

Relative Efficiency of Zinc-Coated Urea and Soil and Foliar Application of Zinc Sulphate on Yield, Nitrogen, Phosphorus, Potassium, Zinc and Iron Biofortification in Grains and Uptake by Basmati Rice (*Oryza sativa* L.)

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Received: October 10, 2014 Accepted: December 16, 2014 Online Published: January 15, 2015

doi:10.5539/jas.v7n2p161

URL: <http://dx.doi.org/10.5539/jas.v7n2p161>

Abstract

Two on-farm trials conducted one each in Aligarh and Meerut districts of the state of Uttar Pradesh, India on zinc (Zn) deficient soils during the rainy season (July-October) showed that Zn application increased not only Zn concentration and uptake by rice but also increased protein content of rice kernels and concentrations of Fe, N, P and K due to the overall improvement in crop growth. Foliar application of Zn was better from the viewpoint of Zn biofortification of rice kernels; nevertheless much of the foliar applied Zn was retained in husk. Since, foliar application of Zn is made at a late stage of crop growth, hence it was not as effective as soil application in increasing yield attributes, yield and concentration and uptake of Fe, N, P and K in rice. This study brought out that adequate soil application of Zn sulphate followed by its foliar application is the best approach. Zn coated urea applying less than half the amount of Zn as applied through soil + foliar application was very close to it and is quite promising.

Keywords: basmati rice, ferti-fortification, nutrient concentrations and uptake, Zn fertilization

1. Introduction

Zinc (Zn) is now recognised as the fourth major micronutrient deficiency in humans and comes after vitamin A, iron and iodine deficiencies (Bell & Dell, 2008). Zn deficiency leads to diarrhoea and pneumonia in infants and children (Black et al., 2008; Graham, 2008) and is considered for responsible for childhood dwarfism (Hotz & Brown, 2004). Zn plays an important role in production of protein and thus helps in wound healing, blood formation and growth and maintenance of tissue (Bell & Dell, 2008).

Rice is staple food in South and Southeast Asia, where about 90% of it is grown and consumed. Polished rice contains only 13-15 mg Zn kg⁻¹ (Welch, 2005) and a rice based diet is thus likely to be deficient in Zn as compared to diet containing grain legumes and animal proteins, which are rich in Zn (Prasad, 2003). Asian, especially Indian soils are low in available Zn (Prasad, 2006; Singh, 2011) and this leads to production of low Zn containing rice. Keeping this in view, programmes such as HarvestPlus and Golden Rice are underway to develop rice varieties capable of producing grains denser in Zn, Fe and other micronutrients (Stein et al., 2007).

Our research at the Indian Agricultural Research Institute (IARI), New Delhi (Shivay et al., 2007; Shivay et al., 2008a, 2008b, 2008c; Shivay et al., 2010; Shivay & Prasad, 2012; Shivay et al., 2013; Shivay & Prasad, 2014) has shown that Zn concentration in rice, wheat, barley and corn grains can be easily increased by adequate Zn fertilization of crops and agronomic biofortification of cereals with Zn and Fe, which are essential plant micronutrients (Prasad & Power, 1997) is a faster and easier way for achieving the goal of obtaining cereal grains denser in Zn. As a follow-up of our research at IARI, two on-farm field trials were therefore conducted to familiarize the farmers about the biofortification of rice grains with Zn and this paper reports the results of these on-farm trials.

2. Materials and Methods

2.1 Description of Study Area

On-farm experiments were conducted at two different places. First on-farm trial was conducted at the Krishi Vigyan Kendra (KVK), Aligarh of Chandra Shekhar Azad University of Agriculture & Technology, Kanpur, Uttar Pradesh, India during rainy season (July-October) of 2008 on a sandy clay loam soil (*typic Ustochrept*). The soil of experimental field had 133.7 kg ha⁻¹ alkaline permanganate oxidizable nitrogen (N) (Subbiah & Asija, 1956), 12.3 kg ha⁻¹ available phosphorus (P) (Olsen et al., 1954), 295.1 kg ha⁻¹ 1 N ammonium acetate exchangeable potassium (K) (Hanway & Heidel, 1952) and 0.36% organic carbon (C) (Walkley & Black, 1934). The pH of soil was 8.5 (1: 2.5 soil and water ratio) (Prasad et al., 2006) and diethylene triamine penta acetic acid (DTPA) extractable Zn and Fe (Lindsay & Norvell, 1978) in soil were 0.33 and 3.7 mg kg⁻¹ of soil, respectively.

The second on-farm trial was conducted at Kulimanpur village of Meerut district, Uttar Pradesh, India during rainy season (July-October) of 2008 on a sandy loam soil. The soils of experimental field at second site had 127.3 kg ha⁻¹ alkaline permanganate oxidizable nitrogen (N) (Subbiah & Asija, 1956), 14.7 kg ha⁻¹ available phosphorus (P) (Olsen et al., 1954), 278.9 kg ha⁻¹ 1 N ammonium acetate exchangeable potassium (K) (Hanway & Heidel, 1952) and 0.35% organic carbon (C) (Walkley & Black, 1934). The pH of soil was 8.2 (1:2.5 soil and water ratio) (Prasad et al., 2006) and diethylene triamine penta acetic acid (DTPA) extractable Zn and Fe (Lindsay & Norvell, 1978) in soil were 0.35 and 4.9 mg kg⁻¹ of soil, respectively. The critical level of DTPA extractable Zn for rice grown on alluvial soils in the rice-wheat belt of north India varies from 0.38-0.90 mg kg⁻¹ soil (Takkar et al., 1997) and thus the response of *Basmati* rice to Zn application was expected on the experimental field.

