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Role of Zinc on Growth, Zinc content and Biophysical Parameters of Rice Genotypes in Hogland Solution

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A B S T R A C T

Hydroponic experiment was conducted to observe the effects of Zn on the growth, biophysical parameters and zinc content in shoot and root of rice genotypes. The experiment was comprised of 20 genotypes and two treatments *viz.*, T1: 0.01 µM (Zn-deficient); T2: 2.0 µM (Zn-sufficient/control), laid out in factorial randomized block design with three replications. Results showed 2.0 µM concentration of zinc sulphate significanty increasead the Plant height (22.0 cm), leaf area (31.3 cm^2 $plant^{-1}$), shoot dry matter (0.92 g $plant^{-1}$), root length (11.4 cm), root dry weight (0.44 g) and biophysical parameters *viz.*, Photosynthetic rate (5.90 µmol CO_2 m^{-2} s^{-1}), stomatal conductance (0.045 µmol m^{-2} s^{-1}) and transpiration rate (0.86 mmol H_2O m^{-2} s^{-1}) and zinc content (ppm) in shoot and root, were measured on 4-week old Seedlings.

Introduction

Rice (*Oryza sativa* L.) being the principal and the stable food for more than half of the world population and is one of the most important food grains of world's inhabitants which provides 21% and 15% per capita of dietary energy and protein, respectively (Maclean *et al.*, 2002). The hope for better nourishment of the population depends upon the development of better rice varieties and improved methods for rice production and processing.

Over two billion people worldwide suffer from micronutrient deficiencies due to a lack of essential vitamins and minerals in their diet. Iron (Fe) and zinc (Zn) deficiencies are the most wide spread human micronutrient deficiencies and are particularly prevalent in resource-poor countries where there is a heavy dietary reliance on staple crops (Sands *et al.*, 2009). Rice is the principal source of calorie intake for about half of the world's population. The potential of bio fortified rice for alleviating widespread micronutrient malnutrition in the world's major rice consuming countries is now widely recognized.

In addition to being essential mineral nutrients for humans, Zn are essential elements for plants and their homeostasis processes such as coordination of uptake, buffering, translocation, and storage are tightly regulated within narrow physiological limits which promote proper plant growth and development (Tekli´c *et al.*, 2013). Zinc is an important

cofactor in gene transcription and the coordination of protein, nucleic acid, carbohydrate and lipid metabolism (Ishimaru *et al.*, 2011).

Zinc deficiency has been reported in various parts of the world (Cakmak, 2002). About 30% of the world's soils are also Zn deficient (Alloway, 2004). It is particularly acute in puddled soils. In the Indian context, more than 50 per cent of the agricultural soils are Zn deficient. The main cause of deficiency of plant available Zn in soil is the precipitation or adsorption of Zn with various soil components, depending on the pH and redox potential (Impa and Johnson-Beebout, 2012).

Zinc deficiency being an important nutrient constraint, any approach to improve Zn uptake and its transport to grains has significant practical relevance. One of the interventions that have been proposed to overcome Zn deficiency in humans is the bio fortification of staple foods with Zn during their natural growth cycle, through either agronomic practices or genetic manipulations (White and Broadly, 2009). Plant breeding strategy appears to be the most sustainable and cost effective approach useful in improving Zn status of plants and also its concentrations in grains.

However, for improving Zn acquisition, one of the primary prerequisites is significant genetic variability in this trait. Such genotypic variations can be exploited in breeding programs to produce genotypes with higher zinc efficiency. This research work was to assess the effect of different levels of zinc on growth and zinc uptake ability in some selected rice zinc contrasting lines.

The primary source of Zn for rice plants is trough root uptake (Welch and Graham, 2002), To increase Zn uptake by roots, the Zn availability in the rhizosphere must be increased (Welch and Shuman, 1995). Some researchers reported that under nutrient-deficient conditions, plants tend to alter their root size and morphology for efficient nutrient acquisition. Enhanced root growth under Zn deficiency, both in length and number of roots, has been associated with Zn-deficiency tolerance of lowland rice genotypes. (Chen, *et al.*, 2009). In addition researchers showed under moderate Zn deficiency, damage to root tip cells was observed in some susceptible genotypes (Widodo, *et al.*, 2010). Most recent studies in rice suggest that among numerous other mechanisms, Zn uptake is most important.

