Chemical Science Review and Letters ISSN 2278-6783

www.chesci.com

Research Article

Enhancement in Growth and Yield of Sorghum (Sorghum bicolor L.) through Agro-Biofortification with Iron and Zinc

Prince Meena, B.L. Choudhary*, Hoshiyar Singh, A.L. Choudhary, Deepika Chanda and Sachin Kumar Meena

Department of Agriculture, Vivekananda Global University, Jaipur, Rajasthan, India

Abstract

A field experiment titled enhancement in growth and yield of sorghum (*Sorghum bicolor* L.) through agro-biofortification with iron and zinc" was conducted during the Kharif season of 2024 at the Agriculture Research Farm of Vivekananda Global University, Jaipur, on sandy loam soils with slightly alkaline pH, low organic carbon and nitrogen, and medium phosphorus and potassium levels. The study employed a Randomized Block Design with three replications and nine treatments (T1-T9) combining the General Recommended Dose of Fertilizers (GRDF) with various iron and zinc applications. Treatment T9, comprising GRDF (90:45:45 kg/ha N: P_2O5:K_2O + 10 t FYM/ha), soil application of $ZnSO_4$ (20 kg/ha) and $FeSO_4$ (25 kg/ha), and foliar application of 0.2% chelated Fe and Zn, significantly enhanced growth parameters, yield attributes, and overall yield. T9 recorded the highest grain yield (3804 kg/ha), stover yield (8500 kg/ha), and biological yield (12304 kg/ha), alongside the highest net return (Rs. 92,911/ha) and benefit-cost ratio (1.57), proving to be the most effective and economically viable treatment for sorghum biofortification.

Keywords: Sorghum, bio fortification, iron, zinc, yield, quality, Randomized Block Design, foliar application, soil application, economic analysis, Biological yield

***Correspondence**
Author: B.L. Choudhary

Introduction

Sorghum is a vital food and fodder crop in dryland agriculture, valued for its resilience to drought, salinity, and high temperatures. With a short growth cycle, rapid growth, and high biomass production, it sustains millions in arid and semi-arid regions, particularly rural and low-income communities. Globally, it covers 39.24 million hectares, producing 53.60 million tonnes with an average productivity of 1370 kg/ha, ranking fifth among cereals and serving as a dietary staple for over 500 million people [1]. While primarily consumed as food in Africa and Asia, it is largely used as animal feed in the America [2]. India accounts for 21.5% of global production, with major producing states including Maharashtra, Karnataka, Rajasthan, and others [3]. However, sorghum and other cereals are often deficient in zinc and iron, essential micronutrients for plants, animals, and humans [4]. Widespread deficiencies in these nutrients, particularly in developing countries, contribute to malnutrition, impaired growth, and high child mortality [5, 6]. Zinc supports protein synthesis, enzyme activity, and carbohydrate metabolism, while iron is crucial for respiration, photosynthesis, and chloroplast function. Both deficiencies limit plant productivity and human nutrition [7]. Iron (Fe) is equally vital, acting as an electron carrier in metabolic processes like DNA synthesis, respiration, and photosynthesis, and supporting chloroplast function [8]. Iron is a key component of cytochromes, heme, and non-heme enzymes, facilitating biological oxidation and reduction [9].

Agronomic interventions such as soil and foliar application of $ZnSO_4$ and $FeSO_4$ [10], or use of chelated micronutrients, can effectively address these issues, with foliar application being more efficient [11, 12]. Alongside genetic biofortification, agronomic biofortification offers a rapid and cost-effective strategy to enhance grain micronutrient content, thereby improving crop productivity and human health.