2.2 Experimental Treatments and Design

The experiment was conducted in a randomized block design with six replications on both sites. The treatments were: check (control, no Zn), 5 kg Zn ha⁻¹ to soil as Zn sulphate (soil), 1 kg Zn ha⁻¹ as Zn sulphate to foliage (foliar), 5 kg Zn ha⁻¹ (soil) + 1 kg Zn ha⁻¹ (foliar) and 2.83 kg Zn ha⁻¹ through Zn-coated urea (soil).

2.3 Application of Treatments and Fertilizers

The experimental field was disk-ploughed twice, puddled three times with a puddler in standing water and levelled. At final puddling 26 kg P ha⁻¹ as single superphosphate and 33 kg K ha⁻¹ as muriate of potash was broadcasted. Addition of 26 kg P as single super phosphate also supplied 45 kg S ha⁻¹ and takes care of S deficiency (if any). Nitrogen at 130 kg N ha⁻¹ as prilled urea or Zn-coated urea (ZnCU) was band applied in two equal splits, half 10 days after transplanting (DAT) and the other half at panicle initiation (40 DAT). Thus, Zn in ZnCU was band applied. When applied at the site, ZnCU supplied 2.83 kg Zn ha⁻¹ for the 1.0% Zn coatings onto prilled urea. Foliar application of Zn was made at flowering and 0.5% ZnSO₄·7H₂O foliar application at the rate of 1,000 liters of solution ha⁻¹ (+ 2.5 kg ha⁻¹ lime) which supplied 1.0 kg Zn ha⁻¹.

2.4 Rice Transplanting

Two 25-day-old seedlings of rice were transplanted per hill at 20 cm × 10 cm in the first fortnight of July at both the places of study. The 'Pusa Sugandh 5', a derivative of Pusa 3A Karnal *Basmati*, is a semi-dwarf (90–100 cm height), high yielding basmati rice variety released in the year 2004 by the Indian Agricultural Research Institute, New Delhi, for commercial cultivation was transplanted in Meerut district of Uttar Pradesh. However, in Aligarh district 'Pusa *Basmati* 1' was transplanted which is an aromatic (*Basmati*) variety released from Indian Agricultural Research Institute, New Delhi, India during 1989 for its commercial cultivation. It is a cross between 'Pusa 150' and 'Karnal Lokal'. It produces long slender grains with good aroma and excellent cooking qualities (Rani et al., 2009; V. P. Singh & A. K. Singh, 2009; Siddiq et al., 2012). Irrigation channels measuring 1 m wide were placed between the replications to ensure easy and uninterrupted flow of irrigation water where an individual plot was independently irrigated from the irrigation channels. Rice crop was grown as per recommended package of practices and was harvested in the second fortnight of October at both the places.

2.5 Recording of Growth, Yield Attributes and Yields of Rice

Ten hills were randomly selected in each plot for measuring plant height and fertile tillers hill⁻¹ 10 days before harvest and the average values were computed. Similarly, 10 panicles were randomly selected from each plot for recording the data on yield attributes (fertile tillers hill⁻¹, panicle length, grains panicle⁻¹ and 1,000-grain weight). At harvest, grain, straw and biological yields have been recorded for each plot and finally converted into tonnes ha⁻¹. The rice grain yield was recorded at 14% moisture. The rough rice grains were hulled and rice kernel and rice husk yields were obtained which were used for chemical analysis of mineral nutrients such as Zn, Fe, N, P and K.

2.6 Chemical Analysis of Zn and Fe Concentration in Rice Kernel, Rice Husk and Rice Straw

At harvest, samples of rice kernel, rice husk and rice straw were drawn from each plot of the experiment for the chemical analysis of Zn and Fe concentrations. Zn and Fe in rice kernel, husk and straw samples was analysed on a di-acid ($\text{HClO}_4 + \text{HNO}_3$ in 3:10 ratio) digest on an Atomic Absorption Spectrophotometer (Prasad et al., 2006). Thereafter, the uptake of the Zn and Fe was calculated by multiplying Zn and Fe concentrations with respective plot yield of rice kernel, rice husk and rice straw yields.

2.7 Chemical Analysis of N, P and K in Rice Kernel, Rice Husk and Rice Straw

At harvest, samples of rice kernel, rice husk and rice straw were drawn from each plot of the experiment for the chemical analysis of N, P and K as per the procedure described by Prasad et al. (2006). Finally recorded data in all the six replications were subjected to statistical analysis and final tabulation were done of the statistically analyzed data.

2.8 Statistical Analysis

All the data obtained from rice for this study were statistically analyzed using the *t*-test as per the procedure given by K. A. Gomez and A. A. Gomez (1984). LSD values at $P = 0.05$ were used to determine the significance of differences between treatment means.