Because of the difficulty in controlling the timing and severity of Zn deficiency in the field, it is important to develop a solution culture method that can be used to compare Zn uptake in contrasting Zn supply conditions and genotypes. The overall aim of the study is to understand the effect of contrasting solution Zn concentrations on growth of rice genotypes, biophysical parameters and zinc uptake by shoot and root of rice genotypes.

Materials and Methods

The experiment was conducted during 2016 at Department of Crop Physiology, College of Agriculture, UAS, Dharwad. Before growing, seeds were surface sterilised in 70 per cent ethanol and 5 per cent sodium hypochlorite for 1 and 15 min, respectively. Seeds were then rinsed five times in deionised water. Seeds were germinated on moist filter paper wetted with deionised water for 3–4 days in the dark at room temperature. Only healthy and uniform seedlings were transplanted to solution culture.

A basal nutrient solution (Hoagland and Arnon 1950; Pandey *et al.*, 2012) was used with the following nutrient concentrations (□ M): KNO_3 (16000), Ca (NO3) $2.4H_2O$

(6000), $NH_4H_2PO_4$ (4000), $MgSO_4.7H_2O$ (2000), KCl (50), H_3BO_3 (25), Fe-EDTA (25), $MnSO_4$. $4H_2O$ (2), $Na_2MoO_4.2H_2O$ (0.5), $CuSO_4.5H_2O$ (0.5) and Zn as $ZnSO_4$ at two levels *viz.* 0.01 (Zn-deficient) and 2.0 □M (Zn-sufficient/control).

All nutrient stock solutions were prepared separately and mixed together in black containers containing double-deionized water (18 MX cm1 resistivity). Concentrations of macronutrients and micronutrients were maintained at half and full strength, respectively until 8 days after transplanting (DAT) and all nutrients at full strength thereafter

The nutrient solution was aerated continuously and replaced at 5 days interval. Target pH values (pH 5.5) were obtained by titrating the basal solution with KOH or H_2SO_4. Plants were grown in 2 L of aerated solution and the environment was strictly maintained under 10 h light and 14 h dark (550–560 □ mol s^{-1} per □ A).

Growth parameters like Plant height (cm), leaf area (cm^2 $plant^{-1}$), shoot dry matter (g $plant^{-1}$), root length (cm) and root dry weight (g) were measured on 4-week old plants grown on solution culture. Plant height and root length was recorded and expressed in centimetre (cm). Leaves, stem and root were separated from each sample and then weighed separately for recording leaf, stem and root weight. Sample was air dried and then placed into oven at 70 C^0 for recording total dry weight (g $plant^{-1}$). Length and breadth of fully open leaf was measured and leaf area was calculated by formula; Leaf Area = Leaf length x breadth x 0.71 (Yoshida, *et al.,* 1976) and expressed in cm^2.

Measurements of rate of photosynthesis (µmol CO_2 m^{-2} s^{-1}), stomatal conductance (mmol H_2O m^{-2} s^{-1}) and rate of transpiration (µmol m^{-2} s^{-1}) were made on fully expanded leaf by using portable photosynthesis system (LI-6400 LICOR, Nebraska, Lincoln USA,). These measurements were made on were measured on 4-week old plants grown on solution culture. Zn concentration was analyzed in shoot and root. Samples were pre-digested by adding ten ml of concentrated nitric acid to 500 mg of powder sample and incubated in a digestion hood overnight. The next day, samples were wet digested (HNO3: $HClO_4$; 4:1) and in the extracts zinc concentration was measured by using atomic absorption spectrophotometer GBC Avanta Ver 2.02 Model. Zinc content was expressed in parts per million (ppm).

Fisher's method of analysis of variance was applied for the analysis and interpretation of the experimental data as suggested by Panse and Sukhatme (1967). The level of significance used in 'F' and 't' test was P=0.01. Critical difference (CD) values were calculated at 1 per cent level, wherever 'F' test was significant.

Results and Discussion

Morphological

Zinc sufficient (Zn^+) hydroponic culture resulted significantly higher plant height (22.0), root length (11.4), leaf area (28.4) and shoot dry matter (0.92) over zinc deficient (Zn^-) hydroponic culture presented in Table 1. Similarly among genotypes, Chandibatta recorded significantly higher plant height (25.0), leaf area (29.8) and shoot dry matter (0.98).

Whereas; MTU-1001 was resulted higher root length. Indeed, interaction between zinc treatment and genotypes were found to be non-significant with respect to plant height, root length, leaf area and shoot dry matter.