Materials and Methods

The field experiment was conducted during the Kharif season of 2024 at the Agronomy Research Farm, Vivekananda Global University, Jaipur (Rajasthan, India). The site lies in the semi-arid region with sandy loam soils, low organic carbon (0.34%), available nitrogen (123.4 kg ha^{-1}), medium phosphorus (20.12 kg ha^{-1}), potassium (153. kg /ha) and low available zinc (0.57 ppm) and iron (2.94 ppm). The soil pH was neutral (pH 6.8) The experimental season received

500 mm rainfall, mostly concentrated between July and September. The average maximum and minimum temperatures during crop growth were 29.5-39.4°C and 20.6-25.4°C, respectively, suitable for sorghum cultivation.

Experimental Design and Treatments

The experiment was laid out in a Randomized Block Design (RBD) with 9 treatments replicated thrice. The treatments were as follows: T1-Absolute control,T2-RDF (90:45:45 kg ha^{-1} $N:P_2O_5:K_2O$),T3-GRDF (90:45:45 kg ha^{-1} $N:P_2O_5:K_2O$ + 10 t FYM ha^{-1}), T4-GRDF + Soil application of $ZnSO_4$ @ 20 kg ha^{-1},T5-GRDF + Soil application of $FeSO_4$ @ 25 kg ha^{-1},T6-GRDF + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ Soil application of $FeSO_4$ @ 25 kg ha^{-1} + Foliar application of 0.2 % chelated Fe,T7-GRDF + Soil application of $ZnSO_4$ @ 20 kg ha^{-1}+ Soil application of $FeSO_4$ @ 25 kg ha^{-1},T8-GRDF + Soil application of $ZnSO_4$ @ 20 kg ha^{-1} + Soil application of $FeSO_4$ @ 25 kg ha^{-1} + Foliar application of 0.2 % chelated Zn,T9-GRDF + Soil application of $ZnSO_4$ @ 20 kg ha^{-1} + Soil application of $FeSO_4$ @ 25 kg ha^{-1} + Foliar application of 0.2 % chelated Fe + Foliar application of 0.2 % chelated Zn. The Materials and Methods section has been revised. The foliar sprays of chelated iron and zinc (0.2%) were applied twice at booting and flowering stages. The concentration of 0.2% was selected based on earlier reports indicating efficient micronutrient absorption and minimum risk of foliar injury.

Observations Recorded- Growth parameters (Count of the plants, plant height, dry matter accumulation), Yield attributes (Ear head length, ear head weight, number of grain/ear head weight of grain/ear head, 1000 grain weight and yield (grain yield, straw yield, biological yield, and harvest index).

Economics: Cost of cultivation, gross returns, net returns, and B:C ratio.

Statistical Analysis- The data were analyzed using ANOVA for RBD. Critical differences (CD) at 5% probability were calculated for comparing treatment means.

Results and Discussion

Impact on Growth Traits

Biofortification with iron and zinc significantly enhanced sorghum growth across all stages. Plant count was highest under T9 (GRDF + $ZnSO_4$ + $FeSO_4$ + foliar Fe and Zn), recording 146,269 plants/ha at 25 DAS and 141,537 plants/ha at harvest, showing clear improvement over control. Plant height also increased markedly, with T9 reaching 288.29 cm at harvest, 27.66% higher than control and 15.65% higher than RDF. Dry matter accumulation consistently improved, with T9 producing 180.67 g/plant at harvest, 34.39% more than control. Nutrient application also influenced phenology, as T9 delayed 50% flowering to 81.37 days compared to 75.61 days in control, suggesting prolonged vegetative growth and resource accumulation. These results show that integrated use of soil and foliar micronutrients promotes vigorous growth, higher biomass, and better physiological development. The superior performance of T9 indicates synergistic effects of Zn and Fe on photosynthesis, enzyme activity, and nutrient metabolism. This confirms the importance of comprehensive nutrient management in optimizing sorghum growth.