3. Results

A. Aligarh Site

3.1 Yield Attributes

Zn application significantly increased tillers m^{-2} and grains panicle $^{-1}$ in rice, but not the panicle length and 1,000-grain weight (Table 1). Tillers m^{-2} and grains panicle $^{-1}$ were the most with soil + foliar application of Zn sulphate (ZnS), significantly more than soil application of ZnS or Zn-coated urea (ZnCU), which in turn was significantly superior to foliar application of ZnS.

Table 1. Effect of various zinc treatments on yield attributes of aromatic rice [Aligarh, Uttar Pradesh site]

Treatments	Plant height (cm)	Tillers m^{-2}	Panicle length (cm)	Grains panicle $^{-1}$ (Nos.)	1,000-grain weight (g)
Check	104	310	24	85	21.1
5 kg Zn ha^{-1} (soil)	107	326	26	91	22.2
1 kg Zn ha^{-1} (foliar)	105	318	25	88	22.0
5 kg Zn ha^{-1} (soil) + 1 kg Zn ha^{-1} (foliar)	108	342	27	94	22.7
2.83 kg Zn ha^{-1} through Zn-coated urea (soil)	107	328	26	91	22.3
SEM \pm	2.12	3.51	0.79	1.03	0.38
LSD ($p = 0.05$)	NS	9.95	NS	2.93	NS

3.2 Yields

Zn application significantly increased grain and straw yield as well as harvest index of rice (Table 2). The highest values of grain, kernel, husk, straw and biological yield were obtained with soil + foliar application of ZnS, followed by soil application of ZnCU, which in turn was significantly superior to soil application of ZnS (Table 2). Foliar application of ZnS recorded the lowest values for all yields. Harvest index was also the highest for soil + foliar application of ZnS followed by ZnCU, which in turn was followed by soil or foliar application of ZnS.

Table 2. Effect of various zinc treatments on yields of aromatic rice [Aligarh, Uttar Pradesh site]

Treatments	Rice grain yield (t ha ⁻¹)	Rice kernel yield (t ha ⁻¹)	Rice husk yield (t ha ⁻¹)	Rice straw yield (t ha ⁻¹)	Biological yield (t ha ⁻¹)	Harvest index (%)
Check	3.58	2.40	1.18	6.80	10.38	34.5
5 kg Zn ha ⁻¹ (soil)	3.93	2.63	1.30	7.45	11.38	34.4
1 kg Zn ha ⁻¹ (foliar)	3.80	2.55	1.25	7.25	11.05	34.4
5 kg Zn ha ⁻¹ (soil) + 1 kg Zn ha ⁻¹ (foliar)	4.52	3.03	1.50	8.12	12.63	35.7
2.83 kg Zn ha ⁻¹ through Zn-coated urea (soil)	4.10	2.75	1.35	7.63	11.73	35.1
SEm±	0.03	0.02	0.01	0.03	0.04	0.21
LSD (<i>p</i> = 0.05)	0.08	0.06	0.03	0.09	0.11	0.60

3.3 Zn Concentration and Uptake

Zn application increased Zn concentration in rice kernels, husk and straw and the highest values were obtained for soil + foliar application of ZnS (Table 3). In the case of kernels and straw soil + foliar application of ZnS recorded significantly higher Zn concentration than ZnCU, which in turn was superior to soil or foliar application of ZnS. In the case of husk ZnCU was superior to foliar application of ZnS, which in turn was superior to soil application of ZnS. Foliar application of ZnS significantly increased Zn concentration in husk but not in kernels.

Zn application increased Zn uptake by rice. In husk and straw as well as in total Zn uptake by rice various treatments were in the following order: soil + foliar application of ZnS > ZnCU > foliar application of Zn > soil application of Zn; soil + foliar application recording the highest Zn uptake. However in the case of rice kernels, soil or foliar application of Zn recorded the same value for Zn uptake.

Table 3. Effect of various zinc treatments on zinc concentrations in rice kernel, rice husk, rice straw and their uptake in aromatic rice [Aligarh, Uttar Pradesh site]

Treatments	Zn concentration in rice kernel (mg kg ⁻¹ rice kernel)	Zn concentration in rice husk (mg kg ⁻¹ rice husk)	Zn concentration in rice straw (mg kg ⁻¹ rice straw)	Zn uptake in rice kernel (g ha ⁻¹)	Zn uptake in rice husk (g ha ⁻¹)	Zn uptake in rice straw (g ha ⁻¹)	Total Zn uptake in rice crop (g ha ⁻¹)
Check	20.0	125.0	91.0	48.0	147.5	618.8	814.3
5 kg Zn ha ⁻¹ (soil)	21.3	130.0	100.0	56.0	169.0	745.0	970.0
1 kg Zn ha ⁻¹ (foliar)	22.0	147.0	102.0	56.1	183.8	739.5	979.4
5 kg Zn ha ⁻¹ (soil) + 1 kg Zn ha ⁻¹ (foliar)	25.0	175.0	107.0	75.7	262.5	868.8	1207.0
2.83 kg Zn ha ⁻¹ through Zn-coated urea (soil)	23.8	170.0	105.0	65.5	229.5	801.2	1096.2
SEm±	0.30	1.46	0.98	1.07	2.41	7.95	9.27
LSD (<i>p</i> = 0.05)	0.86	4.13	2.78	3.02	6.82	22.55	26.26

3.4 Iron Concentration and Uptake

Soil application of ZnS or ZnCU significantly increased Fe concentration in rice kernels, husk and straw. In the case of kernels and husk, soil application of ZnS, ZnCU or soil + foliar application of ZnS were at par (Table 4). However, soil + foliar application of ZnS or ZnCU recorded significantly higher concentration in rice straw than soil application of ZnS. Foliar application of ZnS had no effect on Fe concentration by rice.

