Performance of rice cultivars under SRI and conventional systems: implications for zinc and iron uptake

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ABSTRACT

Two-year field investigations were conducted in West Bengal, India, to evaluate the zinc (Zn) and iron (Fe) sequestration potential of five diverse rice cultivars (IR 64, Satabdi, MTU 1010, GB 1 and KRH 2) under conventional and system of rice intensification (SRI) cultivation methods. The study also assessed the influence of Zn fertilization (basal and foliar) and farmyard manure (FYM) application on yield, yield-attributing traits and micronutrient content in grain and straw. Results showed that the conventional system generally outperformed SRI in plant height, panicle-bearing tillers, straw yield, grain yield and both grain and straw Zn and Fe concentrations. This might be attributed to altered Zn adsorption-desorption kinetics and reduced transpiration rates under SRI's alternate wetting-drying conditions. Zinc fertilization significantly increased plant height, tiller number and both straw and grain yields (up to 24.76% in grain yield) across both systems. It also substantially increased Zn content in rice grain (up to 25.32%) and straw, with FYM further enhancing grain Zn loading. However, a critical finding was the significant reduction in Fe content (up to 9.01%) in both grain and straw due to Zn fertilization, indicating an antagonistic interaction between these two essential micronutrients. This antagonism likely arises from competition during root absorption, xylem loading and transport within the plant. These findings underscore the effectiveness of Zn fertilization for yield enhancement and Zn biofortification in rice. However, they also highlight the challenge of concurrent Fe depletion. Future breeding and management strategies should, therefore, aim to identify or develop rice cultivars that can maintain or enhance both Zn and Fe accumulation, particularly when cultivated under varying water management regimes, to effectively address the global micronutrient malnutrition challenge.

Keywords: Rice; zinc; iron; biofortification; antagonism; SRI; conventional cultivation

INTRODUCTION

Rice is the most important staple food globally, providing 66-70 per cent of calorie intake for nearly half of the world's population (2.7 billion people) (Sinha and Talati 2007, Datta and Singh 2010). It supplies 20 per cent of the world's dietary energy supply (Rahman and Zhang 2022). Besides this, it is rich in nutrients such as vitamin D, calcium, thiamine, riboflavin and glutamic acids and high in fiber (Bhat and Riar 2015, Verma and Srivastav 2017). In Asia, more than 90 per cent of the world's rice is grown and consumed (Bandumula 2017).

Many regions worldwide are experiencing unexpected human population growth. Projections from the 2012 Population Reference Bureau datasheet, for instance, indicate that developing countries will continue to have significantly higher population growth rates than developed countries (Anon 2012).

Zinc (Zn) is an essential co-factor required for the structure and function of numerous proteins and is required in human diet in trace quantities that is approximately 15 mg Zn per day (Tapiero and Tew 2003) and the average amount of Zn in the adult body is about 1.4-2.3 g (Calesnick and Dinan 1988). In plants, Zn deficiency is one of the most widespread mineral deficiencies and may be the most common mineral deficiency in cereals (Ruel and Bouis 1998). Zn deficiency in rice has been widely reported in many rice-growing regions of the world (Tiong et al 2014).

Its deficiency in crop plants results not only in yield reduction but also Zn malnutrition in humans (Chasapis et al 2012). Dietary deficiencies of Zn and Fe are a serious global public health problem affecting over two billion people and causing a loss of 63 million life-years annually (Myers et al 2014). These cases of malnutrition are more severe in populations of Africa, south and southeast Asia, where cereals, the major staple foods, are low in dietary Zn and Fe.

Zn biofortification of rice grains, which aims at increasing Zn concentration and bioavailability of food crop, appears to be the most feasible, sustainable and economical approach among the different interventions to address human Zn deficiency (Zhao and Mcgrath 2009, Salunke et al 2011). Zn fertilization to cereal crops improves productivity and grain Zn concentration (Kang and Okoro1976, Yilmaz et al 1997, Cakmak 2008, Phattarakul et al 2012) and thus contributes to grain nutritional value for human beings. Zinc concentration can be enriched in rice grains by biofortification with popular Zn fertilizers (Cakmak 2009), manipulating Zn transporters and ligands in rice plants (Palmgren et al 2008, Borrill et al 2014) and efficient germplasm screening for higher bio-available Zn (Blair 2013, Trijatmiko et al 2016). All these methods depend on fertilizer or the soil or both as the source of Zn to produce Zn-enriched grains.

Soil supplied Zn is, however, limited depending upon soil properties such as pH and redox potential, contents of CO_3^{2-} and HCO_3^-, oxides of Fe and Al and organic matter (Mandal and Mandal 1990) and inherent Zn status in the upper soil layer (Tuyogon et al 2016). The problem of low Zn availability to plants is aggravated when rice is grown in submerged soils (Meng et al 2014). Application of Zn fertilizer is the most common option to overcome such problems. Its fertilization enriches the zinc content in the edible parts of the cereals.

