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BK Farkade
Ph.D., Student and Assistant Professor, Department of Agronomy, Oilseeds Research Unit, Dr. PDKV, Akola, Maharashtra, India

Dr. VM Bhale
Hon'ble Vice-chancellor, Dr. PDKV, Akola, Maharashtra, India

Dr. VK Kharche
Director of Research, Dr. PDKV, Akola, Maharashtra, India

Dr. BV Saoji
Associate Dean, LAE and Professor of Agronomy Dr. PDKV, Akola, Maharashtra, India

Dr. M.R Deshmukh
Assistant Professor, Department of Agronomy, Dr. PDKV, Akola, Maharashtra, India

Corresponding Author:
BK Farkade
Ph.D., Student and Assistant Professor, Department of Agronomy, Oilseeds Research Unit, Dr. PDKV, Akola, Maharashtra, India

Influence of iron and manganese biofortification on growth, yield and development stages of upland irrigated rice cultivars

BK Farkade, VM Bhale, VK Kharche and MR Deshmukh

Abstract
A field experiment was undertaken at Department of Agronomy, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India to study the influence of iron and manganese biofortification on growth, yield and development stages of upland irrigated rice cultivars during *Kharif* 2017 and 2018. The experiment was laid out in factorial randomized block design (FRBD) with three replications. The testing variables consisted of three cultivars i.e. Kamesh (CR Dhan-40), Avishkar (PBNR 93-1) and Sindewahi-1 (Sye-1) and seven combinations of nutrient sources of recommended dose of fertilizers (NPK) with Fe and Mn levels. Two years a result reveals that, significantly highest plant height was recorded in variety Kamesh (78.77cm). Significantly highest no. of tillers and dry matter accumulation were recorded by variety Parbhani Avishkar. However, highest no. of functional leaves was recorded by genotype Sindewahi-1 at Akola condition. The significantly highest plant height, no. of tillers, no. of functional leaves, dry matter and yield were recorded by nutrients treatment of RDF with $FeSO_4$ @ 25 Kg ha^{-1} and $MnSO_4$ @ 5 Kg ha^{-1}. The maximum grain yield and straw yield were recorded by variety Avishkar and found significantly superior over other varieties. The development stages show little more variation. This variation in attaining phenotypic stages might be due to genetic makeup of cultivars. Response to growth Fe and Mn in growth and nutrition of the rice plant has been reported (Chiu, 1967, Alam 1982). Fe and Mn were essential for better plant growth and efficient utilization of these nutrients by rice plants.

Keywords: Biofortification, RDF, Fe and Mn, $FeSO_4$, $MnSO_4$, growth, yield and development

Introduction
Manganese (Mn) and Iron (Fe) are essential micronutrients for almost all living organisms including plants. Iron and manganese are needed for chlorophyll synthesis, numerous enzymes in plant system (Evans and Sorger, 1966) [5]. Karim and Alam (1967) [7] have reported that, the combine role of Fe and Mn is much more important than their individual role in nutrition of rice plant. Activities of micronutrients are essential mineral elements required for both plant and human development. However, micronutrients are often lacking in soils, crop, and food. Rice however is a poor source of many essential minerals nutrients, especially iron (Fe) and manganese (Mn). For human nutrition Fe help in production of hemoglobin in human blood, which carries oxygen around the body; moreover the immune system to needs Fe to work well. Manganese nutrition is crucial for human health as well. The deficiency of Mn has rarely been observed in flooded rice; nonetheless, it has been reported in direct seeded aerobic rice (DSAR) systems (Snyder *et al*. 1990) [13], owing to oxidation of $Mn^{2+,}$ which results in precipitation of the oxides of Mn^{3+} and Mn^{4+} which are unavailable to plants (Tao *et al.* 2006) [14], especially under high soil pH conditions. Manganese (Mn) and Iron (Fe) are essential micronutrients for almost all living organisms including plants. On flooding, the concentrations of Fe, Mn, Cu, Mg, P and total soluble salts in soil solution were reported to increase. (Ansari *et al*., 1994, Ponnamperuma 1972, Seng *et al*., 1999) [2, 8, 10].