It's clear that zinc has bold role in auxin

biosynthesis and this hormone has been known as a plant growth simulation. Because with more probability, zinc plays as a cofactor in many enzyme activity so zinc has important role in tryptophan amino acid biosynthesis or conversion tryptophan amino acid to indole acetic acid. It has been reported that activity of enzyme regarding cell reproduction and enlargement can be motivated by zinc (Rion, 2004).

Further, Increase in leaf area was responsible for increased shoot weight (TDM) and helped the photosynthetic area to remain active for longer period which was responsible for a overall growth of plant in terms of dry matter production. The prerequisite for getting higher yields in any crop is higher total dry matter production (TDMP) and it's partitioning into various plant parts, coupled with maximum translocation of photosynthates to the sink. Mahmood *et al.,* (2005) observed similar increase in TDM of rice genotypes with zinc application.

Simmilarly significantly higher root dry matter was recorded with zinc sufficient (0.44) over zinc deficient (0.37). Among genotypes, Karibatta recorded significantly higher root dry matter (0.55).The interaction effect between zinc treatments and genotypes was significant, indicating that genotypes respond differently to the zinc treatments. Significantly higher root dry matter was resulted with Karibatta (0.58) and Chandibatta (0.56) with Zinc sufficient (Zn^{+}) hydroponic culture, whereas; significantly lower root dry matter was recorded with genotype, Budda (0.27) followed by Halga (0.28) and SIRI-1253 (0.29) under Zinc deficient (Zn^{-}) hydroponic culture.

Root characteristics improved with Zn treatment which is due to the role of the zinc in the biosynthesis of growth promoting hormone such as indole-3-acetic acid (IAA), (Cakmak, 2000). Additionally, zinc is an activator of many enzymes involved in cell elongation and cell division (Cakmak, 2000; Yu *et al.*, 1999). Auxin involved in several aspects of root architecture involving primary root elongation, lateral root primodail formation, lateral root elongation and tropic growth.

Biophysical

Zinc sufficient (Zn^{+}) hydroponic culture produced significantly higher photosynthetic rate (5.90), stomatal conductance (0.045) and transpiration rate (0.86) and over Zinc deficient hog land solution (Table 2). Contrary, interaction between genotypes and treatments was found to be non-significant.

Among genotypes, Chandibatta and MTU-100 recorded significantly higher photosynthetic rate (6.72 & 6.67) and stomatal conductance (0.051 each). However, SIRI-1253 (0.96) and Kalanamak (0.96) recorded significantly higher transpiration rate followed by MTU-1001 (0.95). Similarly, genotype MTU-100 (0.051) and Chandibatta (0.051) observed significantly higher stomatal conductance followed by BPT-5204 (0.050) and Budda (0.050). Whereas, significantly lower stomatal conductance was recorded in Ambemohar-2 (0.030) which was followed by Doddabatta (0.031).

The data pertaining to transpiration rate presented in Table 2 showed significant difference among treatments and genotypes, contrary their interaction effect non-significant with respect to transpiration rate. Significantly higher transpiration rate was found in hogland solution with zinc sulphate (0.86) over zinc deficient (Zn^{-}) hydroponic culture (0.75). The results are in agreement with the findings Sasaki *et al.,* (1998) and Wang *et al.,* (2009) and in rice and maize.

Table.1 Effect of zinc on growth parameters in 04 week old seedlings of rice genotypes in the Hogland solution culture