Anaemia remains a significant global health challenge, impacting an estimated half a billion women (15-49 years) and 269 million children (6-59 months) worldwide. In 2019 alone, 30 per cent (539 million) of non-pregnant women and 37 per cent (32 million) of pregnant women aged 15-49 years suffered from this condition. The burden of anaemia is particularly concentrated in the WHO regions of Africa and southeast Asia. Africa accounts for an estimated 106 million affected women and 103 million children, while southeast Asia bears the highest burden with 244 million women and 83 million children affected. (https://www.who.int/news-room/fact-sheets/detail/anaemia).

Enriched Zn can sometimes exhibit an antagonistic effect towards iron, thereby, reducing its content in the edible portion of grains. Again the antagonistic interaction may vary with the cultivars used for cultivation (Saha 2014). However, amongst the cereals, rice has the tremendous potential to sequester the applied Zn and Fe in the edible grains. Such sequestration potential and Zn bio-fortification in cereals were functionally described by many workers (Cakmak 2008, Saha 2015b) and as such the phenomenon is mostly studied in conventional method of rice cultivation. There is hardly any report on Zn and Fe sequestration potential of different rice cultivars raised under system of rice intensification (SRI). This study hypothesized that the Zn and Fe sequestration potential of different rice cultivars would vary significantly between conventional and system of rice intensification (SRI) cultivation methods. Accordingly, the present investigations were conducted to analyze the interaction of Zn and Fe and their sequestration potential in diverse rice cultivars.

MATERIAL and METHODS

The study was conducted in rabi season for consecutive two years at the central research farm of the Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal located at 22° 58.154' N latitude and 88° 29.563' E longitude. The study area receives mean annual rainfall of 1,500 mm with mean annual minimum and maximum temperatures of 14.0 and 36.5°C respectively. The soil of the area is sandy loam (Typic Aeric Haplaquept) in texture (43.6% sand, 22.0% silt and 34.4% clay) and neutral to slightly alkaline in reaction (pH 7.5). The soil at the study site had medium organic carbon content (0.73%), available nitrogen (120.64 kg/ha), available phosphorus (27.18 kg/ha) and available potassium (155.45 kg/ha). The DTPA extractable available Fe (110.40 mg/kg), Mn (20.0 mg/kg) and Cu (3.50 mg/kg) were in high status but Zn (1.67 mg/kg) was medium in the experimental soil.

The experiment was conducted using strip-split statistical design with three replications in the plot sizes of 5 m × 4 m size. Five rice cultivars viz IR 64, Satabdi, MTU 1010, GB 1 and KRH 2 with wide genetic variation were raised with standard management practices under two different rice cultivation systems viz system of rice intensification (SRI) and conventional method. A general recommended dose of NPK (80:40:40 kg/ha) was applied and the plots were treated with FYM (5 tonnes/ha) and Zn (25 kg $ZnSO_4$/ha) at basal and one foliar spray (0.5% $ZnSO_4$) at maximum tillering stage to observe their influence on yield and yield attributing characters of rice as well as the changes in the content of Zn and Fe in the grain and straw. The plant to plant spacing was maintained same in the two systems of rice cultivation (25 cm x 25 cm) but the age of transplanted seedlings differed for two systems (25-day-old seedlings for conventional method and 8 to 10-day-old for SRI method).

Yield attributing characters viz plant height and panicle bearing tillers per m^2 were recorded for each cultivar. The grain and straw yields were also recorded at the harvest.

Harvested plant samples (grain and straw) were washed thoroughly with tap water followed by deionized water and then dried at 50°C until they attained a constant weight. The dried samples were dry-ashed at 550°C in a muffle furnace and dissolved in 2.0 N HCl, filtered through Whatman number 42 filter paper into 50 ml volumetric flask. After making up the volume by double distilled water, that aliquot was used for estimation of total Zn and Fe as described by Jackson (1973).

With the help of SPSS software (SPSS 14.0), all variables were statistically analyzed following methods meant for strip-split design. The variables were measured repeatedly; they were further subjected to general linear model repeated measures to compare the effects due to treatment. Their mean effects were further subjected to Post-Hoc test like CD (critical difference) tests to identify the homogenous means at 5 per cent level of significance.

RESULTS and DISCUSSION

Yield attributing characters

Plant height: Plant height of the five rice cultivar plants were measured prior to harvesting and the results (Table 1) showed that the application of zinc had significant influence on the plant height. Plant height was found more (0.67%) under conventional system than SRI irrespective of cultivars and treatments (zinc and organic matter) considered. Out of five rice cultivars, highest plant height was recorded by KRH 2 (106.44 cm and 106.13 cm) followed by GB 1 (104.13 cm and 104.31 cm) under SRI and conventional systems respectively. On an average, 2 per cent increase in plant height was observed due to the effect of organic matter under both the rice cultivation systems, whereas, 3-3.5 per cnet increase in plant height was observed due to zinc application over control, irrespective of cultivars and systems. The response of Zn on plant height was higher under conventional system (3.45%) than SRI (3.02%), irrespective of cultivars and organic treatments tested.

