crops were harvested at maturity. Based on grain yield screening of high yielding efficient rice genotypes under Zn deficient and sufficient condition, following various stress indices proposed by different authors were employed.

1) Zinc efficiency (ZE)

This was calculated using the formula suggested by Blum (1988)

$$ZE = \frac{Yield\ S}{Yield\ P} \times 100$$

Where

S = Grain yield produced under Zn deficiency

P= Grain yield produced with Zn fertilization

2) Stress tolerance (TOL)

This was calculated using the formula suggested by Rosielle and Hamblin (1981).

$TOL = (Yp - Ys)$

where

Ys – The yield in stress conditions

Yp – The yield in non-stress condition

3) Mean productivity (MP)

This was calculated using the formula suggested by Rosielle and Hamblin (1981)

$$MP = \frac{(Y_S + Y_P)}{2}$$

Where

MP = the average yield of Y_S and Y_P

4) Geometric mean productivity (GMP)

This was calculated using the formula suggested by Ramirez and Kelly (1988).

$$GMP = \sqrt{Y_S . Y_P}$$

5) Stress susceptibility index (SSI)

This was calculated using the formula suggested by Fischer and Maurer (1978).

$$SSI = \frac{\left[1 - \frac{Y_S}{Y_P}\right]}{SI}$$

Where

SI (stress intensity) and is estimated as $\left[1 - \left(\overline{Y}_S / \overline{Y}_P\right)\right]$

Where

$\overline{Y}_S$ – mean yield over all genotypes evaluated under stress conditions

$\overline{Y}_P$ – mean yield over all genotypes evaluated under non-stress conditions

6) Stress tolerance index (STI)

This was calculated using the formula suggested by Fernandez (1992).

$$STI = \left[\frac{Y_P . Y_S}{Y_P{}^{2}}\right]$$

In identify the best stress indices, simple correlation was worked out between grain yield under Zn stress and Zn non-stress condition with various stress indices. The stress indices with high correlation value at both condition was selected as the best one.

Results and Discussion

Grain and straw yield of rice responded significantly to zinc application (Table 1). The rice genotypes produced significantly ($p = .0.05$) different grain and straw yield. The grain yield ranged from 29.87 g/pot) to 82.10 g/pot and straw yield ranged from 50.89 g/pot to 107.6 g/pot due to zinc application. The highest grain yield (82.10 g/pot) and straw yield (107.6 g/pot) was noticed with genotype ADT 43 and the minimum grain yield (29.87 g/pot) and straw yield (50.89 g/pot) was observed with ADT 48. The grain yield response varied from 2.10 g/pot to 3.80 g/pot among rice genotypes due to application of 5 ppm. Zn The per cent increase in grain yield due to zinc application among rice genotypes varied from 4.2 to 13.5 over control, while in straw yield percent increase among rice genotypes ranged from 1.8 to 11.33 .On an average 5 ppm Zn caused 5.75% and 4.69% increase in grain and straw yield respectively over control. The increase in grain and straw yield with application of zinc was attributed to adequate supply of zinc that might have increased the availability and uptake of other essential nutrients resulting in improvement in metabolic activities (Hafeez *et al.*, 2010) and also due to the effect of zinc on the proliferation of roots so that uptake rate from soil was increased and supplying it to the aerial part of the plant. This was confirmed by the positive significant linear relationship between grain Zn uptake and grain yield (Fig 1) and also by significant positive linear relationship between grain yield and Zn recovery efficiency (Fig.2) Yaseen *et al.*, (2000) reported similar results. Pandey *et al.*, (2005) reported poor grains could be produced in zinc deficient plants. The variation in the potential grain yield among rice genotypes demonstrates that genotype is an important contributor to overall variability and has to be considered in Zn fertilization management (Khoshgoftarmanesh *et al.*, 2009). Differences in growth among cultivars have been related to the absorption, translocation, shoot demand, DMP potential per unit of nutrient absorbed (Baligar *et al.*, 1990). Large genotypic variation in response to Zn deficiency have been reported among rice (Hafeez *et al.*, 2010) and wheat (Khoshgoftarmanesh *et al.*, 2004).

Selection of Zn inefficient and efficient rice genotypes

The various stress indices that are used for identification of rice genotypes with higher yield under zinc stress and zinc adequate are furnished in table 2. Rice genotypes with small response to zinc fertilization are considered as the zinc efficient genotypes and zinc inefficient genotypes have larger yield response. Zinc efficiency as per Peleg *et al.* (2007) was worked and it ranged from 88 to 96 per cent among rice genotypes. Accordingly, the genotypes ADT 48, CO 43, ADT 39, ADT 45, ADT 36 and ADT 46 were considered Zn inefficient, while ADT 37, ADT 38, CO 45 and ADT 43 are considered Zn efficient.