Zn application increased Fe uptake by rice. As regards grain and straw and total Fe uptake by rice, different

treatments were in the following order: soil + foliar application of ZnS > ZnCU > soil application of ZnS > foliar application of ZnS. In the case of husk soil application of ZnS and ZnCU were at par. In general, as a contrast to Zn uptake, soil application of Zn recorded the higher Fe uptake than foliar application of ZnS.

Table 4. Effect of various zinc treatments on Fe concentrations in rice kernel, rice husk, rice straw and their uptake in aromatic rice [Aligarh, Uttar Pradesh site]

Treatments	Fe concentration in rice kernel (mg kg ⁻¹)	Fe concentration in rice husk (mg kg ⁻¹)	Fe concentration in rice straw (mg kg ⁻¹)	Fe uptake in rice kernel (g ha ⁻¹)	Fe uptake in rice husk (g ha ⁻¹)	Fe uptake in rice straw (g ha ⁻¹)	Total Fe uptake in rice crop (g ha ⁻¹)
Check	8.2	12.3	42.0	19.7	14.5	285.6	319.8
5 kg Zn ha ⁻¹ (soil)	9.0	13.4	48.0	23.7	17.4	357.6	398.7
1 kg Zn ha ⁻¹ (foliar)	8.4	12.8	45.0	21.4	16.0	326.3	363.7
5 kg Zn ha ⁻¹ (soil) + 1 kg Zn ha ⁻¹ (foliar)	9.3	14.1	55.0	28.2	21.2	446.6	496.0
2.83 kg Zn ha ⁻¹ through Zn-coated urea (soil)	9.1	13.8	56.0	25.0	18.6	427.3	470.9
SEm±	0.15	0.39	0.58	0.79	0.53	4.55	4.59
LSD (<i>p</i> = 0.05)	0.44	1.10	1.66	2.24	1.51	12.88	13.01

3.5 Nitrogen Concentration and Uptake

Zn application significantly increased N concentration and crude protein content in rice kernel and N concentration in straw. In general, soil + foliar application of ZnS or ZnCU recorded significantly higher N concentration in rice kernel and straw than foliar application of ZnS (Table 5). The N concentration in rice kernel was about 2.5 times of that in straw.

As regards N uptake by rice kernel, straw as well as total N uptake by rice crop, different treatments were in the following order: soil + foliar application of ZnS > soil application of ZnCU > soil application of ZnS > foliar application of ZnS; soil + foliar application recording the highest N uptake.

Table 5. Effect of various zinc treatments on N concentrations in rice kernel, rice husk, rice straw and their uptake in aromatic rice and crude protein content in brown rice [Aligarh, Uttar Pradesh site]

Treatments	N concentration in rice kernel (%)	N concentration in rice straw (%)	N uptake in rice kernel (kg ha ⁻¹)	N uptake in rice straw (kg ha ⁻¹)	Total N uptake in rice crop (kg ha ⁻¹)	Crude protein content in rice kernel (%)
Check	1.50	0.62	36.0	42.2	78.2	8.92
5 kg Zn ha ⁻¹ (soil)	1.60	0.66	42.1	49.2	91.3	9.52
1 kg Zn ha ⁻¹ (foliar)	1.53	0.64	39.0	46.4	85.4	9.10
5 kg Zn ha ⁻¹ (soil) + 1 kg Zn ha ⁻¹ (foliar)	1.62	0.67	49.1	54.4	103.5	9.64
2.83 kg Zn ha ⁻¹ through Zn-coated urea (soil)	1.61	0.67	44.3	51.1	95.4	9.58
SEm±	0.007	0.005	0.54	0.41	0.61	0.05
LSD (<i>p</i> = 0.05)	0.020	0.015	1.54	1.16	1.72	0.14

3.6 Phosphorus Concentration and Uptake

A significant increase in P concentration in rice due to Zn application was recorded only in kernels, where soil

application of ZnS recorded significantly higher P concentration than foliar application of ZnS or soil application of ZnS. Least P concentration was recorded with soil + foliar application of ZnS (Table 6).

Uptake of P by kernel was much more than that by husk or straw. In kernels and total P uptake by rice was the highest with soil application of ZnS followed by soil + foliar application of ZnS or ZnCU, which were at par. Least P uptake by kernels and total P uptake by the rice crop was recorded with foliar application of ZnS.