Considering the labour crises and soil strata in Vidarbha region of Maharashtra, having *montmorillonite* mineralogy with swelling and shrinkage properties, direct seeded rice planting is advocated. High alkalinity and calcium may cause low availability and uptake of Fe and Mn element. Therefore, it becomes essential to undertake an investigation on agronomic biofortification of rice with Fe and Mn as vital elements and to undertakes study to test its content and availability in both i.e. in plant and in soil so as to provide a new to grow fortified rice cultivars in clayey soil of this region under aerobic (upland) condition in drilled method of sowing. Iron fortification has been used to enhance iron intake in many developed countries for more than 50 years, but only in the last decade has this strategy been applied on a large scale to other parts of the world. Fortifying Fe in food has been suggested as a mean to improve Fe level in food products and human diets. Iron deficiency is a widespread nutrition and health problem in developing countries, causing impairments in physical activity and cognitive development, as well as maternal mortality. The existence of a negative relationship between irrigation and iron (Scagel *et al.*, 2012) [8] and similar negative relationship between phosphorus and iron also lead to lower the accumulation of these micronutrients in cereal grains.

Upland rice is grown in *rainfed* fields prepared and seeded when dry, much like wheat or maize. Being a new crop for the *rainfed* region in untraditional area, technological aspect for cultivation knowhow has been lacking. The growth and development of rice crop are often subjected to suffer from moisture and nutrient stress, more particularly micronutrients deficiency, in addition to the deficiency of essential nutrient elements. The amount of nutrients can be intensified in to these crops are generally much lower than can be provided through post production fortification and food supplementation. The main hypothesis behind the study is to give an alternate crop which has high yield potential with nutritive value and to replace the existing *rainfed* cropping system. Fe and Mn being deficit in upland system, if applied in sufficient quantity through agronomic fortification, it will become nutritive and mobilize other nutrients in plant system, thereby improving the quantity and quality of crop produce and subsequently help to eliminate the Iron and Manganese malnutrition problem. This investigation was undertaken to study the influence of iron and manganese biofortification on growth, yield and development stages of upland irrigated rice cultivars.

Methodology

Experimental site and soil

A field experiment was carried out at Agronomy Farm, Department of Agronomy, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during *kharif season* of 2017-18 and 2018-19 in neutral to slightly alkaline clayey soil (pH 7.81, Ec 0.37 dSm^{-1}), medium in organic matter (0.51%), low in available nitrogen, phosphorus, Fe and Mn (209.5, 16.4 kg ha^{-1} and 4.06, 8.46 mg Kg^{-1}). Akola is situated in subtropical region between 22.42^{o}N latitude and 77.02^o E longitude at an altitude of 307.42 m above the mean sea level. The climate of Akola is semi-arid and characterized by three distinct seasons i.e. hot and dry summer from March to May, warm humid and rainy monsoon from June to October and mild cold winter from November to February.

Table 1: Physical and chemical properties of soil

Characteristics	
Sand (%)	19.84
Silt (%)	28.89
Clay (%)	51.27
Textural class	Clayey
pH (1:2.5)	7.81
EC (dsm^{-1}) (1:2.5)	0.37
Organic carbon (%)	0.51
Available N. (Kg ha^{-1})	209.50
Available P (Kg ha^{-1})	16.40
Available K Kg ha^{-1})	345.10
Available Fe (mg Kg^{-1})	4.06
Available Mn (mg Kg^{-1})	8.46

Experimental design and treatments

The experiment was laid out in factorial randomized block design (FRBD) replicated trice times.