Number of panicle bearing tillers per square meter: The number of panicle bearing tillers was found more (3.18%) under conventional system (226.68) as compared to SRI (220.18), irrespective of cultivars and the applied treatments (zinc, organic matter) (Table 1). The higher number of panicle bearing tillers were observed in cultivar KRH 2 (235 and 236.63) followed by GB 1 (222.38 and 228.25) under SRI and conventional systems respectively. Among the five cultivars, the lowest number of panicles was recorded in the cultivar IR 64 under SRI (209.38) and conventional (220.25) systems. Results showed that application of zinc significantly increased the number of panicle bearing tillers in both the rice cultivation systems. The magnitude of increase in the panicle number due to zinc fertilization over control was 9.34 and 8.25 per cent for SRI and conventional systems respectively. On an average, 5-6 per cent increase in the number of panicles was observed under both the systems due to application of organic matter, irrespective of five rice cultivars.

The zinc fertilization increased the tiller number and plant height of rice cultivars which might be attributed to the adequate supply of zinc that contributed to accelerated enzymatic activity and auxin metabolism in plants. The results are in line with the findings of Patel (1979), Jahiruddin et al (1981) and Hazra et al (2015).

Straw and grain yield: Data given in Table 2 depict that straw yield was found more (2.53%) under conventional than SRI system, irrespective of zinc and organic treatments and cultivars. The application of zinc significantly increased the straw yield of cultivars and the magnitude of increase was 17.41 and 12.59 per cent over control under conventional and SRI

Table 1. Effect of zinc fertilization and organic matter on plant height and panicle-bearing tillers of rice cultivars under conventional and SRI cultivation systems

Cultivar	Organic matter treatment	Zn treatment					
		SRI			Conventional		
		Zn_0	Zn_1	Mean	Zn_0	Zn_1	Mean
Plant height (cm)							
Satabdi	OM_0	97.50	100.78	99.14	99.50	101.50	100.50
	OM_1	99.25	102.50	100.88	101.50	104.00	102.75
	Mean	98.38	101.64	100.01	100.50	102.75	101.63
KRH 2	OM_0	104.00	106.50	105.25	102.75	107.25	105.00
	OM_1	106.50	108.75	107.63	105.50	109.00	107.25
	Mean	105.25	107.63	106.44	104.13	108.13	106.13
GB 1	OM_0	101.50	104.50	103.00	101.50	104.50	103.00
	OM_1	104.00	106.50	105.25	103.75	107.50	105.63
	Mean	102.75	105.50	104.13	102.63	106.00	104.31
IR 64	OM_0	96.50	101.50	99.00	97.75	101.50	99.63
	OM_1	98.75	102.50	100.63	99.00	102.75	100.88
	Mean	97.63	102.00	99.81	98.38	102.13	100.25
MTU 1010	OM_0	95.75	97.75	96.75	96.50	100.50	98.50
	OM_1	99.25	102.00	100.63	99.75	103.75	101.75
	Mean	97.50	99.88	98.69	98.13	102.13	100.13
Panicle bearing tillers/m^2							
Satabdi	OM_0	197.00	219.00	208.00	206.50	225.50	216.00
	OM_1	210.50	231.50	221.00	219.00	240.50	229.75
	Mean	203.75	225.25	214.50	212.75	233.00	222.88
KRH 2	OM_0	220.00	240.00	230.00	218.00	244.00	231.00
	OM_1	231.50	248.50	240.00	231.50	253.00	242.25
	Mean	225.75	244.25	235.00	224.75	248.50	236.63
GB 1	OM_0	206.00	231.50	218.75	213.00	228.50	220.75
	OM_1	212.50	239.50	226.00	227.00	244.50	235.75
	Mean	209.25	235.50	222.38	220.00	236.50	228.25
IR 64	OM_0	193.50	213.00	203.25	208.50	220.00	214.25
	OM_1	206.00	225.00	215.50	217.50	235.00	226.25
	Mean	199.75	219.00	209.38	213.00	227.50	220.25
MTU 1010	OM_0	207.00	218.00	212.50	213.00	226.00	219.50
	OM_1	219.50	234.00	226.75	223.00	239.50	231.25
	Mean	213.25	226.00	219.63	218.00	232.75	225.38

	Plant height			Panicle bearing tillers		
	CV	CD	SED	CV	CD	SED
System	0.52	0.42	0.09	0.71	1.24	0.29
OM	1.14	0.91	0.21	0.73	1.28	0.30
Zn	2.12	1.70	0.40	2.03	3.56	0.83
Variety	1.47	1.00	0.43	1.40	2.09	0.90
System × OM × Zn × Variety	1.83	3.05	1.52	1.83	6.68	3.35

Om_0 = No organic matter, Om_1 = FYM 5 tonnes/ha, Zn_0 = No zinc, Zn_1= Zn 5 kg/ha as basal + one foliar application of 0.5% $ZnSO_4.7H_2O$ at maximum tillering stage

systems respectively, irrespective of organic treatments and cultivars. Due to zinc fertilization, increase in straw yield was found more under conventional than SRI system for all the cultivars except GB 1 (Fig 1).