Impact on Yield Attributes and Yield Traits

Yield components such as earhead length, earhead weight, grain number, and test weight were significantly improved by biofortification. T9 recorded the longest earhead (24.46 cm) and heaviest earhead (93.5 g), showing 41.72% and 46.41% increases over control, respectively. Grain number per earhead was also highest in T9 (2222), which was 30.32% greater than control. Grain weight per earhead in T9 (74.48 g) exceeded control by 50.39%, while test weight (33.81 g) improved by 28.21%. Treatments combining both soil and foliar Zn and Fe consistently outperformed sole applications. RDF and FYM-based treatments showed modest improvements, but the addition of micronutrients maximized yield attributes. These findings highlight the role of Zn in pollen viability, seed setting, and enzyme activation, while Fe supports chlorophyll formation and grain filling. T9 clearly demonstrates how balanced macro- and micronutrient management translates into stronger yield attributes, forming the foundation for higher productivity. Grain, fodder, and biological yields were highly responsive to nutrient management. T9 produced the maximum grain yield (3804 kg/ha), which was 101.38% higher than control and significantly higher than RDF (2156 kg/ha). Fodder yield under T9 (8500 kg/ha) also improved by 79.03% over control, ensuring dual benefits of grain and stover production. Biological yield reached 12,304 kg/ha in T9, showing an 85.39% increase over control. Although T9 recorded the highest grain yield (3804 kg ha^{-1}), the maximum harvest index (31.4%) was observed in T8, indicating relatively greater partitioning of total biomass towards grain production under this treatment. The results highlight that micronutrient enrichment not only boosts grain productivity but also improves fodder availability, critical in dryland agriculture. Synergistic effects of Zn and Fe enhanced photosynthate translocation, reproductive efficiency, and biomass accumulation. T9 clearly emerged as the most productive and sustainable practice, showing that biofortification significantly strengthens yield potential. Similar results had found, showing that the yield attributes and yield of wheat significantly increased with the application of different zinc and iron treatment combinations [14].

Table 1 Growth attributes of sorghum as impacted by various treatments

Sr. No.	Treatment Details	Plant count /ha.		Plant height (cm) at				Dry matter /plant (g) at				Days required to 50% flowering
		25 DAS	harvest	25 DAS	55 DAS	85 DAS	harvest	25 DAS	55 DAS	85 DAS	harvest	
T1	Absolute control	142555	138548	37.69	117.96	216.64	225.83	10.79	88.31	127.18	134.44	75.61
T2	RDF (90:45:45 kg ha-1 N:P2O5:K2O)	142903	139126	39.76	124.24	213.31	233.99	10.97	96.74	139.32	145.72	76.32
T3	GRDF (90:45:45 kg ha-1 N:P2O5:K2O + 10 t FYM ha-1)	143195	139645	40.44	130.14	219.15	240.74	11.35	97.64	140.63	151.42	77.22
T4	GRDF + Soil application of ZnSO4 @ 20 kg ha-1	143684	139918	42.11	137.46	229.26	251.39	12.09	100.17	143.9	159.72	80.92
T5	GRDF + Soil application of FeSO4 @ 25 kg ha-1	144147	140170	41.14	134.03	225.72	246.58	11.63	98.18	141.95	156.27	79.63
T6	GRDF + Soil application of ZnSO4 @ 20 kg ha-1+ Soil application of FeSO4 @ 25 kg ha-1 + Foliar application of 0.2 % chelated Fe	144555	140358	43.6	142.66	234.68	258.51	12.33	102	146.52	165.33	81.05
T7	GRDF + Soil application of ZnSO4 @ 20 kg ha-1+ Soil application of FeSO4 @ 25 kg ha-1	145277	140770	44.76	151.39	251.05	277.3	12.92	108.33	156.02	176	80.02
T8	GRDF + Soil application of ZnSO4 @ 20 kg ha-1 + Soil application of FeSO4 @ 25 kg ha-1 + Foliar application of 0.2 % chelated Zn	145636	141137	44.22	146.17	243.65	265.16	12.61	103.89	149.58	171	78.83
T9	GRDF + Soil application of ZnSO4 @ 20 kg ha-1 + Soil application of FeSO4 @ 25 kg ha-1 + Foliar application of 0.2 % chelated Fe + Foliar application of 0.2 % chelated Zn	146269	141537	45.33	157.42	263.21	288.29	13.34	114.47	164.92	180.67	81.37
	CD (P = 0.05)	N/A	N/A	1.657	5.811	14.008	15.808	0.742	3.849	7.131	6.849	3.741
	SEm+	2009.92	2147.18	0.548	1.922	4.632	5.228	0.245	1.273	2.358	2.265	1.237
	C.V. (%)	2.413	2.654	2.254	2.413	3.444	3.562	3.541	2.181	2.806	2.451	2.713