The stress tolerance (TOL) ranged from 2.10 to 3.80 and the lowest value of TOL was recorded by ADT 38, ADT 39 and ADT 37. The average yield (MP) ranged from 29.87 to 82.10 g pot^{-1} among genotypes and on an average genotypes recorded a MP value of 53.45 g pot^{-1}. Similarly, geometric mean yield (GMP) ranged from 29.80 to 82.08 g pot^{-1} among genotypes. The average GMP among genotypes was 53.43 g pot^{-1}. The stress susceptible index (SSI) ranged from 1.0 to 2.4 per cent.Smaller the value of SSI, greater the resistance to zinc stress among genotypes. Accordingly, genotypes ADT 37, ADT 38, CO 45, ADT 46, ADT 43 and ADT 39 have lower SSI indicating that they perform well under Zn stress while recording low yield under non-zinc stress cond. Stress tolerance index (STI) was employed to find out the best stress tolerance with good yield potential. Stress tolerance index ranged from 0.29 to 2.23 per cent. Accordingly, genotypes were grouped into three categories. STI greater than 1.0 per cent - ADT 43, CO 45, ADT 46 and ADT 36. STI- 0.7 to 1.0 per cent - ADT 37, ADT 45 and ADT 38. STI < 0.7 per cent - ADT 39, CO 43 and ADT 48. Selection and breeding for increased zinc efficiency is a promising strategy of increasing crop productivity in low input and environmental friendly agricultural production system (Cakmak *et al.*, 2001). Genotypes that are more efficient in zinc acquisition from deficiency condition are generally considered better adoptable for zinc deficiency in soils. Sufficient genetic variability exists among several crops species and genotypes for zinc acquisition and utilization under low zinc environment (Cakmak *et al.*, 2001; Irshad *et al.*, 2004). There are several stress indices proposed by

Table 1: Effect of zinc fertilization on grain and straw yield (g pot^{-1}) in rice genotypes

Rice genotypes	**Grain yield**			**Straw yield**		
	Zinc levels (mg kg^{-1})					
	Zn$_0$	**Zn$_{5.0}$**	**Mean**	**Zn$_0$**	**Zn$_{5.0}$**	**Mean**
ADT 36	53.23	56.31	54.77	69.55	73.88	71.72
ADT 37	50.90	53.06	51.98	66.06	6844	67.25
ADT 45	50.34	53.83	52.08	67.49	70.32	68.90
ADT 38	50.15	52.25	51.20	67.00	69.01	68.01
CO 45	54.78	57.06	55.92	71.43	74.63	73.03
ADT 43	80.30	83.90	82.10	106.65	108.58	107.61
ADT 46	60.56	63.73	62.14	81.09	84.13	82.61
ADT 39	47.32	50.45	48.88	64.40	68.31	66.36
CO 43	44.49	47.61	46.05	62.60	66.22	64.41
ADT 48	27.97	31.77	29.87	48.16	53.62	50.89
Mean	52.00	54.99		70.44	73.71	
	Zn	G	Zn x G	Zn	G	Zn x G
SEd	0.28	0.62	0.88	0.28	0.62	0.88
CD (p=0.05)	0.56	1.26	1.78	0.56	1.27	1.79

Table 2: Stress tolerance attributes in rice genotypes estimated from yields under zinc stress, zinc non-stress and zinc efficiency

Genotypes	Y_S	Y_P	TOL	MP	GMP	SSI	STI	Zn efficiency (%)
ADT 36	53.23	56.31	3.08	54.77	54.75	1.2	0.99	94.53
ADT 37	50.90	53.06	2.16	51.98	51.97	1.0	0.89	95.92
ADT 45	50.34	53.83	3.49	52.08	52.05	1.4	0.89	93.51
ADT 38	50.15	52.25	2.10	51.20	51.19	1.0	0.86	95.98
CO 45	54.75	57.06	2.28	55.92	55.91	0.8	1.03	96.00
ADT 43	80.30	83.90	3.60	82.10	82.08	1.0	2.23	95.70
ADT 46	60.56	63.73	3.17	62.14	62.12	1.0	1.28	95.02
ADT 39	47.32	49.45	2.13	48.39	48.37	1.0	0.77	95.69
CO 43	44.49	47.61	3.12	46.05	46.02	1.4	0.70	93.44
ADT 48	27.97	31.77	3.80	29.87	29.80	2.4	0.29	88.03
Mean	52.00	54.90	2.89	53.45	53.43	1.22	0.99	94.38

different workers as ways to identify genotype with better stress tolerance and high yield potential.