Further application of organic matter significantly increased the straw yield and the magnitude of increase was 7.1 per cent over control, irrespective of cultivars, systems and zinc treatments. Among the five cultivars, the highest straw yield was recorded for KRH 2 followed by MTU 1010 irrespective of organic and zinc treatments and systems considered. It is clear that Zn fertilization along with FYM was the better option to optimize rice yield in both SRI and conventional systems.

The grain yield was found more (2.56%) under conventional system than SRI and it was 35.29 and 34.41 q per ha for conventional and SRI systems respectively, irrespective of zinc and organic treatments and cultivars considered (Table 2). The magnitude of grain yield increase due to zinc application over control was 24.76 and 23.78 per cent under SRI and conventional systems respectively, irrespective of cultivars and organic treatments. It was observed that application of organic matter increased the grain yield and such increase was 12.37 per cent over control, irrespective of systems and cultivars. All cultivars gave higher grain yield under conventional than SRI system but the case was found reverse for cultivars KRH 2 and IR 64. Among the five cultivars the highest grain yield was recorded in cultivar KRH 2 (38.91 q/ha) followed by MTU 1010 (37.48 q/ha) irrespective of systems, organic treatment and zinc treatment. Thus Zn application was very effective to increase the grain yield compared to straw yield. This may be due to enhanced activity of the mettalo-enzymes like proteinases and peptidases which accelerated physiological activities (Mudenoor 2002).

Increased grain yield upon zinc fertilization was reported by Reddy et al (2010) and Phattarakul et al (2012). Similar observations were made by Cakmak (2008) and Saha et al (2015b).

Zinc and iron content of rice grain: The zinc content in rice grain was found more (6.36%) under conventional than SRI system which was 27.94 and 26.27 mg per kg for conventional and SRI systems respectively, irrespective of treatments (zinc, organic matter) and cultivars (Table 3). The application of zinc increased the zinc content in rice grain in both the systems and the magnitude of increase was 25.32 and 22.72 per cent over control under conventional and SRI systems respectively, irrespective of cultivars and organic treatment. Results further revealed that application of organic matter showed on an average 9.55 per cent increase in zinc content in rice grain over control irrespective of systems and cultivars. All the cultivars showed higher zinc content in rice grain under conventional than SRI system. The highest zinc content in grain was recorded for Satabdi (29.25 mg/kg) followed by MTU 1010 (27.95 mg/kg), irrespective of systems and treatments (zinc, organic matter). It was also found that due to zinc fertilization, the zinc enrichment in rice grain was more in cultivar Satabdi (29.64%) followed by IR 64 (26.28%) over control under both the systems.

The zinc enrichment in rice grain might have occurred due to zinc fertilization in both the rice cultivation systems. Similar findings were reporte by Cakmak et al (2008).

The iron content in rice grain was more (5.38%) under conventional than SRI system irrespective of treatments (zinc, organic matter) and cultivars considered. The application of zinc significantly reduced the iron concentration in grains of the cultivars. The magnitude of decrease in the iron concentration due to application of zinc was 8.53 and 7.46 per cent for SRI and conventional systems respectively (Fig 2), irrespective of cultivars and organic treatment. The application of organic matter increased the iron content in grains by 7.72 and 6.33 per cent over control for SRI and conventional systems respectively, irrespective of cultivars and zinc treatment. All the cultivars showed higher iron content in grains under conventional than SRI system. The highest iron content was recorded by the cultivar Satabdi (45.53 mg/kg) followed by GB 1 (44.67 mg/kg), irrespective of systems, zinc and organic treatments.

Zinc and iron content in rice straw: Application of Zn significantly increased the zinc content of rice straw which varied from 34.88 to 37.86 mg per kg under SRI system, whereas, for conventional system it was 35.03 to 37.84 mg per kg, irrespective of cultivars and organic treatments (Table 4). The conventional system lead to more Zn content (7.72%) than SRI system, irrespective of cultivars. The magnitude of increase in zinc content due to zinc fertilization over control was 16.65 and 16.09 per cent under conventional and SRI systems respectively (Fig 2). Organic-treated plots showed

Table 2. Effect of zinc fertilization and organic matter on straw and grain yield of rice cultivars under conventional and SRI cultivation systems

