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Effect of zn and fe biofortification on growth, yield and economics of sorghum (*Sorghum Bicolor* L)

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Abstract

The present investigation, entitled “Effect of Zn and Fe Biofortification on Growth, Yield and Economics of Sorghum (*Sorghum bicolor* L.)”, was conducted during the *kharif* season of 2025 at the Crop Research Centre, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, Uttar Pradesh. The experiment was laid out in a Randomized Block Design with ten treatments replicated thrice, viz., T1: Absolute control, T2: 100% RDF (90:45:45 kg NPK ha⁻¹), T3: RDF + ZnSO₄ 25 kg ha⁻¹ soil application, T4: RDF + FeSO₄ 25 kg ha⁻¹ soil application, T5: RDF + 0.5% ZnSO₄ foliar spray at 25 and 45 DAS, T6: RDF + 0.5% FeSO₄ foliar spray at 25 and 45 DAS, T7: RDF + 0.5% ZnSO₄ and 0.5% FeSO₄ foliar spray at 25 and 45 DAS, T8: 75% RDF + foliar spray of liquid NPK (0.3%) + 0.5% ZnSO₄ foliar spray at 25 and 45 DAS, T9: 75% RDF + foliar spray of liquid NPK (0.3%) + 0.5% FeSO₄ foliar spray at 25 and 45 DAS, and T10: 75% RDF + foliar spray of liquid NPK (0.3%) + foliar spray of 0.5% ZnSO₄ and 0.5% FeSO₄ at 25 and 45 DAS. Among all the maximum maximum values of yield attributes viz. number of earhead m⁻² (24.33), earhead length (23.56 cm), number of grains per earhead (2345) and test weight (34.57 g) was recorded with the application of (T10) 75% RDF + foliar spray of liquid NPK (0.3%) + foliar spray of 0.5% ZnSO₄ and 0.5% FeSO₄ at 25 and 45 DAS which remained statistically at par with (T7) RDF + 0.5% ZnSO₄ and 0.5% FeSO₄ foliar spray at 25 and 45 DAS but significantly higher than rest of the treatments. Similarly, maximum grains yield 38.93(q ha⁻¹) & straw yield (125.1 q ha⁻¹), and Zn content in grain (47.83 ppm) and Fe content in grain (76.12 ppm) was noticed with the application of (T10) 75% RDF + foliar spray of liquid NPK (0.3%) + foliar spray of 0.5% ZnSO₄ and 0.5% FeSO₄ at 25 and 45 DAS which remained statistically at par with (T7) RDF + 0.5% ZnSO₄ and 0.5% FeSO₄ foliar spray at 25 and 45 DAS. Thus, it may be concluded that the application of 75% RDF + foliar spray of liquid NPK (0.3%) + foliar spray of 0.5% ZnSO₄ and 0.5% FeSO₄ at 25 and 45 DAS seems best combination for achieving higher yield & Zn and Fe content in grain and straw.

Keywords: Biofortification, Zn and Fe content, earhead length, no. of grain per earhead and liquid NPK

Introduction

Sorghum (*Sorghum bicolor* L.), a member of the family Poaceae, is one of the most versatile and resilient cereal crops cultivated across the semi-arid and arid tracts of the world. Sorghum is also known as the “king of millets” and the “camel crop” on account of its drought tolerance. World sorghum output was placed at about 52.8 million tonnes during 2024-25, with the United States (14%), Nigeria (11%), Brazil (8%) and India (8%) together accounting for more than 40% of global production (CARP, 2024). In India, sorghum is cultivated on about 4.6 million hectares with a production of 4.8 million tonnes at a productivity of 1.1 tonnes/hectare (DES, MoA&FW, 2023), although India remains among the leading sorghum-growing countries, the area under the crop has been shrinking steadily over the past six decades in favour of more remunerative crops, even as productivity has improved through varietal and management interventions (Choi and Eltahir, 2023 and CARP, 2024).

Micronutrient malnutrition, often described as ‘hidden hunger’, remains one of the most pervasive yet under-addressed public health challenges of the present century. The World Health Organization has long recognised inadequate levels of Zn, Fe and vitamin A among the populations of developing countries as a major public health and socio-economic problem (WHO 2002 and Welch 2002), with Zn deficiency cited as the fifth leading cause of morbidity and mortality in these nations (WHO, 2002) and approximately 2.7 billion people estimated to

be Zn deficient worldwide (Muller and Krawinkel, 2005). Because a substantial share of anaemia in women and children continues to be attributed to inadequate dietary Fe even after decades of supplementation and fortification programmes, cereal-based agronomic interventions capable of simultaneously raising both grain Zn and Fe density have assumed considerable importance in national nutrition strategies (Ullah *et al.*, 2024).