Genotypes	Plant height (cm)			Leaf area (cm^2 $pant^{-1}$)			Shoot dry matter (g $plant^{-1}$)			Root length (cm)		Mean	Root dry matter (g)		Mean
	T_1	T_2	Mean	T_1	T_1	T_1	T_1	T_2	Mean	T_1	T_2		T_1	T_2	
Ambemohar 1	13.6	18.0	**15.8**	23.0	28.1	**25.6**	0.74	0.90	**0.82**	7.0	8.9	**8.0**	0.35	0.44	**0.40**
Koorigenellu	21.9	26.7	**24.3**	21.1	26.2	**23.6**	0.68	0.86	**0.77**	7.3	9.1	**8.2**	0.43	0.54	**0.48**
Dambersali	20.7	25.3	**23.0**	24.1	29.1	**26.6**	0.77	0.92	**0.85**	7.3	8.8	**8.1**	0.46	0.56	**0.51**
Kempunellu	23.7	26.4	**25.0**	22.7	26.0	**24.4**	0.71	0.84	**0.78**	6.7	8.6	**7.6**	0.31	0.40	**0.35**
Dodda Batta	16.3	18.7	**17.5**	25.5	28.3	**26.9**	0.80	0.91	**0.85**	7.0	8.7	**7.9**	0.39	0.49	**0.44**
Ambemohar 2	15.9	17.8	**16.8**	23.4	25.3	**24.3**	0.74	0.82	**0.78**	7.6	10.0	**8.8**	0.37	0.46	**0.42**
Dodigya	18.4	20.5	**19.4**	27.7	30.3	**29.0**	0.94	1.00	**0.97**	8.2	10.0	**9.1**	0.31	0.39	**0.35**
Laldodki	22.4	24.4	**23.4**	26.3	29.1	**27.7**	0.83	0.92	**0.87**	7.8	9.6	**8.7**	0.34	0.43	**0.39**
Budda	16.6	18.9	**17.7**	26.8	30.3	**28.5**	0.86	0.98	**0.92**	8.2	9.9	**9.1**	0.27	0.33	**0.30**
Wari M. S.	17.0	19.7	**18.3**	25.9	29.5	**27.7**	0.84	0.93	**0.88**	9.0	10.7	**9.9**	0.49	0.57	**0.53**
Champakali	23.4	26.6	**25.0**	24.2	27.9	**26.0**	0.74	0.88	**0.81**	8.9	10.6	**9.7**	0.29	0.35	**0.32**
Improved chitimutayalu	16.4	18.2	**17.3**	21.9	25.0	**23.5**	0.71	0.79	**0.75**	10.3	12.1	**11.2**	0.33	0.41	**0.37**
Karibatta	19.1	22.4	**20.8**	22.1	25.4	**23.8**	0.72	0.82	**0.77**	11.1	12.8	**11.9**	0.52	0.58	**0.55**
Chandibatta	17.7	20.1	**18.9**	28.3	31.3	**29.8**	0.96	1.07	**1.02**	9.7	10.8	**10.2**	0.51	0.56	**0.53**
Halga	21.6	23.5	**22.5**	27.1	29.6	**28.3**	0.87	0.93	**0.90**	10.3	11.2	**10.7**	0.28	0.30	**0.29**
Siri1253	21.2	23.2	**22.2**	27.4	30.4	**28.9**	0.94	1.02	**0.98**	11.2	12.4	**11.8**	0.29	0.30	**0.30**
Kalanamak	19.7	21.1	**20.4**	25.0	27.2	**26.1**	0.80	0.85	**0.82**	14.8	16.2	**15.5**	0.47	0.52	**0.49**
Hugibatta-1	22.2	23.8	**23.0**	25.0	27.2	**26.1**	0.78	0.85	**0.81**	14.1	15.0	**14.6**	0.44	0.49	**0.47**
MTU1001	22.3	24.8	**23.5**	27.5	30.8	**29.2**	0.93	1.03	**0.98**	14.8	16.4	**15.6**	0.32	0.34	**0.33**
BPT5204	17.5	20.9	**19.2**	25.9	31.3	**28.6**	0.87	1.06	**0.96**	12.0	15.4	**13.7**	0.30	0.36	**0.33**
Mean	**19.4**	**22.0**	**20.7**	**25.0**	**28.4**	**26.7**	**0.81**	**0.92**	**0.86**	**9.7**	**11.4**	**10.5**	**0.37**	**0.44**	**0.41**
For comparing means of	**S.Em. ±**		**C.D. @ 5 %**	**S.Em. ±**		**C.D. @ 5 %**	**S.Em. ±**		**C.D. @ 5 %**	**S.Em. ±**		**C.D. @ 5 %**	**S.Em. ±**		**C.D. @ 5 %**
Genotypes (G)	**0.42**		**1.56**	**0.53**		**1.99**	**0.02**		**0.06**	**0.22**		**0.82**	**0.01**		**0.03**
Treatments (T)	**0.13**		**0.49**	**0.17**		**0.63**	**0.01**		**0.02**	**0.07**		**0.26**	**0.00**		**0.01**
G x T	**0.59**		**NS**	**0.75**		**NS**	**0.02**		**NS**	**0.31**		**NS**	**0.01**		**0.04**

T_1: Zinc deficient (Zn -) hydroponic culture T_2: Zinc sufficient (Zn +) hydroponic culture

Table.2 Effect of Zinc on Biophysical parameters and Zinc content of the rice genotypes in the Hogland solution culture