Table 6. Effect of various zinc treatments on P concentrations in rice kernel, rice husk, rice straw and their uptake in aromatic rice [Aligarh, Uttar Pradesh site]

Treatments	P concentration in rice kernel (%)	P concentration in rice husk (%)	P concentration in rice straw (%)	P uptake in rice kernel (kg ha ⁻¹)	P uptake in rice husk (kg ha ⁻¹)	P uptake in rice straw (kg ha ⁻¹)	Total P uptake in rice crop (kg ha ⁻¹)
Check	0.64	0.03	0.07	15.36	0.35	4.76	20.47
5 kg Zn ha ⁻¹ (soil)	0.73	0.04	0.08	19.20	0.52	5.96	27.68
1 kg Zn ha ⁻¹ (foliar)	0.64	0.03	0.08	16.32	0.38	5.80	22.56
5 kg Zn ha ⁻¹ (soil) + 1 kg Zn ha ⁻¹ (foliar)	0.61	0.03	0.08	18.48	0.45	6.50	25.43
2.83 kg Zn ha ⁻¹ through Zn-coated urea (soil)	0.65	0.04	0.08	17.87	0.54	6.10	24.51
SEm±	0.007	0.002	0.005	0.66	0.021	0.26	0.44
LSD (<i>p</i> = 0.05)	0.020	0.004	NS	0.75	0.060	0.75	1.24

3.7 Potassium Concentration and Uptake

Zn application significantly increased K concentration in kernels only and soil application of ZnS and soil + foliar application of ZnS were at par significantly superior to soil application of ZnCU or foliar application of Zn (Table 7).

As regards K uptake in kernels, soil + foliar application of ZnS recorded the highest K uptake followed by the soil application of ZnCU and soil or foliar application of ZnS. In husk the treatments were in the following order: soil + foliar application of ZnS > soil application of ZnCU or ZnS > foliar application of ZnS. Straw contributed most to K uptake by rice and different treatments were in the following order: soil + foliar application of ZnS > soil application of ZnCU > soil application of ZnS > foliar application of ZnS.

Table 7. Effect of various zinc treatments on K concentrations in rice kernel, rice husk, rice straw and their uptake in aromatic rice [Aligarh, Uttar Pradesh site]

Treatments	K concentration in rice kernel (%)	K concentration in rice husk (%)	K concentration in rice straw (%)	K uptake in rice kernel (kg ha ⁻¹)	K uptake in rice husk (kg ha ⁻¹)	K uptake in rice straw (kg ha ⁻¹)	Total K uptake in rice crop (kg ha ⁻¹)
Check	0.18	0.47	3.40	4.32	5.55	231.2	241.1
5 kg Zn ha ⁻¹ (soil)	0.20	0.49	3.67	4.26	6.37	273.4	285.0
1 kg Zn ha ⁻¹ (foliar)	0.19	0.47	3.53	4.84	5.88	255.9	266.6
5 kg Zn ha ⁻¹ (soil) + 1 kg Zn ha ⁻¹ (foliar)	0.21	0.50	3.70	6.36	7.50	300.4	314.3
2.83 kg Zn ha ⁻¹ through Zn-coated urea (soil)	0.19	0.49	3.68	5.22	6.62	280.8	292.6
SEm±	0.004	0.007	0.013	0.12	0.11	1.52	2.11
LSD (<i>p</i> = 0.05)	0.012	0.021	0.037	0.34	0.31	4.31	5.99

3.8 Zn, N, P and K Concentration in Flag Leaf

Zn application significantly increased Zn, N and K concentration but not the P concentration in rice flag leaf (Table 8). Soil + foliar application of ZnS and soil application of ZnCU were at par and significantly superior to soil or foliar application of ZnS. As regards N concentration in flag leaf, different treatments were in the following order: soil application of ZnCU > soil + foliar application of ZnS > soil application of ZnS > foliar application of ZnS.

Table 8. Effect of various zinc treatments on Zn, Fe, N, P and K concentrations in aromatic rice flag leaf [Aligarh, Uttar Pradesh site]

Treatments	Zn concentration in rice flag leaf (mg kg ⁻¹ rice leaf DM)	N concentration in rice leaf (%)	P concentration in rice flag leaf (%)	K content in rice flag leaf (%)
Check	95.0	1.29	0.35	4.04
5 kg Zn ha ⁻¹ (soil)	105.0	1.39	0.36	4.31
1 kg Zn ha ⁻¹ (foliar)	107.0	1.32	0.40	4.15
5 kg Zn ha ⁻¹ (soil) + 1 kg Zn ha ⁻¹ (foliar)	112.0	1.41	0.41	4.47
2.83 kg Zn ha ⁻¹ through Zn-coated urea (soil)	111.0	1.46	0.42	4.58
SEm±	1.01	0.005	0.025	0.06
LSD (<i>p</i> = 0.05)	2.86	0.014	0.072	0.16

B. Meerut Site

3.9 Yield Attributes

Zn application significantly increased tillers m⁻² and grains panicle⁻¹ but not the panicle length and 1,000-grain weight (Table 9). Soil application of ZnS or ZnCU or soil + foliar application of ZnS resulted in significantly more effective tillers than foliar application of ZnS. The highest number of grains panicle⁻¹ were produced by soil application of ZnS or ZnCU.