In the plant system, Zn functions as a structural or catalytic cofactor for more than three hundred enzymes and proteins involved in carbohydrate metabolism, protein synthesis, membrane integrity and the biosynthesis of the growth hormone auxin, and is therefore indispensable for cell division, internode elongation and reproductive development (Alloway, 2008). Fe is necessary to carry out metabolic processes like DNA synthesis, respiration, photosynthesis, nitrate and sulphate reduction, and to maintain the structure and functionality of chloroplasts because it acts as an electron carrier in the electron transport chain (Rout and Sahoo, 2015).

Biofortification is a novel and sustainable agricultural strategy that seeks to enhance the Zn and Fe content in crops to tackle these deficiency problem through genetic, agronomic and conventional breeding approaches. Among these, agronomic bio fortification is comparatively rapid and low-cost method for increasing Zn and Fe content within one season through soil and foliar application.

2. Materials and Methods

A field experiment entitled “Effect of Zn and Fe Biofortification on Growth, Yield and Economics of Sorghum (*Sorghum bicolor* L.)” was conducted in 2025 during the *Kharif* season at crop research centre of the Sardar Vallabhbhai Patel University of Agriculture and Technology in Meerut (U.P.). The experimental

site is located at a latitude of 29° 40' North and a longitude of 77° 42' East, at an altitude of 237 metres above mean sea level with a subtropical climate, Meerut lies in the central part of western Uttar Pradesh. The soil of the experimental field was sandy loam in texture, low in organic carbon (0.40 %) and available nitrogen (218.5 kg/ha), medium in available phosphorus (13.70 kg/ha), available potassium (238.8 kg/ha), Zn (0.64 ppm) and Fe (7.7 ppm), exhibited a near-neutral reaction.

CSV-15 is a dual-purpose sorghum variety was sown on 22 august 2025. The experiment was laid out in a Randomized Block Design (RBD) comprising 10 treatments with 3 replications. Therefore, in each replication, there were 10 plots of gross plot size (5m x 4.5m) and net plot size (4.4m x 3.6m). The treatment comprised, T1: Absolute control, T2: 100% RDF (90:45:45 kg NPK ha⁻¹), T3: RDF + ZnSO₄ 25 kg ha⁻¹ soil application, T4: RDF + FeSO₄ 25 kg ha⁻¹ soil application, T5: RDF + 0.5% ZnSO₄ foliar spray at 25 and 45 DAS, T6: RDF + 0.5% FeSO₄ foliar spray at 25 and 45 DAS, T7: RDF + 0.5% ZnSO₄ and 0.5% FeSO₄ foliar spray at 25 and 45 DAS, T8: 75% RDF + foliar spray of liquid NPK (0.3%) + 0.5% ZnSO₄ foliar spray at 25 and 45 DAS, T9: 75% RDF + foliar spray of liquid NPK (0.3%) + 0.5% FeSO₄ foliar spray at 25 and 45 DAS, and T10: 75% RDF + foliar spray of liquid NPK (0.3%) + foliar spray of 0.5% ZnSO₄ and 0.5% FeSO₄ at 25 and 45 DAS.

3. Results and discussion

1. Yield attributing characters

The data on yield attributing characters, viz., number of earhead m⁻², length of earhead, number of grains per earhead and test weight as influenced by Zn and Fe biofortification are presented in Table 1.

Table 1: Effect of Zn and Fe biofortification on yield attributes of sorghum

Symbol	Treatments	Yield Attributes			
		No. of earhead m ⁻²	Length of earhead (cm)	No. of grain/earhead	Test weight (g)
T1	Absolute Control	19.98	15.06	1743	26.58
T2	100% RDF (90: 45: 45 kg NPK / ha.)	20.86	16.15	1865	28.90
T3	RDF + ZnSO ₄ 25 kg/ha soil application	21.83	19.05	1945	29.85
T4	RDF + FeSO ₄ 25 kg/ha soil application	21.52	18.62	1917	29.58
T5	RDF + 0.5 % ZnSO ₄ foliar spray at 25 and 45 DAS	22.48	19.64	2053	30.03
T6	RDF + 0.5 % FeSO ₄ foliar spray at 25 and 45 DAS	22.05	19.33	2031	29.71
T7	RDF + 0.5% ZnSO ₄ and 0.5% FeSO ₄ foliar spray at 25 and 45 DAS	23.77	22.48	2219	32.76
T8	75% RDF + Foliar spray of liquid NPK (0.3%) + 0.5% ZnSO ₄ foliar spray at 25 and 45 DAS	23.21	21.11	2115	31.09
T9	75% RDF + Foliar spray of liquid NPK (0.3%) + 0.5 % FeSO ₄ foliar spray at 25 and 45 DAS	22.89	20.77	2082	30.65
T10	75 % RDF + Foliar spray of liquid NPK (0.3%) + Foliar spray of 0.5% ZnSO ₄ and 0.5% FeSO ₄ at 25 and 45 DAS	24.33	23.56	2345	34.57
SEm±		0.23	0.72	72.66	1.1
CD(P=0.05)		0.69	2.14	215.86	3.23