Genotypes	Photosyntheic rate (µmol m^2 sec^{-1})			Stomatal conductance (µmol m^2 sec^{-1})			Transpiration rate (mmol H_2O m^2 s^{-1})			Shoot zinc (ppm)			Root zinc (ppm)		
	T_1	T_2	Mean	T_1	T_2	Mean	T_1	T_2	Mean	T_1	T_2	Mean	T_1	T_2	Mean
Ambemohar 1	4.75	5.88	**5.31**	0.037	0.045	**0.041**	0.73	0.87	**0.80**	10.3	13.3	**11.8**	17.0	22.0	**19.5**
Koorigenellu	4.59	5.35	**4.97**	0.033	0.041	**0.037**	0.65	0.79	**0.72**	10.4	12.9	**11.6**	17.0	21.6	**19.3**
Dambersali	4.85	5.93	**5.39**	0.038	0.045	**0.041**	0.72	0.86	**0.79**	10.7	13.1	**11.9**	15.7	20.0	**17.9**
Kempunellu	4.35	4.94	**4.64**	0.035	0.041	**0.038**	0.52	0.64	**0.58**	10.4	12.6	**11.5**	14.9	18.5	**16.7**
Dodda Batta	3.99	4.87	**4.43**	0.028	0.034	**0.031**	0.74	0.89	**0.81**	9.5	11.8	**10.6**	17.7	20.8	**19.2**
Ambemohar 2	4.12	4.88	**4.50**	0.028	0.033	**0.030**	0.82	1.01	**0.92**	9.4	11.3	**10.3**	16.5	20.7	**18.6**
Dodigya	5.84	6.34	**6.09**	0.047	0.054	**0.050**	0.77	0.86	**0.82**	10.5	12.1	**11.3**	15.0	17.6	**16.3**
Laldodki	5.47	6.03	**5.75**	0.040	0.045	**0.042**	0.83	0.91	**0.87**	9.8	11.0	**10.4**	16.5	18.8	**17.6**
Budda	5.28	6.14	**5.71**	0.046	0.054	**0.050**	0.58	0.67	**0.62**	10.5	12.4	**11.4**	16.2	19.8	**18.0**
Wari M. S.	5.67	6.25	**5.96**	0.046	0.050	**0.048**	0.77	0.86	**0.82**	9.4	10.4	**9.9**	17.0	19.1	**18.1**
Champakali	5.24	6.03	**5.64**	0.038	0.044	**0.041**	0.57	0.68	**0.63**	8.4	9.6	**9.0**	16.5	19.4	**17.9**
Improved chitimutayalu	4.26	4.87	**4.57**	0.029	0.034	**0.031**	0.80	0.91	**0.86**	10.3	11.5	**10.9**	16.2	18.4	**17.3**
Karibatta	4.38	5.12	**4.75**	0.032	0.037	**0.034**	0.82	1.00	**0.91**	9.3	10.7	**10.0**	15.4	17.4	**16.4**
Chandibatta	6.29	7.15	**6.72**	0.048	0.054	**0.051**	0.81	0.92	**0.86**	8.5	9.9	**9.2**	15.0	18.0	**16.5**
Halga	6.13	6.66	**6.39**	0.046	0.050	**0.048**	0.71	0.75	**0.73**	8.3	9.0	**8.7**	15.5	16.6	**16.0**
Siri1253	6.17	6.59	**6.38**	0.046	0.050	**0.048**	0.92	0.99	**0.96**	7.4	8.1	**7.7**	14.7	16.2	**15.4**
Kalanamak	4.59	4.95	**4.77**	0.032	0.034	**0.033**	0.92	0.99	**0.96**	7.9	8.5	**8.2**	15.1	16.3	**15.7**
Hugibatta-1	5.43	5.79	**5.61**	0.041	0.044	**0.042**	0.65	0.71	**0.68**	7.0	7.6	**7.3**	15.5	17.0	**16.2**
MTU1001	6.34	7.01	**6.67**	0.049	0.054	**0.051**	0.90	0.99	**0.95**	7.8	8.7	**8.3**	15.0	17.0	**16.0**
BPT5204	5.77	7.24	**6.50**	0.045	0.055	**0.050**	0.70	0.85	**0.78**	6.6	7.9	**7.2**	16.4	20.2	**18.3**
Mean	**5.17**	**5.90**	**5.54**	**0.039**	**0.045**	**0.042**	**0.75**	**0.86**	**0.80**	**9.1**	**10.6**	**9.9**	**15.9**	**18.8**	**17.4**
For comparing means of	**S.Em. ±**		**C.D. @ 5 %**	**S.Em. ±**		**C.D. @ 5 %**	**S.Em. ±**		**C.D. @ 5 %**	**S.Em. ±**		**C.D. @ 5 %**	**S.Em. ±**		**C.D. @ 5 %**
Genotypes (G)	**0.113**		**0.421**	**0.001**		**0.003**	**0.016**		**0.061**	**0.2**		**0.7**	**0.3**		**1.2**
Treatments (T)	**0.036**		**0.133**	**0.000**		**0.001**	**0.005**		**0.019**	**0.1**		**0.2**	**0.1**		**0.4**
G x T	**0.159**		**NS**	**0.001**		**NS**	**0.023**		**NS**	**0.3**		**1.0**	**0.5**		**1.8**