Table 9. Effect of various zinc treatments on yield attributes of aromatic rice [Meerut, Uttar Pradesh site]

Treatments	Plant height (cm)	Effective tillers hill ⁻¹	Panicle length (cm)	Grains panicle ⁻¹ (Nos.)	1,000-grain weight (g)
Check	105	7.1	27.0	124	24.0
5 kg Zn ha ⁻¹ (soil)	108	7.8	27.7	131	24.5
1 kg Zn ha ⁻¹ (foliar)	107	7.3	27.4	128	24.3
5 kg Zn ha ⁻¹ (soil) + 1 kg Zn ha ⁻¹ (foliar)	109	8.0	28.0	125	24.7
2.83 kg Zn ha ⁻¹ through Zn-coated urea (soil)	109	7.8	27.8	131	24.5
SEm±	2.25	0.10	0.63	1.20	0.40
LSD (<i>p</i> = 0.05)	NS	0.27	NS	3.40	NS

3.10 Yields

Zn application significantly increased grain and straw yield as well as harvest index in rice (Table 10). Soil + foliar application of ZnS recorded significantly more grain, kernel, husk and total biological yield than other treatments. As regards straw yield, soil + foliar application of ZnS was at par with soil application of ZnCU and both these treatments were significantly superior to soil or foliar application of ZnS. Harvest index was not significantly affected by Zn application.

Table 10. Effect of various zinc treatments on yields of aromatic rice [Meerut, Uttar Pradesh site]

Treatments	Rice grain yield (t ha ⁻¹)	Rice kernel yield (t ha ⁻¹)	Rice husk yield (t ha ⁻¹)	Rice straw yield (t ha ⁻¹)	Biological yield (t ha ⁻¹)	Harvest index (%)
Check	5.40	3.62	1.78	8.50	13.90	38.8
5 kg Zn ha ⁻¹ (soil)	5.70	3.82	1.88	8.90	14.60	39.0
1 kg Zn ha ⁻¹ (foliar)	5.60	3.75	1.85	8.70	14.30	39.2
5 kg Zn ha ⁻¹ (soil) + 1 kg Zn ha ⁻¹ (foliar)	6.00	4.02	1.98	9.20	15.20	39.5
2.83 kg Zn ha ⁻¹ through Zn-coated urea (soil)	5.70	3.82	1.88	9.00	14.70	38.8
SEm±	0.09	0.07	0.03	0.09	0.14	0.44
LSD (<i>p</i> = 0.05)	0.27	0.20	0.09	0.26	0.40	NS

3.11 Zinc Concentration and Uptake

Zn application increased Zn concentration in rice kernel, husk and straw of rice (Table 11). Zn concentration in rice kernels was the highest with soil application of ZnCU, significantly more than that obtained with soil + foliar application of ZnS, which in turn was superior to foliar application of ZnS. However, foliar application of ZnS recorded significantly more Zn concentration in rice kernels than soil application of ZnS. Zn concentration in rice husk was the highest with soil + foliar application of ZnS, significantly superior to foliar application of ZnS, which in turn was superior to ZnCU. Lowest Zn concentration was obtained with soil application of ZnS. As regards Zn concentration in straw, soil + foliar application of ZnS and soil application of ZnCU were at par and significantly superior to foliar application of ZnS, which in turn was superior to soil application of ZnS.

Zn uptake significantly increased Zn uptake by rice kernels, husk and straw in rice and this resulted in a significant increase in total Zn uptake by rice. As regards rice kernels soil + foliar application of ZnS and soil application of ZnCU were at par and significantly superior to soil or foliar application of ZnS. In the case of rice husk, foliar application of ZnS was next only to soil + foliar application of ZnS and was followed by soil application of ZnCU. Soil application of ZnS recorded the least Zn uptake by rice.

Table 11. Effect of various zinc treatments on Zn concentrations in rice kernel, rice husk, rice straw and their uptake in aromatic rice [Meerut, Uttar Pradesh site]

Treatments	Zn concentration in rice kernel (mg kg ⁻¹ rice kernel)	Zn concentration in rice husk (mg kg ⁻¹ rice husk)	Zn concentration in rice straw (mg kg ⁻¹ rice straw)	Zn uptake in rice kernel (g ha ⁻¹)	Zn uptake in rice husk (g ha ⁻¹)	Zn uptake in rice straw (g ha ⁻¹)	Total Zn uptake in rice crop (g ha ⁻¹)
Check	18.0	17.7	110.3	65.2	31.5	937.6	1034.3
5 kg Zn ha ⁻¹ (soil)	18.7	23.8	117.0	71.4	44.7	1041.3	1157.4
1 kg Zn ha ⁻¹ (foliar)	20.2	34.7	124.2	75.8	64.2	1080.5	1220.5
5 kg Zn ha ⁻¹ (soil) + 1 kg Zn ha ⁻¹ (foliar)	21.2	37.7	126.0	85.2	74.6	1159.2	1319.0
2.83 kg Zn ha ⁻¹ through Zn-coated urea (soil)	22.2	25.7	124.8	84.8	48.3	1123.2	1256.3
SEm±	0.28	0.42	0.49	2.57	1.29	15.3	15.76
LSD (<i>p</i> = 0.05)	0.79	1.20	1.40	7.30	3.65	43.3	44.65

3.12 Iron Concentration and Uptake

Fe concentration in rice kernels, husk and straw was increased by Zn application and for all the components soil + foliar application of ZnS or ZnCU were at par and significantly superior to foliar application of ZnS (Table 12). Foliar application of ZnS had no significant effect on Fe concentration in rice kernels, husk and straw.

All treatments except foliar application of Zn significantly increased Fe uptake by rice kernels, husk and straw and total Fe uptake by rice crop.