Cultivar	Organic matter treatment	Zn treatment					
		SRI			Conventional		
		Zn_0	Zn_1	Mean	Zn_0	Zn_1	Mean
Straw yield (q/ha)							
Satabdi	OM_0	42.31	48.42	45.37	43.58	50.54	47.06
	OM_1	46.63	52.03	49.33	44.59	54.71	49.65
	Mean	44.47	50.23	47.35	44.08	52.63	48.35
KRH 2	OM_0	49.01	53.25	50.17	45.50	55.75	50.63
	OM_1	48.87	55.75	53.27	48.57	59.19	53.88
	Mean	48.94	54.50	51.72	47.04	57.47	52.25
GB 1	OM_0	43.50	51.67	47.59	48.00	54.20	51.10
	OM_1	47.42	55.74	51.58	52.75	55.50	54.13
	Mean	45.46	53.70	49.58	50.38	54.85	52.61
IR 64	OM_0	41.50	48.91	45.21	42.86	49.45	46.15
	OM_1	47.25	51.81	49.53	44.70	53.47	49.08
	Mean	44.38	50.36	47.37	43.78	51.46	47.62
MTU 1010	OM_0	46.00	51.47	48.73	45.93	54.39	50.16
	OM_1	51.50	54.88	53.19	48.75	58.50	53.63
	Mean	48.75	53.17	50.96	47.34	56.44	51.89
Grain yield (q/ha)							
Satabdi	OM_0	26.19	33.80	29.99	28.33	35.97	32.15
	OM_1	29.89	39.63	34.76	31.75	41.15	36.45
	Mean	28.04	36.71	32.38	30.04	38.56	34.30
KRH 2	OM_0	32.53	39.30	35.91	33.75	39.62	36.68
	OM_1	39.73	45.95	42.84	36.59	43.83	40.21
	Mean	36.13	42.62	39.37	35.17	41.72	38.45
GB 1	OM_0	26.30	35.59	30.94	30.04	39.18	34.61
	OM_1	30.25	38.50	34.38	32.98	43.50	38.24
	Mean	28.28	37.04	32.66	31.51	41.34	36.42
IR 64	OM_0	24.95	32.47	28.71	24.36	30.96	27.66
	OM_1	29.93	37.38	33.65	26.75	33.06	29.91
	Mean	27.44	34.92	31.18	25.56	32.01	28.78
MTU 1010	OM_0	31.45	38.24	34.84	33.72	39.72	36.72
	OM_1	35.00	41.12	38.06	37.12	43.45	40.28
	Mean	33.22	39.68	36.45	35.42	41.58	38.50

	Straw yield			Grain yield		
	CV	CD	SED	CV	CD	SED
System	0.89	0.35	0.08	1.83	0.50	0.12
OM	8.59	3.37	0.78	0.94	0.26	0.06
Zn	1.59	0.62	0.15	0.18	0.05	0.01
Variety	1.17	0.39	0.17	1.42	0.33	0.14
System × OM × Zn × Variety	1.90	1.55	0.78	1.97	1.12	0.56

Om_0 = No organic matter, Om_1 = FYM 5 tonnes/ha, Zn_0 = No zinc, Zn_1= Zn 5 kg/ha as basal + one foliar application of 0.5% $ZnSO_4.7H_2O$ at maximum tillering stage

Table 3. Effect of zinc fertilization and organic matter on grain zinc and iron content of rice cultivars under conventional and SRI cultivation systems

Cultivar	Organic matter treatment	Zn treatment					
		SRI			Conventional		
		Zn_0	Zn_1	Mean	Zn_0	Zn_1	Mean
Zn content (mg/kg)							
Satabdi	OM_0	24.10	29.90	27.00	25.81	31.64	28.72
	OM_1	26.91	32.14	29.52	28.27	35.24	31.75
	Mean	25.50	31.02	28.26	27.04	33.44	30.24
KRH 2	OM_0	21.01	27.82	24.41	22.54	29.69	26.11
	OM_1	24.15	30.87	27.51	24.57	32.50	28.53
	Mean	22.58	29.34	25.96	23.55	31.09	27.32
GB 1	OM_0	22.17	26.68	24.42	21.50	28.45	24.97
	OM_1	23.95	29.33	26.64	24.73	30.60	27.67
	Mean	23.06	28.00	25.53	23.12	29.52	26.32
IR 64	OM_0	21.10	26.66	23.88	22.50	28.74	25.62
	OM_1	24.11	28.01	26.06	25.35	30.10	27.73
	Mean	22.60	27.33	24.97	23.93	29.42	26.67
MTU 1010	OM_0	23.47	28.09	25.78	25.31	30.15	27.73
	OM_1	25.42	30.06	27.74	27.38	33.67	30.52
	Mean	24.44	29.08	26.76	26.34	31.91	29.13
Fe content (mg/kg)							
Satabdi	OM_0	45.74	41.29	43.51	47.67	42.84	45.25
	OM_1	47.86	43.88	45.87	48.82	46.17	47.49
	Mean	46.80	42.59	44.69	48.24	44.50	46.37
KRH 2	OM_0	36.08	34.04	35.06	37.53	35.83	36.68
	OM_1	40.85	36.39	38.62	41.26	37.11	39.18
	Mean	38.47	35.22	36.84	39.39	36.47	37.93
GB 1	OM_0	42.64	38.46	40.55	46.88	42.16	44.52
	OM_1	48.39	42.71	45.55	50.18	45.89	48.03
	Mean	45.51	40.58	43.05	48.53	44.03	46.28
IR 64	OM_0	36.29	33.74	35.02	38.01	35.19	36.60
	OM_1	37.59	35.44	36.51	39.59	37.66	38.62
	Mean	36.94	34.59	35.76	38.80	36.43	37.61
MTU 1010	OM_0	42.11	39.70	40.90	44.82	42.92	43.87
	OM_1	45.68	41.44	43.56	48.73	44.62	46.67
	Mean	43.89	40.57	42.23	46.78	43.77	45.27