T_1: Zinc deficient (Zn -) hydroponic culture T_2: Zinc sufficient (Zn +) hydroponic culture

Net photosynthesis increased and intercellular CO_2 decreased with increasing stomatal conductance. These results suggest that the capacity of stomatal response to carbon fixation may be partially lost under Zn deficiency.

Similarly among the genotypes, SIRI-1253 (0.96) and Kalanamak (0.96) recorded significantly higher transpiration rate followed by MTU-1001 (0.95) and Karibatta (0.91), whereas; significantly lower transpiration rate was observed with genotype, Kempunellu (0.58) which was followed by Champakali (0.63).

The reasons for Zn-deficiency depressed plant leaf photosynthetic capacity may be associated to decrease in intercellular CO_2 concentration and stomatal conductance (Sharma *et al.,* 1994), stomatal closure allows plants to limit transpiration, but it also limits CO_2 absorption, which leads to a decreased photosynthetic activity. Sharma *et al.,* (1995) reported a significant role of Zn in the regulation of the stomatal aperture, which is accounted for possible role of Zn in maintaining a high K content in guard cells.

A decrease in carbonic anhydrase activity due to Zn deficiency may also contribute to the reduced net photosynthetic rate, P_N (Hacisalihoglu *et al.,* 2003). In addition, the accumulation of saccharides in leaves may be an important factor for the inhibition of photosynthesis under Zn-deficiency (Cakmak, 2000).

Biochemical

It was observed from Table 2 that the shoot zinc (ppm) and root zinc (ppm) differed significantly among the treatments, genotypes and similarly interaction between zinc treatments and genotypes was resulted significant.

Among the treatments in hydroponic culture, zinc sufficient (Zn^+) treatment recorded significantly higher shoot zinc content (10.6) and root zinc (18.8) over zinc deficient (Zn^-) (9.1 and 15.9, respectively). Among the genotypes, Dambersali was found to have significantly higher shoot zinc content (11.9) followed by Ambemohar-1 (11.8), whereas Ambemohar-1 (19.5) and Koorigenellu (19.3) noted higher root zinc content.

Among interactions, Ambemohar-1 resulted significantly higher shoot zinc content (13.3) and root zinc content (22.0) with zinc sufficient hogland solution. While, However, significantly lower shoot zinc content was found with genotype BPT-5204, whereas SIRI-1253 (14.7) resulted lower root zinc content in hogland solution without zinc sulphate (6.6).

The increase in the zinc content in shoot might be due to the presence of increased amount of Zn in solution, which could be attributed to its synergistic effects on the enhancement of root development and facilitated greater absorption of Zn (Chaudhary and Sinha, 2007). Increase in Zn content in shoot due to zinc fertilization was reported earlier (Fageria *et al.,* 2011). Similar result was reported by Naik and Das (2007). The increase in Zn uptake was due to their increased application could be ascribed to the variation in the availability of applied Zn in the root zone and their role in the growth and development of the plant.

Root zinc concentration increased by 15.0 per cent. Similarly genotypes showed significant difference with respect to root zinc content. Apart from this, genotypes with higher root length and root weight *viz.*, Dambersalib and Koorigenellu showed higher zinc content in root and shoot. Hence, root traits of these genotypes also contribute for zinc content. The increase in root zinc content may be

attributed to increase in root proliferation due to greater availability of the cation zinc which enhanced its uptake from solution through diffusion and mass flow from the immediate vicinity of plant roots. Mehdi *et al.*, (1990) also reported that increase in level of Zn increases the zinc content of roots. It was concluded from the experiment that 2.0 µM Zn-sufficient solution culture found to have beneficial effects on increasing the growth parameters, physiological and zinc content of rice plant.

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