Table 12. Effect of various zinc treatments on Fe concentrations in rice kernel, rice husk, rice straw and their uptake in aromatic rice [Meerut, Uttar Pradesh site]

Treatments	Fe concentration in rice kernel (mg kg ⁻¹ rice kernel)	Fe concentration in rice husk (mg kg ⁻¹ rice husk)	Fe concentration in rice straw (mg kg ⁻¹ rice straw)	Fe uptake in rice kernel (g ha ⁻¹)	Fe uptake in rice husk (g ha ⁻¹)	Fe uptake in rice straw (g ha ⁻¹)	Total Fe uptake in rice crop (g ha ⁻¹)
Check	21.2	56.0	98.2	76.7	99.7	834.7	1011.1
5 kg Zn ha ⁻¹ (soil)	22.4	58.0	103.6	85.6	109.0	922.0	1116.6
1 kg Zn ha ⁻¹ (foliar)	21.6	55.0	100.3	81.0	101.8	872.6	1055.4
5 kg Zn ha ⁻¹ (soil) + 1 kg Zn ha ⁻¹ (foliar)	22.8	58.0	105.2	91.7	114.8	967.8	1174.3
2.83 kg Zn ha ⁻¹ through Zn-coated urea (soil)	22.7	58.0	104.3	86.7	109.0	938.7	1134.4
SEm±	0.37	0.50	1.59	2.26	2.23	24.26	29.07
LSD (<i>p</i> = 0.05)	1.06	1.42	4.51	6.40	6.31	68.34	82.37

3.13 Nitrogen Concentration and Uptake

Nitrogen concentration and crude protein content in rice kernels was significantly increased due to Zn fertilization and soil + foliar application of ZnS and soil application of ZnCU were at par and significantly superior to soil application of ZnS, which in turn was significantly superior to foliar application of ZnS (Table 13).

Nitrogen uptake by rice kernels and straw and total N uptake by the rice crop was most with soil + foliar application ZnS or ZnCU, which were at par. Foliar application of ZnS recorded the lowest N uptake.

Table 13. Effect of various zinc treatments on N concentrations in rice kernel, rice straw and their uptake in aromatic rice and also crude protein content [Meerut, Uttar Pradesh site]

Treatments	N concentration in rice kernel (%)	N concentration in rice straw (%)	N uptake in rice kernel (kg ha ⁻¹)	N uptake in rice straw (kg ha ⁻¹)	Total N uptake in rice crop (kg ha ⁻¹)	Crude protein content in rice kernel (%)
Check	1.29	0.79	46.7	67.1	113.8	7.7
5 kg Zn ha ⁻¹ (soil)	1.43	0.89	54.6	79.2	133.8	8.5
1 kg Zn ha ⁻¹ (foliar)	1.34	0.85	50.2	74.0	124.2	8.0
5 kg Zn ha ⁻¹ (soil) + 1 kg Zn ha ⁻¹ (foliar)	1.50	0.92	60.3	84.6	144.9	8.9
2.83 kg Zn ha ⁻¹ through Zn-coated urea (soil)	1.47	0.85	56.2	76.5	132.7	8.7
SEm±	0.01	0.005	1.55	1.23	2.39	0.08
LSD (<i>p</i> = 0.05)	0.03	0.014	4.41	3.48	6.77	0.23

3.14 Phosphorus Concentration and Uptake

In rice kernels soil application of ZnCU recorded the highest P concentration and was followed by soil + foliar application of ZnS, which in turn was significantly superior to soil application of ZnS (Table 14). In the case of husk, however, soil + foliar application of ZnS was superior to soil application of ZnS or ZnCU, which were at par. In straw, soil application of ZnCU recorded the highest P concentration followed by soil application of ZnS,

which in turn was significantly superior to soil + foliar application of ZnS.

Phosphorus uptake by rice kernels was increased by soil application of ZnS or ZnCU or soil + foliar application of ZnS, which were at par. Foliar application of ZnS did not increase P uptake by rice crop. Zn application did not increase P uptake by husk. However in rice straw, different treatments were in the following order: soil application of ZnCU > soil application of ZnS > soil + foliar application of Zn > foliar application of ZnS. Soil application of ZnCU recorded the highest P uptake, significantly higher than soil + foliar application of ZnS or soil application of ZnS. Foliar application of ZnS did not increase P uptake by rice.

Table 14. Effect of various zinc treatments on P concentrations in rice kernel, rice husk, rice straw and their uptake in aromatic rice [Meerut, Uttar Pradesh site]

Treatments	P concentration in rice kernel (%)	P concentration in rice husk (%)	P concentration in rice straw (%)	P uptake in rice kernel (kg ha ⁻¹)	P uptake in rice husk (kg ha ⁻¹)	P uptake in rice straw (kg ha ⁻¹)	Total P uptake in rice crop (kg ha ⁻¹)
Check	0.58	0.063	0.14	21.00	1.12	11.90	34.02
5 kg Zn ha ⁻¹ (soil)	0.66	0.065	0.19	25.21	1.22	16.91	43.34
1 kg Zn ha ⁻¹ (foliar)	0.55	0.063	0.15	20.62	1.16	13.05	34.83
5 kg Zn ha ⁻¹ (soil) + 1 kg Zn ha ⁻¹ (foliar)	0.63	0.067	0.16	25.33	1.33	14.72	41.38
2.83 kg Zn ha ⁻¹ through Zn-coated urea (soil)	0.66	0.065	0.21	25.21	1.22	18.9	45.33
SEm±	0.006	0.0004	0.004	0.49	0.086	0.48	1.035
LSD ($p = 0.05$)	0.016	0.0011	0.011	1.38	0.283	1.37	2.931