The testing variables consisted of three varieties i.e. Kamesh (CR Dhan 40), Avishkar (PBNR-93-1) and Sindewahi-1 (Sye-1) and seven combinations of nutrient sources of recommended dose of fertilizers (NPK) with Fe and Mn levels. Planting carried out by DSAR method with 30 cm spacing in between two rows. The plot size was 3.6 x 4.0 m. The irrigation provided by check basin with control irrigation.

Treatments Details

Varieties (V)

V_1 - Kamesh (CR Dhan 40)
V_2 - Avishkar (PBNR-93-1)
V_3 - Sindewahi-1 (Sye-1)

Micronutrients (N)

N_1 - RDF (100:50:50) NPK kg ha^{-1}
N_2 - RDF + $FeSO_4$ @ 25 Kg ha^{-1}
N_3 - RDF + $MnSO_4$ @ 5 Kg ha^{-1}
N_4 - RDF + Foliar spray of $FeSO_4$ @1.0% at flowering and dough stage
N_5 - RDF + Foliar spray of $MnSO_4$ @ 0.5% at flowering and dough stage
N_6 - RDF + Foliar spray of $FeSO_4$ @ 1.0% and $MnSO_4$ @. 5% at flowering and dough stage
N_7 - RDF + $FeSO_4$ @ 25 Kg $ha^{-1}$and RDF + $MnSO_4$ @ 5 Kg ha^{-1} (Soil application)

Plant observation & Fertilizer management

Five plants were selected randomly and tagged in each treatment at plot for recording non-destructive sampling parameters like plant height, no. of tillers per plant, leaf area, dry matter per plant etc. The doses of nutrients applied to rice were 100:50:50 kg N, P_2O_5 and K_2O kg ha^{-1}. Half dose of nitrogen and full dose of phosphorus, potassium, ferrous and manganese were applied during sowing as basal and remaining half dose of nitrogen was applied at 30 DAS. Also the foliar spray of $FeSO_4$ @ 1.0% and $MnSO_4$ @ 0.5% was sprayed at flowering and dough stage.

Observation recorded

Different growth, yield and development stages and root studies were recorded and statistical analysis of variance (ANOVA)

Statistical analysis

The data recorded for different parameters were analyzed by analysis of variance (ANOVA). The results are presented at 5% level of significance.

Results and Discussion

The genotype 'Kamesh' found superior in respect of plant height in both the years of study and in pooled also. The significantly highest no. of tillers and dry matter per plant were recorded in Variety 'Avishkar'. However, highest no. of functional leaves was recorded by genotype Sindewahi-1. This was due to the genotypic variation of varieties. The significantly highest plant height, no. of tillers, functional leaves and dry matter $plant^{-1}$ were recorded by nutrient treatment N_7 i.e. RDF with $FeSO_4$ @ 25kg ha^{-1} and $MnSO_4$ @5 kg ha^{-1} which was found numerically at par with treatment N_2 in respect of no. of tillers per plant. The interaction effect was found non-significant in respect of growth parameters (Table-2).

The grain yield and straw yield of individual year and pooled are presented in Table-3, the results revealed that, the significantly highest pooled grain yield (3371 kg ha^{-1}) and straw yield (6952 kg ha^{-1}) were recorded by variety Avishkar during two years of experimentation. However, variety Kamesh (CR Dhan-40) was found at par with Sye-1 during 2018 in respect of grain yield and straw yield. However, grain and straw yield were significantly influenced due to combine use of RDF with $FeSO_4$ @ 25 kg ha^{-1} + $MnSO_4$ @ 5kh ha^{-1}. The application of RDF with $FeSO_4$ and $MnSO_4$ recorded significantly higher grain yield (3175 kg ha-^{1}) of rice and found at par with alone application of $FeSO_4$ (25 kg ha^{-1}). The same trend was found in respect of straw yield. The interaction effect was found non-significant. The application of Fe might have increased the vigor, photosynthates accumulation and better translocation of photosynthates to the sink (Kanda and Dixit, 1995) [6]. Singh, Raha and Yadav (2005) [12] found that the application of both sulfur and Mn significantly enhanced the bran content and yield of rice over the control. The beneficial effect of micronutrients combination Fe and Mn could be attributed to the synergistic effect between these nutrient in a balanced proportion, which lead to higher nutrient uptake (Shanmugam and Veeraputhran 2000) [11]. These results are substantiated by the findings of the study Ashok Kumar *et al*., (2017) [3], he reported that zinc @ 10 kg ha^{-1}, iron 15 kg ha^{-1} and manganese 5 kg ha^{-1} recorded the maximum yield of rice. Iron and manganese are needed for chlorophyll synthesis and activities of numerous enzymes in plant system (Evans and Sorger, 1966) [5].