1.1 Number of ear head m⁻²

Zn and Fe biofortification had marked influence on number of earhead m⁻². Treatment T10 (75% RDF + foliar spray of liquid NPK (0.3%) + foliar spray of 0.5% ZnSO₄ and 0.5% FeSO₄) produced maximum no. of earhead (24.33 m⁻²) which remained

statistically at par with treatment T7 (RDF + 0.5% ZnSO₄ and 0.5% FeSO₄ foliar spray at 25 and 45 DAS) which recorded (23.77 m⁻²), but significantly higher than all other treatments. The lowest no. of earhead was recorded in absolute control (T₁) is (19.98 m⁻²).

1.2 Length of earhead (CM)

The earhead length was influenced by Zn and Fe biofortification at different time of crop growth. Treatment T10 (75% RDF + foliar spray of liquid NPK (0.3%) + foliar spray of 0.5% ZnSO₄ and 0.5% FeSO₄) recorded maximum earhead length (23.56 cm) which remained statistically at par with treatment T7 (RDF + 0.5% ZnSO₄ and 0.5% FeSO₄ foliar spray at 25 and 45 DAS) recorded (22.48 cm), but significantly higher than all other treatments. The lowest earhead length was recorded in absolute control (T₁) is (15.06 cm).

1.3 Number of grains per ear head

The number of grains per earhead was influenced by Zn and Fe biofortification at different time of crop growth. Treatment T10 (75% RDF + foliar spray of liquid NPK (0.3%) + foliar spray of 0.5% ZnSO₄ and 0.5% FeSO₄) recorded maximum no. of grains per earhead (2345) which remained statistically at par with

treatment T7 (RDF + 0.5% ZnSO₄ and 0.5% FeSO₄ foliar spray at 25 and 45 DAS) which recorded (2219), but significantly higher than all other treatments. The lowest number of grains per earhead was recorded in absolute control (T₁) is (1743).

1.4 Test weight (g)

The test weight was affected by Zn and Fe biofortification at different time of crop growth. Treatment T10 (75% RDF + foliar spray of liquid NPK (0.3%) + foliar spray of 0.5% ZnSO₄ and 0.5% FeSO₄) recorded maximum test weight (34.57 g) which remained statistically at par with treatment T7 (RDF + 0.5% ZnSO₄ and 0.5% FeSO₄ foliar spray at 25 and 45 DAS) recorded (32.76 g), but significantly higher than all other treatments. The lowest test weight was recorded in absolute control (T₁) is (26.58 g). Comparable improvement in yield attributes of sorghum due to Zn and Fe biofortification has been reported by Yankam *et al.* (2024), Kubsad (2019) and Akhila *et al.* (2021).

2. Yield (q ha⁻¹)

Table 2: The data pertaining to grain yield and stover yield as influenced by Zn and Fe biofortification are presented in

Symbol	Treatments	Yield (q/ha)	
		Grains	Stover
T1	Absolute Control	19.76	75.3
T2	100% RDF (90: 45: 45 kg NPK / ha.)	23.56	88.6
T3	RDF + ZnSO ₄ 25 kg/ha soil application	27.87	99.6
T4	RDF + FeSO ₄ 25 kg/ha soil application	26.12	96.8
T5	RDF + 0.5 % ZnSO ₄ foliar spray at 25 and 45 DAS	32.19	111.8
T6	RDF + 0.5 % FeSO ₄ foliar spray at 25 and 45 DAS	30.85	108.0
T7	RDF + 0.5% ZnSO ₄ and 0.5% FeSO ₄ foliar spray at 25 and 45 DAS	37.45	121.9
T8	75% RDF + Foliar spray of liquid NPK (0.3%) + 0.5% ZnSO ₄ foliar spray at 25 and 45 DAS	34.12	117.8
T9	75% RDF + Foliar spray of liquid NPK (0.3%) + 0.5 % FeSO ₄ foliar spray at 25 and 45 DAS	33.05	114.9
T10	75 % RDF + Foliar spray of liquid NPK (0.3%) + Foliar spray of 0.5% ZnSO ₄ and 0.5% FeSO ₄ at 25 and 45 DAS	38.93	125.1
SEm±		0.64	1.69
CD(P=0.05)		1.89	5.01