The rice genotypes tested under zinc stress and non-stress environment differed significantly among them. The grain yield under zinc stress ranged from 27.97 g pot^{-1} (ADT 48) to 80.30 g pot^{-1} (ADT 43) with a mean value of 52.09 g pot^{-1}. While under zinc adequate condition, grain yield ranged from 31.77 g pot^{-1} (ADT 48) to 83.5 g pot^{-1} (ADT 43) with a mean value of 54.99 g pot^{-1}. Large genotypic variation in response to zinc deficiency has been reported earlier (Hafeez *et al.*, 2010; Hafeez *et al.*, 2013). Rice genotypes with small response to zinc fertilization are considered to be zinc efficient genotypes and zinc inefficient genotypes have larger yield response to zinc fertilization (Marschner, 1995). Accordingly in the present study, genotypes ADT 48, CO 43, ADT 39, ADT 45, ADT 36 and ADT 46 were considered zinc inefficient while genotypes ADT 37, ADT 36, CO 45 and ADT 43 were considered Zn efficient. Zinc efficiency as per Peng *et al.* (2007) was worked out and it ranged from 88 to 96 per cent among rice genotypes (Table 2). There are several mechanism that could be involved in nutrient efficiency that include root process that increase the bioavailability of soil nutrients to root uptake, enhanced root uptake and translocation of nutrients from root to shoot (Baligar *et al.*, 2001; Fageria and Baligar, 2003) and may also be due to different crop demand to zinc (Marschner, 1995). There was limitation in using zinc efficiency as parameter to identify zinc efficient genotype with high yield potential. This is because a genotype which is considered as zinc efficient produced yield which is lower than zinc inefficient for e.g. genotypes ADT 46, ADT 36 which is considered as zinc inefficient recorded higher grain yield than zinc efficient genotypes like ADT 37, ADT 38 and CO 43. This was supported by weak relationship between zinc efficiency and grain yield under zinc stress (Y=3.7041x - 297.59, R^2=0.473, Fig. 2a) and between zinc efficiency and grain yield under zinc adequate (Y=3.5461x -279.69, R^2=0.434; Fig. 2b). Sadrarhami *et al.* (2010) also reported similar relationship in selecting high grain yield iron deficiency tolerant wheat genotype in calcareous soil.

Thus to identify a rice genotype which will provide high yield both under zinc deficient and adequate condition and high stress tolerance, various stress tolerance indicators were studied (Table 2. Roselle and Hamblin (1981) defined stress tolerance (TOL) as the difference in yield between zinc stress (Ys) and zinc non-stress (Yp). Accordingly, in the present study, lowest value of TOL was recorded with ADT 38, ADT 39 and ADT 37. This index only pointed out that above genotypes that performed poorly under non-stress condition. Greater the TOL value, the larger the yield reduction under zinc stress condition and higher sensitivity to zinc deficiency. In the present study, TOL had poor correlation with yield under zinc stress and zinc adequate condition (Table 130). Fact that small value of TOL is desirable, selection for this parameter would tend to favour low yielding

Table 3: Correlation between several stress tolerance parameters

Genotypes	Y_S	Y_P	TOL	MP	GMP	SSI	STI
Y_S	1						
Y_P	0.9987**	1					
TOL	0.0291	0.0792	1				
MP	0.9997**	0.9997**	0.0539	**Stress tolerance index (STI) :** This was calculated using the formula suggested by Fernandez (1992).1			
GMP	0.0997	0.9996**	0.0529	0.9999**	1		
SSI	-0.6984**	0.6641**	0.6450**	0.6816**	0.6824**	1	
STI	0.9801**	0.9861**	0.1712	0.9834**	0.9832**	0.5560**	1