	Zn content			Iron content		
	CV	CD	SED	CV	CD	SED
System	0.97	0.21	0.05	1.01	0.33	0.08
OM	1.54	0.33	0.08	0.83	0.27	0.06
Zn	2.27	0.48	0.11	2.16	0.71	0.16
Variety	1.46	0.26	0.11	1.89	0.53	0.23
System × OM × Zn × Variety	1.87	0.83	0.41	1.82	1.24	0.62

Om_0 = No organic matter, Om_1 = FYM 5 tonnes/ha, Zn_0 = No zinc, Zn_1= Zn 5 kg/ha as basal + one foliar application of 0.5% $ZnSO_4.7H_2O$ at maximum tillering stage

higher zinc content in rice straw over control and the increment was 9.40 and 9.10 per cent under SRI and conventional systems respectively, irrespective of cultivars and zinc treatment. The straw of all the cultivars had more zinc under conventional than SRI system. Out of five rice cultivars, the highest Zn content in rice straw was recorded in Satabdi (40.49 mg/kg) followed by MTU 1010 (37.49 mg/kg), irrespective of systems and treatments (zinc, organic matter).

The iron content was found more (4.65%) under conventional than SRI system, irrespective of cultivars and other treatments (zinc, organic matter). It was found that application of Zn generally decreased the iron content in rice straw. The magnitude of such decrease was more in conventional as compared to SRI system (Fig 2) which was 9.01 and 8.31 per cent over control for conventional and SRI systems respectively. Application of organic matter increased the iron content in rice straw and that increase was 5.38 and 4.95 per cent under SRI and conventional systems respectively irrespective of cultivars.

All cultivars showed higher iron content straw under conventional than SRI system. Among five rice cultivars, highest iron content was recorded for MTU 1010 (124.25 mg/kg) followed by KRH 2 (120.58 mg/kg) irrespective of systems. Due to zinc fertilization, the magnitude of decrease in iron content was more in MTU 1010 (11.73%) followed by GB 1 (9.32%), irrespective of systems and organic treatment.

Results showed that all the tested cultivars of rice could accumulate more Zn in their grain under the conventional as compared to the SRI system. Alternate wetting-drying method prevails in the SRI method of rice cultivation. Such condition alters Zn adsorption-desorption kinetics in soil (Hazra et al 1987, Mandal et al 1988) and fixation of Zn on various insoluble Fe and Mn oxides (Abdullah 2015) leaving a meagre amount of Zn for root absorption.

Yang et al (2009) and Rehman et al (2012) observed a significant reduction in Zn availability in such fluctuated moisture regimes generated from alternate wetting-drying method especially after application of organic matter. In paddy soils, nicotianamine (NA) loses an amino group mediated by NA amino transferase and forming 33 -keto intermediate which reacts with mugineic acid and loses another amino group, producing DMA. The DMA is then released into the rhizosphere by mugineic acid phytosiderophores (MAs) which binds to Zn and forms Zn-MAs complexes (Guerinot 2000).

These complexes are then absorbed through yellow stripe 1-like transporter protein (Clemens 2001, Ishimaru et al 2010). Under flooded conditions, higher expressions of DMA related genes have been found in rice leaves than roots, hence Zn-DMA biosynthesis and transport is likely to be influenced by transpiration fluxes (Curie et al 2009, Fujimaki et al 2010, Ramesh et al 2003). The alternate wetting-drying condition reduces transpiration rates due to arable moisture regimes and thus restricts the mass flow leading to lower Zn transport into the developing grains (Jung and Thornton 1997).

Zn fertilization significantly increased Zn loading in the rice grain and straw of all the tested cultivars under both the cultivation systems viz SRI and conventional. Zinc loading in rice grains was further improved by the addition of organic matter in the form of FYM. Application of Zn through foliar is capable to accelerate the re-translocation of Zn from leaves to the developing grains after leaf senescence (Saha et al 2017b).

These results are corroborated with the findings of previous workers on Zn biofortification in cereals (Giordano and Mortvedt 1972, Cakmak 2008, Cakmak et al 2010, Saha et al 2015a, 2015b, 2017a, 2017b).

Such Zn fertilization showed a significant depletion in Fe in the grain and straw of all the rice cultivars under both the cultivation systems. This can be attributed to a known competition between Zn and Fe for absorption by roots in soils (Dutta et al 1989), loading into the xylem (Alloway 2008), chelation for translocation (Kabata-Pendias 2001) and cross membrane transport by particular carrier proteins (ZIP family proteins) (Palmgren et al 2008). Zinc and Fe translocation in plants is facilitated by substrate-specific transporters (Ricachenevsky et al 2015); a limited expression of such transporters in the vegetative stage may create an acute competition between these two elements for an efficient xylem translocation in rice.