3.15 Potassium Concentration and Uptake

A significant increase in K concentration in rice kernels was obtained only with soil + foliar application of ZnS or soil application of ZnCU (Table 15). There was no significant increase in K uptake due to Zn application. In the case of rice straw, soil application of ZnS or ZnCU or soil + foliar application of ZnS were at par and significantly superior to foliar application of ZnS.

Foliar application of ZnS did not significantly increase K uptake in rice kernels or husk, but did so in straw and therefore in total K uptake by rice crop. Soil application of ZnS or ZnCU and soil + foliar application of ZnS recorded significantly more K uptake than foliar application of ZnS.

Table 15. Effect of various zinc treatments on K concentrations of rice kernel, rice husk, rice straw and their uptake in aromatic rice [Meerut, Uttar Pradesh site]

Treatments	K concentration in rice kernel (%)	K concentration in rice husk (%)	K concentration in rice straw (%)	K uptake in rice kernel (kg ha ⁻¹)	K uptake in rice husk (kg ha ⁻¹)	K uptake in rice straw (kg ha ⁻¹)	Total K uptake in rice crop (kg ha ⁻¹)
Check	0.31	0.34	1.78	11.22	6.05	151.30	168.57
5 kg Zn ha ⁻¹ (soil)	0.33	0.37	1.87	12.61	6.96	166.43	186.00
1 kg Zn ha ⁻¹ (foliar)	0.32	0.35	1.84	12.00	6.48	160.08	178.56
5 kg Zn ha ⁻¹ (soil) + 1 kg Zn ha ⁻¹ (foliar)	0.34	0.38	1.89	13.67	7.52	173.88	195.07
2.83 kg Zn ha ⁻¹ through Zn-coated urea (soil)	0.34	0.37	1.87	12.99	6.96	168.30	188.25
SEm±	0.007	0.009	0.013	0.39	0.21	2.59	2.92
LSD ($p = 0.05$)	0.021	NS	0.037	1.10	0.60	7.34	8.26

4. Discussion

Foliar application of Zn resulted in higher Zn concentration in rice kernels than soil application of ZnS in the on-farm trial in Meerut but not at the Farmers Science Centre in Aligarh. However in both the on-farm trials Zn concentration in husk was significantly more with foliar than with soil application of Zn. Impa and Johnson-Beebout (2012) reported that biofortification recovery of Zn with foliar application was 8 times of that obtained with soil application. However data reported by Shivay and Prasad (2010) suggested that Zn concentration in rice grain was 47.5 mg kg^{-1} , while that in kernel was only 40.3 mg kg^{-1} . Thus more of foliar applied Zn tended to be retained by the husk. From a study involving multi-country and multi-location trials, Phattrakul et al. (2012) also reported that a major share of foliar applied Zn was retained in husk.

It needs to be considered that in Asian countries food security is a serious problem alongwith low Zn concentration in rice (Prasad et al., 2014). In the present study, highest values of yield attributes, rice grain yield and concentrations and uptake of Zn, Fe, N, P and K were obtained by soil + foliar application of Zn. This is because soil applied Zn on Zn deficient soils results in overall better growth, higher yield attributes and grain and straw yield in rice (Pooniya & Shivay, 2013), which results in increased uptake of all nutrients. This does not happen with foliar application of Zn, which is made at a much latter stage of crop growth. Soil application of Zn but not the foliar application of Zn also resulted in increased crude protein content in rice kernels, which is important from the viewpoint of wide spread protein malnutrition in India and other Asian countries (Prasad, 2003).

For most of the characters studied ZnCU performed better than ZnS and was next only to soil + foliar application of Zn. These results are in conformity of our results reported earlier (Shivay et al., 2007, 2008a; Prasad et al., 2013). The major advantage with ZnCU is saving in the amount of Zn to be applied; only $2.83 \text{ kg Zn ha}^{-1}$ was applied with ZnCU as against 6 kg Zn ha^{-1} in the case of soil + foliar application of ZnS. The ZnCU is therefore a promising fertilizer.

Zn application also increased Fe, N, P and K concentration and uptake in rice. Thus, a soil-foliar Zn biofortification programme also results in enrichment of rice kernels in Fe, N, P and K. A close relationship between Zn, Fe, N, P and K in wheat germplasms has been reported by Gomez-Beccera et al. (2010) and Zhao et al. (2009).

In conclusion, the present study brings out that for increased production of rice alongwith its biofortification with micronutrients Zn and Fe, adequate soil application of Zn should be followed by some foliar application of Zn.

Acknowledgements

The authors are grateful to the Director and Head, Division of Agronomy, Indian Agricultural Research Institute, New Delhi 110 012, India for providing necessary facilities to carry out this research work. Rajendra Prasad is grateful to the Indian National Science Academy for awarding him an Honorary Scientist position, which made this research possible.

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