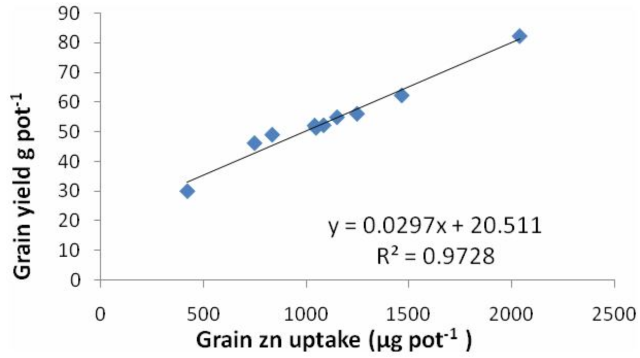


Fig. 1: Linear relationship between grain yield and grain Zn uptake

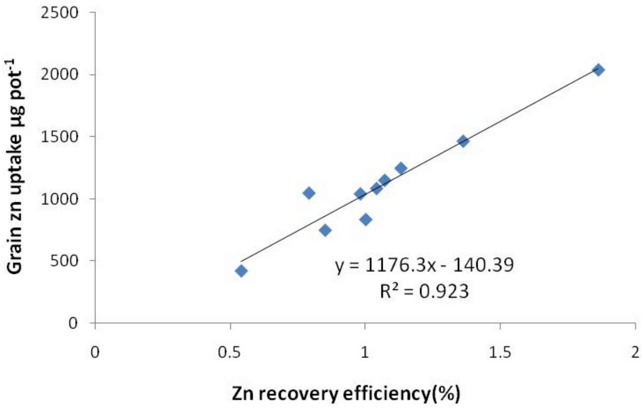
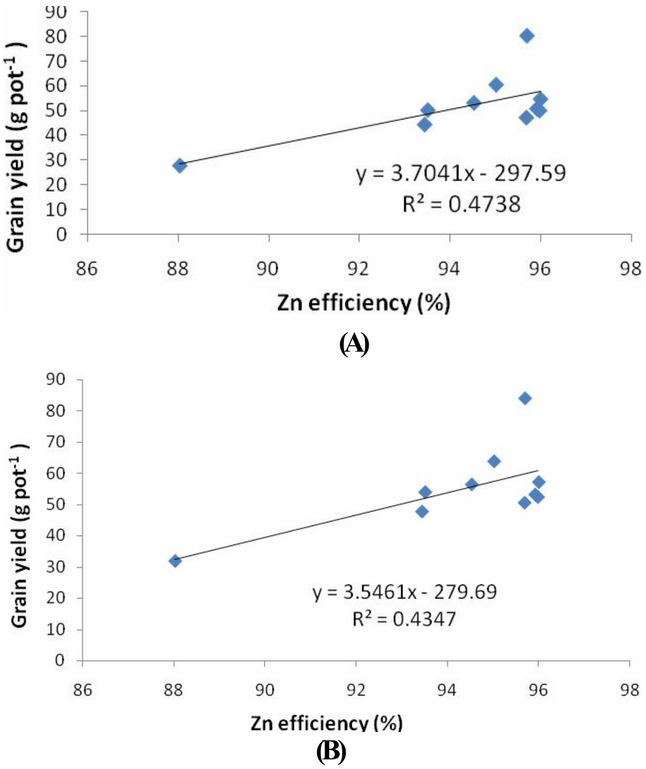


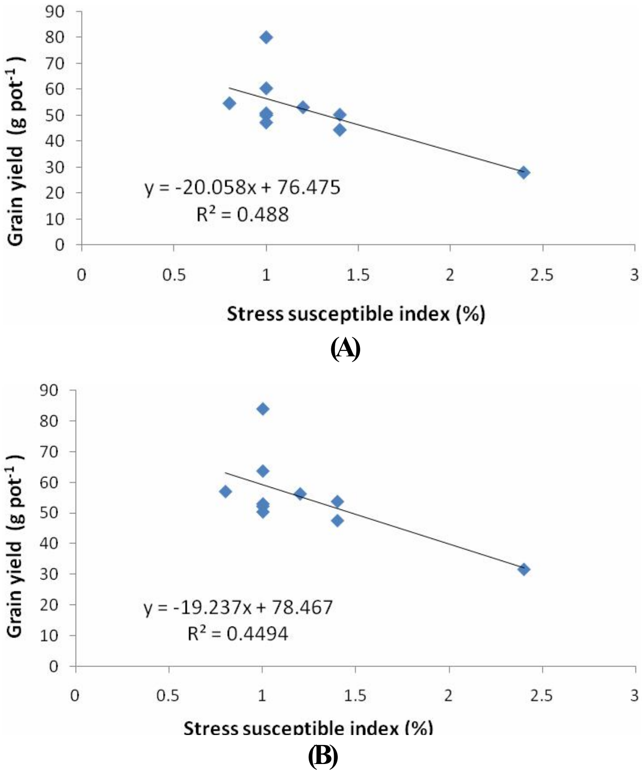
Fig. 2: Linear relationship between grain Zn uptake and Zn recovery efficiency



(A)

(B)