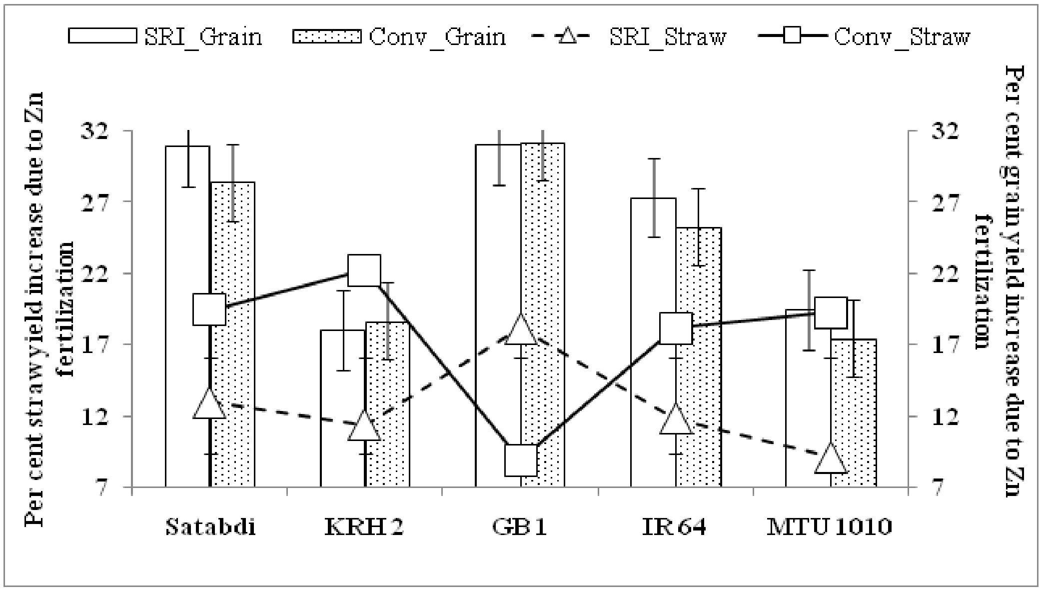

Fig 1. Effect of zinc application increase in rice yield over control

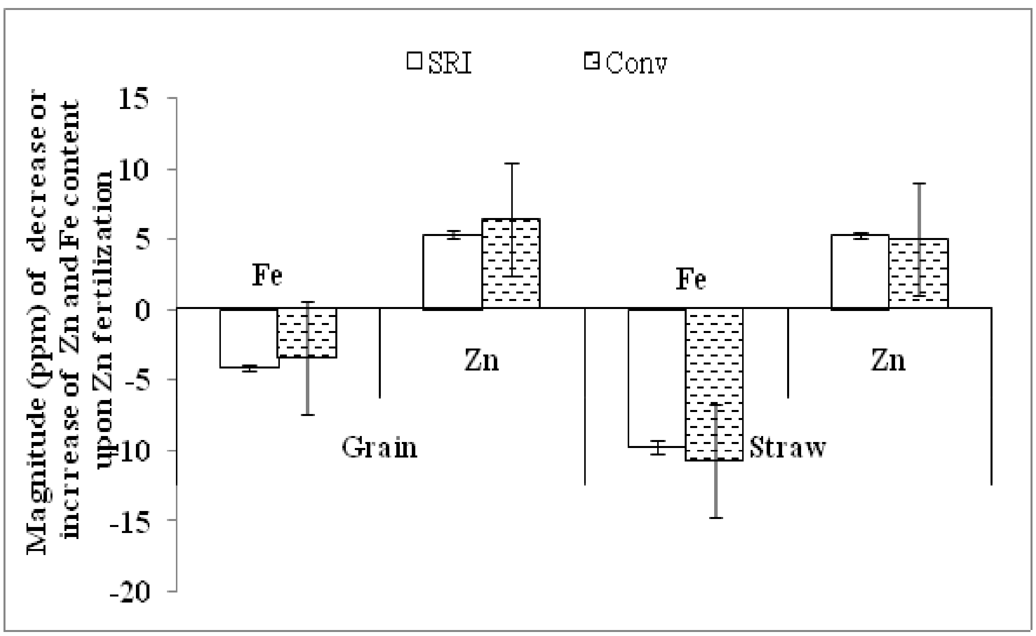

Fig 2. Magnitude of increase or decrease in Zn and Fe content (ppm) due to zinc fertilization under SRI and conventional system

CONCLUSION

This two-year study in West Bengal investigated how conventional vs system of rice intensification (SRI) cultivation and zinc (Zn) fertilization influenced rice yield, growth and the uptake of Zn and iron (Fe) in five rice cultivars. It was found that conventional system generally led to higher yields and greater Zn/Fe content than SRI, possibly due to SRI's alternate wetting-drying conditions limiting Zn transport. Crucially, Zn fertilization significantly boosted yield and grain Zn concentration, with organic matter further enhancing this effect, affirming its role in improving rice productivity and nutritional value. However, a significant finding was Zn's antagonistic effect, which substantially reduced Fe content in both grain and straw across all systems and cultivars. This antagonism suggests competition between Zn and Fe during plant uptake and transport. In short, while Zn fertilization is excellent for yield and Zn biofortification, its Fe-depleting effect requires careful consideration. Future efforts should focus on strategies and cultivars that can efficiently accumulate both Zn and Fe to combat widespread micronutrient deficiencies.