2.1 Grain yield (q ha⁻¹)

The grain yield was influenced by Zn and Fe biofortification at different time of crop growth. Treatment T₁₀ (75% RDF + foliar spray of liquid NPK (0.3%) + foliar spray of 0.5% ZnSO₄ and 0.5% FeSO₄) recorded maximum grain yield (38.93 q ha⁻¹) which remained statistically at par with treatment T₇ (RDF + 0.5% ZnSO₄ and 0.5% FeSO₄ foliar spray at 25 and 45 DAS) which recorded (37.45 q ha⁻¹), but significantly higher than all other treatments. The mean increased in grain yield was 97.01% and 89.5% in T₁₀ (75% RDF + foliar spray of liquid NPK (0.3%) + foliar spray of 0.5% ZnSO₄ and 0.5% FeSO₄) and T₇ (RDF + 0.5% ZnSO₄ and 0.5% FeSO₄ foliar spray at 25 and 45 DAS) respectively over control treatment. The lowest grain yield was recorded in absolute control (T₁) is (19.76 q ha⁻¹).

2.2 Stover yield (q ha⁻¹)

The stover yield was influenced by Zn and Fe biofortification at different time of crop growth. Treatment T₁₀ (75% RDF + foliar spray of liquid NPK (0.3%) + foliar spray of 0.5% ZnSO₄ and

0.5% FeSO₄) recorded maximum stover yield (125.1 q ha⁻¹) which remained statistically at par with treatment T₇ (RDF + 0.5% ZnSO₄ and 0.5% FeSO₄ foliar spray at 25 and 45 DAS) which recorded (121.9 q ha⁻¹), but significantly higher than all other treatments. The mean increased in stover yield was 66.1% and 61.8% in T₁₀ (75% RDF + foliar spray of liquid NPK (0.3%) + foliar spray of 0.5% ZnSO₄ and 0.5% FeSO₄) and T₇ (RDF + 0.5% ZnSO₄ and 0.5% FeSO₄ foliar spray at 25 and 45 DAS) respectively over control treatment. The lowest stover yield was recorded in absolute control (T₁) is (75.3 q ha⁻¹).

The same results were in agreement with those reported by Yankam *et al.* (2024) and Kubsad (2019).

3. Zn and Fe content and uptake

3.1 Zn content and uptake

The data on Zn content in grain and straw, and Zn uptake by grain, straw and total uptake as influenced by Zn and Fe biofortification are presented in Table 3.1.

Table 3: Effect of Zn and Fe biofortification on Zn content (ppm) and Zn uptake (g ha⁻¹) by sorghum

Symbol	Treatments	Zn content (ppm)		Zn uptake (g/ha)		Total Uptake (g/ha)
		Grains	Straw	Grains	Straw	
T1	Absolute Control	16.73	12.91	33.06	97.2	130.3
T2	100% RDF (90: 45: 45 kg NPK / ha.)	19.48	15.88	45.89	140.7	186.6
T3	RDF + ZnSO ₄ 25 kg/ha soil application	29.87	25.87	83.25	257.7	340.9
T4	RDF + FeSO ₄ 25 kg/ha soil application	23.94	18.63	62.53	180.3	242.9
T5	RDF + 0.5 % ZnSO ₄ foliar spray at 25 and 45 DAS	34.81	31.86	112.05	356.2	468.2
T6	RDF + 0.5 % FeSO ₄ foliar spray at 25 and 45 DAS	27.65	21.35	85.30	230.6	315.9
T7	RDF + 0.5% ZnSO ₄ and 0.5% FeSO ₄ foliar spray at 25 and 45 DAS	46.12	41.12	172.72	501.3	674.0
T8	75% RDF + Foliar spray of liquid NPK (0.3%) + 0.5% ZnSO ₄ foliar spray at 25 and 45 DAS	38.13	34.23	130.10	403.2	533.3
T9	75% RDF + Foliar spray of liquid NPK (0.3%) + 0.5 % FeSO ₄ foliar spray at 25 and 45 DAS	31.26	27.45	103.31	315.4	418.7
T10	75 % RDF + Foliar spray of liquid NPK (0.3%) + Foliar spray of 0.5% ZnSO ₄ and 0.5% FeSO ₄ at 25 and 45 DAS	47.83	43.52	186.20	544.4	730.6
Sem±		1.21	1.07	4.84	15.21	19.6
CD(P=0.05)		3.61	3.18	14.38	45.18	58.4