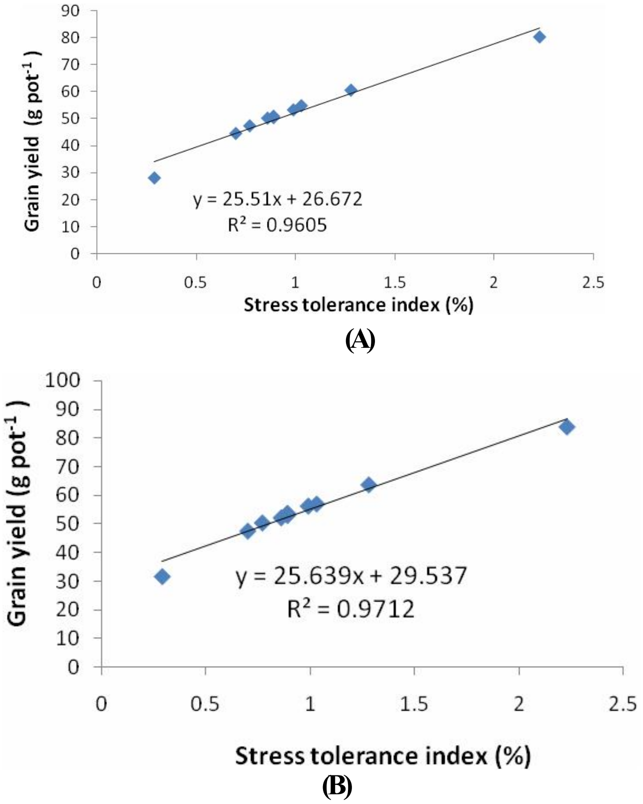
Fig. 3: Linear relationship between Zn efficiency with grain yield (A) Zn stress (B) Zn adequate



(A)

(B)

Fig. 4: Linear relationship between SSI with grain yield (A) Zn stress (B) Zn adequate



(A)

(B)

Fig. 5: Linear relationship between STI with grain yield (A) Zn stress (B) Zn adequate

genotypes. Mean productivity (MP) is the average yield of Ys and Yp. The highest average yield (MP) was recorded in genotype ADT 43 (82.10 g pot^{-1}), ADT 46 (62.14 g pot^{-1}) and CO 45 (55.92 g pot^{-1}). On an average MP value was 53.45 g pot^{-1}. Mean productivity had strong and positive correlation with Ys and Yp (Table 3). Similarly, geometric mean productivity (GMP) was recorded highest by the above genotypes and also had significant and positive correlation with Ys and Yp. Further MP and GMP strongly correlated between each other (r=0.99*), while both were poorly correlated with TOL. Stress susceptible index (SSI) is another indicator used for screening genotypes. Greater the value of SSI indicates relatively more sensitive to stress and thus a smaller value of tolerance is favoured. Accordingly, genotypes ADT 37, ADT 38, CO 45, ADT 43, ADT 46 and ADT 39 had lower SSI indicating that they perform well under zinc stress, while recording low yield under non-Zn stress condition. In the present study, SSI was strongly negatively correlated with yield under zinc stress and had positive correlation with yield under zinc adequate condition (Table 3). Selection for this parameter would also tend to favour low yield genotypes. It was confirmed by poor linear relationship between SSI and yield under zinc stress ($Y=-20.058\,x + 76.475$, $R^2=0.488$; Fig. 4a) and with yield under zinc adequate ($Y=-19.237\,x + 78.467$, $R^2=0.489$; Fig. 4b) SSI has been ordinarily used by researchers for identifying sensitive and tolerant genotypes (Sio-Se Mardeh *et al.*, 2006;Golabadi *et al.*, 2006). Fernandez (1992) claimed that the selection based on stress tolerance index (STI) would result in genotype with higher stress tolerance and good yield potential. Larger the value of STI for a genotype in a stress environment, the higher was its tolerance and yield potential. This was supported in the present study by significant and positive correlation between STI and rice yield without zinc ($Y=25.51\,x + 26.672$, $R^2=0.960^{**}$ Fig. 5a) and with yield under zinc adequate ($Y=25.639\,x + 29.537$, $R^2=0.971^{**}$; Fig. 5b). Further STI had significant positive correlation with Ys, Yp, MP and GMP, while poor relationship with TOL and negative correlation with SSI (Table 3). Thus MP, GMP and STI were good predictor of Ys and Y_P than TOL and SSI. The observed relations were consistent with those reported by Fernandez (1992) in mungbean, Farshadfar and Sutka (2002).

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