The variety Kamesh (CR Dhan 40) showed earlier panicle initiation (34 and 35 DAS), 50% heading (52 and 54 DAS), 50% flowering (69 and 68 DAS) and grain maturation (88 and 93 DAS) during both consecutive year of experimentation. However, Avishkar showed little late panicle initiation (36 and 40 DAS), 50% heading (62 and 64 DAS), 50% flowering (73 and 74 DAS) and grain maturation (95 and 97 DAS) at 2017-18 and 2018-19. The variety Sindewahi-1 recorded late performance in upland condition than other two varieties and showed little late panicle initiation (40 and 43 DAS), 50% heading (65 and 67 DAS), 50% flowering (81 and 83 DAS) and late grain maturation (105 and 107 DAS) during 2017-18 and 2018-19. This variation in attaining phenotypic stages might be due to genetic makeup of cultivars. These variations in crop growth period among different cultivars in upland situation are also reported by Kadam *et al*. (2018).

There was no significant difference found on the panicle initiation due to application of micronutrients along with RDF at various levels during both years of experimentation. However, 50% heading and 50% flowering shows early effect of 1 to 2 days from DAS. The application of NPK fertilizer had no significant effects on duration of rice flowering. However combine application of RDF + $FeSO_4$ @ 25 Kg ha^{-1} and $MnSO_4$ @ 5 Kg ha^{-1} (N_7) had recorded delay effect on 50% flowering and grain maturation during 2017-18 and foliar application of micronutrients Fe 1% and Mn 0.5% at flowering and dough stage recorded no significant effect on flowering and grain maturation. The results are in line with the findings of Tinghong Ye *et al*, 2019 [15].

Table 2: Growth characters at harvest as influenced by different treatments during 2017-18 to 2019-20 and pooled.