Table 4. Effect of zinc fertilization and organic matter on straw zinc and iron content of rice cultivars under conventional and SRI cultivation systems

Cultivar	Organic matter treatment	Zn treatment					
		SRI			Conventional		
		Zn_0	Zn_1	Mean	Zn_0	Zn_1	Mean
Zn content (mg/kg)							
Satabdi	OM_0	35.71	41.73	37.51	35.03	41.30	39.91
	OM_1	38.95	45.43	41.09	39.76	44.89	43.45
	Mean	37.33	43.58	39.30	37.40	43.09	41.68
KRH 2	OM_0	27.65	33.64	30.55	28.62	34.24	31.26
	OM_1	31.70	34.73	33.38	32.35	34.90	34.17
	Mean	29.67	34.18	31.96	30.49	34.57	32.72
GB 1	OM_0	26.63	30.00	26.77	25.31	29.82	30.00
	OM_1	27.91	34.50	29.49	27.44	33.94	33.14
	Mean	27.27	32.25	28.13	26.37	31.88	31.57
IR 64	OM_0	25.17	30.25	27.07	25.48	30.35	29.64
	OM_1	27.76	33.14	29.95	28.49	33.98	33.15
	Mean	26.47	31.69	28.51	26.99	32.17	31.40
MTU 1010	OM_0	35.22	38.81	34.54	33.75	39.44	37.96
	OM_1	36.65	41.50	37.26	36.13	41.50	40.18
	Mean	35.93	40.15	35.90	34.94	40.47	39.07
Fe content (mg/kg)							
Satabdi	OM_0	111.63	102.39	107.01	119.38	108.10	113.74
	OM_1	117.10	106.85	111.97	126.25	118.14	122.20
	Mean	114.36	104.62	109.49	122.82	113.12	117.97
KRH 2	OM_0	119.82	113.05	116.44	124.17	118.41	121.29
	OM_1	125.18	117.99	121.58	128.10	117.89	122.99
	Mean	122.50	115.52	119.01	126.13	118.15	122.14
GB 1	OM_0	109.47	97.40	103.43	116.30	104.09	110.19
	OM_1	116.06	107.15	111.61	122.12	112.07	117.09
	Mean	112.76	102.28	107.52	119.21	108.08	113.64
IR 64	OM_0	103.08	95.41	99.24	108.93	99.69	104.31
	OM_1	109.08	100.60	104.84	114.58	106.02	110.30
	Mean	106.08	98.00	102.04	111.75	102.85	107.30
MTU 1010	OM_0	126.21	113.66	119.93	132.39	113.95	123.17
	OM_1	132.52	118.37	125.44	136.92	119.99	128.46
	Mean	129.36	116.01	122.69	134.66	116.97	125.81

	Zn content			Iron content		
	CV	CD	SED	CV	CD	SED
System	1.22	0.33	0.08	0.74	0.67	0.16
OM	1.37	0.37	0.09	0.72	0.65	0.15
Zn	0.64	0.17	0.04	2.03	1.83	0.43
Variety	0.94	0.21	0.09	1.88	1.43	0.62
System × OM × Zn × Variety	2.05	1.14	0.57	1.81	3.38	1.69

Om_0 = No organic matter, Om_1 = FYM 5 tonnes/ha, Zn_0 = No zinc, Zn_1 = Zn 5 kg/ha as basal + one foliar application of 0.5% $ZnSO_4.7H_2O$ at maximum tillering stage

Table 5. Analysis of variance (ANOVA) of the results obtained from the experiment

Component	Plant height	Panicle bearing tillers/m^2	Grain yield	Straw yield	Grain Zn	Straw Zn	Grain Fe	Straw Fe
System	*	**	*	**	**	**	**	**
Zn	**	**	**	*	**	**	**	**
OM	**	**	**	**	**	**	**	**
Variety	**	**	**	**	**	**	**	**
System x Zn	NS	NS	**	*	NS	NS	NS	NS
System x OM	NS	NS	NS	**	**	NS	NS	NS
System x Variety	NS	**	**	**	**	**	**	**
Zn x OM	NS	NS	*	**	NS	NS	NS	NS
Zn x Variety	NS	NS	**	NS	NS	NS	**	*
OM x Variety	NS	**	**	*	**	**	**	**
System x Zn x OM	NS	NS	*	NS	NS	*	NS	NS
System x Zn x Variety	NS	NS	**	NS	NS	NS	NS	NS
System x OM x Variety	NS	*	NS	**	NS	NS	NS	NS
Zn x OM x Variety	NS	NS	NS	**	**	*	**	NS
System x Zn x OM x Variety	NS	NS	NS	**	*	NS	NS	NS

NS = Non-significant, * = Significant at $P < 0.05$, ** = Significant at $P < 0.01$

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