Zn content and uptake in grain and straw was significantly influenced by various treatments imposed. The maximum Zn content in grain (47.83 ppm) and straw (43.52 ppm) and Zn uptake in grain (186.2 g ha⁻¹) and straw (544.4 g ha⁻¹) was recorded under T10 (75% RDF + foliar spray of liquid NPK (0.3%) + foliar spray of 0.5% ZnSO₄ and 0.5% FeSO₄), which remained statistically at par with T7 (RDF + 0.5% ZnSO₄ and 0.5% FeSO₄ foliar spray at 25 and 45 DAS) which recorded Zn content in grain (46.12 ppm) and straw (41.12 ppm) and Zn

uptake in grain (172.72 g ha⁻¹) and straw (501.3 g ha⁻¹). The same results were in agreement with those reported by Cakmak (2008) and Erenoglu *et al.* (2002).

3.2 Fe content and uptake

The data on Fe content in grain and straw, and Fe uptake by grain, straw and total uptake as influenced by Zn and Fe biofortification are presented in Table 3.2.

Table 4: Effect of Zn and Fe biofortification on Fe content (ppm) and Fe uptake (g ha⁻¹) by sorghum

Symbol	Treatments	Fe content (ppm)		Fe uptake (g/ha)		Total Uptake (g/ha)
		Grains	Straw	Grains	Straw	
T1	Absolute Control	31.71	61.83	62.7	465.6	528.2
T2	100% RDF (90: 45: 45 kg NPK / ha.)	34.38	73.86	81.0	654.4	735.4
T3	RDF + ZnSO ₄ 25 kg/ha soil application	38.36	79.77	106.9	794.5	901.4
T4	RDF + FeSO ₄ 25 kg/ha soil application	50.73	93.96	132.5	909.5	1042.0
T5	RDF + 0.5 % ZnSO ₄ foliar spray at 25 and 45 DAS	41.76	87.61	134.4	979.5	1113.9
T6	RDF + 0.5 % FeSO ₄ foliar spray at 25 and 45 DAS	59.28	112.87	182.9	1219.0	1401.9
T7	RDF + 0.5% ZnSO ₄ and 0.5% FeSO ₄ foliar spray at 25 and 45 DAS	73.97	128.76	277.0	1569.6	1846.6
T8	75% RDF + Foliar spray of liquid NPK (0.3%) + 0.5% ZnSO ₄ foliar spray at 25 and 45 DAS	53.45	106.36	182.4	1252.9	1435.3
T9	75% RDF + Foliar spray of liquid NPK (0.3%) + 0.5 % FeSO ₄ foliar spray at 25 and 45 DAS	64.53	121.43	213.3	1383.7	1597.0
T10	75 % RDF + Foliar spray of liquid NPK (0.3%) + Foliar spray of 0.5% ZnSO ₄ and 0.5% FeSO ₄ at 25 and 45 DAS	76.12	132.54	296.3	1658.1	1954.4
Sem±		2.06	3.80	7.78	50.83	57.9
CD(P=0.05)		6.16	11.28	23.1	150.99	172.1

Fe content in grain and straw was significantly influenced by various treatments imposed. The maximum Fe content in grain (76.12 ppm) and straw (132.54 ppm) and Fe uptake in grain (296.3 g ha⁻¹) and straw (1658.1 g ha⁻¹) was recorded under T₁₀ (75% RDF + foliar spray of liquid NPK (0.3%) + foliar spray of 0.5% ZnSO₄ and 0.5% FeSO₄), which remained statistically at par with T₇ (RDF + 0.5% ZnSO₄ and 0.5% FeSO₄ foliar spray at

25 and 45 DAS) which recorded Fe content in grain (73.97 ppm) and straw (128.76 ppm) and Fe uptake in grain (277.0 g ha⁻¹) and straw (1569.6 g ha⁻¹). The same results were in agreement with those reported by Habib (2009).

4. Conclusion

On the basis of the results obtained during the present

investigation, it may be concluded that combined foliar application of 0.5% ZnSO₄ and 0.5% FeSO₄ at 25 and 45 DAS along with 75% RDF supplemented with foliar spray of liquid NPK (0.3%) treatment T₁₀ was the most effective and remunerative treatment for realising yield attributes, yield, and Zn and Fe content and uptake in sorghum. Treatment T₇ (100% RDF + combined foliar spray of 0.5% ZnSO₄ and 0.5% FeSO₄ at 25 and 45 DAS) was the next best treatment means statistically at par with T₁₀ and may be recommended where farmers are unwilling to reduce the level of major fertilizer application.

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