Treatments	Plant Height (cm)			No. of tillers plant^{-1}			No. of functional leaves plant^{-1}			Dry matter accumulation at harvest (g plant^{-1})		
	2017	2018	Avg.	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
A) Varieties (V)												
V_1 - Kamesh (CR Dhan 40)	64.08	87.96	78.77	5.79	6.45	5.91	15.32	14.09	14.54	13.47	15.90	14.69
V_2 - Parbhani Avishkar	53.11	84.67	70.14	6.84	7.08	6.93	15.79	14.44	15.06	14.73	23.87	19.30
V_3 - Sindewahi-1 (Sye-1)	33.25	53.07	45.56	6.41	7.06	6.66	18.57	15.82	17.40	13.48	15.06	14.27
SE (m) ±	0.39	0.68	0.41	0.10	0.11	0.07	0.40	0.26	0.23	0.12	0.12	0.11
CD (P=0.05)	1.12	1.95	1.16	0.28	0.32	0.21	1.15	0.75	0.66	0.35	0.33	0.33
B) Nutrients (N)												
N_1 - RDF (100:50:50) NPK Kg ha^{-1}	47.92	72.62	62.31	5.38	6.30	5.90	14.78	13.12	13.78	12.35	17.01	14.68
N_2 - RDF + $FeSO_4$ @ 25 Kg ha^{-1}	50.89	75.54	65.55	6.82	7.29	6.94	17.44	15.01	16.30	14.92	19.24	17.08
N_3 - RDF + $MnSO_4$ @ 5 Kg ha^{-1}	49.78	74.69	64.16	6.63	7.06	6.62	16.33	14.10	15.10	14.35	18.55	16.45
N_4 - RDF + Foliar spray of $FeSO_4$ @1.0% at flowering and dough stage	49.57	74.49	63.90	6.17	6.44	6.20	16.13	14.84	15.49	13.38	17.78	15.58
N_5 - RDF + Foliar spray of $MnSO_4$ @ 0.5% at flowering and dough stage	48.87	75.77	64.41	5.89	6.43	6.05	16.69	14.84	15.87	13.34	17.03	15.19
N_6 - RDF + Foliar spray of $FeSO_4$ @ 1.0% and $MnSO_4$ @ 0.5% at flowering and dough stage	50.78	75.60	65.49	6.30	6.89	6.47	16.07	14.82	15.64	13.55	18.46	16.01
N_7 - RDF + $FeSO_4$ @ 25 Kg ha^{-1} and $MnSO_4$ @ 5 Kg ha^{-1} (Soil application)	53.21	77.91	67.94	7.22	7.62	7.31	18.49	16.73	17.49	15.45	19.86	17.66
SE (m) ±	0.60	1.04	0.62	0.15	0.17	0.11	0.61	0.40	0.35	0.19	0.18	0.15
CD (P=0.05)	1.71	2.98	1.77	0.42	0.50	0.32	1.75	1.15	1.00	0.54	0.51	044
C) Interaction Vx N												
SE (m) ±	1.04	1.80	1.07	0.26	0.30	0.19	1.06	0.69	0.61	0.33	0.31	0.27
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.88	0.76
General Mean	50.15	75.23	64.82	6.34	6.86	6.50	16.56	14.78	15.67	13.89	18.28	16.09

Table 3: Grain yield (kg ha^{-1}) and straw yield (kg ha^{-1}) of upland irrigated rice as influenced by different treatments during 2017-18 and 2018-19

Treatments	Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})		
A) Varieties (V)	**17-18**	**18-19**	**Pooled**	**17-18**	**18-19**	**Pooled**
V_1 - Kamesh (CR Dhan 40)	2256	2872	2564	3941	4894	4382
V_2 - Avishkar (PBNR 93-1)	3223	3520	3371	6858	7037	6952
V_3 - Sindewahi-1 (Sye-1)	1736	2640	2188	3069	4933	3875
SE (m) ±	99	131	82	228	216	177
CD (P=0.05)	282	375	233	653	619	506
B) Nutrients (N)						
N_1 - RDF (100:50:50) NPK kg ha^{-1}	1925	2438	2181	3599	4533	4066
N_2 - RDF + $FeSO_4$ @ 25 Kg ha^{-1}	2607	3381	2994	5435	6413	5710
N_3 - RDF + $MnSO_4$ @ 5 Kg ha^{-1}	2558	3078	2818	4674	5754	5199
N_4 - RDF + Foliar spray of $FeSO_4$ @1.0% at flowering and dough stage	2284	2921	2602	4201	5233	4708
N_5 - RDF + Foliar spray of $MnSO_4$ @ 0.5% at flowering and dough stage	2093	2793	2443	3993	5196	4627
N_6 - RDF + Foliar spray of $FeSO_4$ @ 1.0% and $MnSO_4$ @ 0.5% at flowering and dough stage	2488	2993	2740	4518	5547	4864
N_7 - RDF + $FeSO_4$ @ 25 Kg ha-1and $MnSO_4$ @ 5 Kg ha-1 (Soil application)	2880	3469	3175	5941	6680	6311
SE (m) ±	150	200	125	349	331	271
CD (P=0.05)	430	573	356	997	946	774
C) Interactions (V x N)						
SE (m) ±	261	347	216	604	573	469
CD (P=0.05)	NS	NS	NS	NS	NS	NS
General Mean	2405	3010	2708	4422	5620	5069

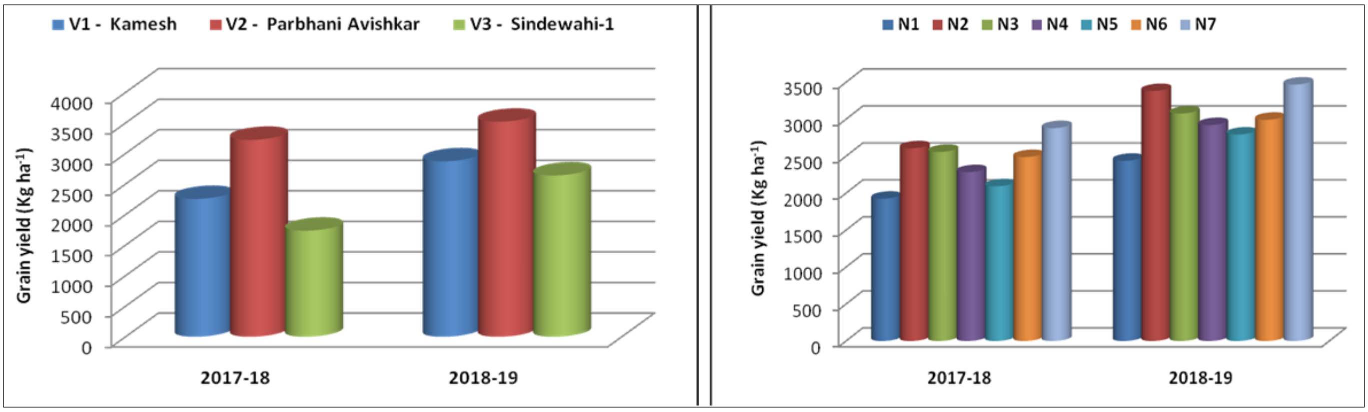

Fig 1: Grain yield (kg ha-^{1}) of upland irrigated rice cultivars as influenced by different treatments during 2017-18 and 2018-19

Fig 2: General view of Trial

Table 4: Development stages of upland irrigated rice cultivars as influence by different treatments during 2017-18 and 2018-19

Treatments	2017-18				2018-19			
	Days				Days			
	Panicle initiation	**50% heading**	**50% flowering**	**Grain maturation**	**Panicle initiation**	**50% heading**	**50% flowering**	**Grain maturation**
A) Varieties (V)								
V_1 - Kamesh (CR Dhan 40)	34	52	69	88	35	54	68	93
V_2 - Avishkar (PBNR 93-1)	36	62	73	95	40	64	74	97
V_3 - Sindewahi-1 (Sye-1)	40	65	81	105	43	67	83	107
B) Nutrients (N)								

N_1 - RDF (100:50:50) NPK kg ha^{-1}	37	59	74	95	39	61	74	99
N_2 - RDF + $FeSO_4$ @ 25 Kg ha^{-1}	36	60	74	96	39	62	76	100
N_3 - RDF + $MnSO_4$ @ 5 Kg ha^{-1}	36	59	75	96	39	62	74	99
N_4 - RDF + Foliar spray of $FeSO_4$ @1.0% at flowering and dough stage	36	60	74	96	39	62	75	99
N_5 - RDF + Foliar spray of $MnSO_4$ @ 0.5% at flowering and dough stage	36	60	74	96	39	61	74	99
N_6 - RDF + Foliar spray of $FeSO_4$ @ 1.0% and $MnSO_4$ @ 0.5% at flowering and dough stage	36	60	75	97	39	62	74	99
N_7 - RDF + $FeSO_4$ @ 25 Kg $ha^{-1}$and $MnSO_4$ @ 5 Kg ha^{-1} (Soil application)	36	61	75	97	40	63	76	100
General Mean	37	60	74	96	39	62	75	99

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