Table 2 Yield attributes and yield of sorghum impact by various treatments

Sr. No.	Treatment Details	Yield attributes					Yield			
		Earhead length (cm)	Earhead weight (g)	Number of grain/ earhead	Weight of grain/ earhead (g)	1000 grain weight (g)	Grain yield (kg/ha)	Fodder yield (kg/ha)	Biological yield (kg/ha)	harvest index
T1	Absolute control	17.26	63.86	1705	49.53	26.37	1889	4748	6637	28.46
T2	RDF (90:45:45 kg ha-1 N:P2O5:K2O)	17.34	65.79	1866	52.14	28.84	2156	5707	7863	27.41
T3	GRDF (90:45:45 kg ha-1 N:P2O5:K2O + 10 t FYM ha-1)	18.58	70.71	1926	55.72	29.77	2417	6437	8854	27.29
T4	GRDF + Soil application of ZnSO4 @ 20 kg ha-1	20.44	78.05	1944	60.52	30.04	2800	7055	9855	28.41
T5	GRDF + Soil application of FeSO4 @ 25 kg ha-1	19.33	73.49	1931	58.21	29.84	2654	6624	9278	28.6
T6	GRDF + Soil application of ZnSO4 @ 20 kg ha-1+ Soil application of FeSO4 @ 25 kg ha-1 + Foliar application of 0.2 % chelated Fe	20.81	79.52	1978	63.07	30.77	2949	7287	10236	28.81

T7	GRDF + Soil application of ZnSO4 @ 20 kg ha-1+ Soil application of FeSO4 @ 25 kg ha-1	22.43	85.88	2091	68.92	32.31	3463	8150	11613	29.82
T8	GRDF + Soil application of ZnSO4 @ 20 kg ha-1 + Soil application of FeSO4 @ 25 kg ha-1 + Foliar application of 0.2 % chelated Zn	21.84	83.43	2074	66.9	32.04	3578	7787	11365	31.4
T9	GRDF + Soil application of ZnSO4 @ 20 kg ha-1 + Soil application of FeSO4 @ 25 kg ha-1 + Foliar application of 0.2 % chelated Fe + Foliar application of 0.2 % chelated Zn	24.46	93.5	2222	74.48	33.81	3804	8500	12304	30.9
	CD (P = 0.05)	1.144	3.622	75.023	3.017	1.575	128.009	357.288	544.96	1.275
	SEm+	0.378	1.198	24.811	0.998	0.521	42.333	118.158	180.223	0.422
	C.V. (%)	3.231	2.69	2.181	2.831	2.966	2.567	2.957	3.192	2.517

Analysis of Economic

This highlights that integrated nutrient application is not only agronomically superior but also economically sustainable. A combined micronutrient strategy (T9) demonstrated the maximum gross returns (Rs. 1,51,806/ha), net returns (Rs. 92,911/ha), and B:C ratio (1.57). Compared to the control, T9 increased gross returns by over 93% and net returns by over 170%, proving that integrated nutrient management is a profitable and sustainable option for farmers.

Conclusion

Among the treatments, T9 (GRDF + soil application of $ZnSO_4$ @ 20 kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} + foliar application of 0.2% chelated Fe and 0.2% chelated Zn) recorded the highest growth, yield attributes, grain yield (3804 kg ha^{-1}), net returns (Rs. 92,911 ha^{-1}) and B:C ratio (1.57). Therefore, T9 may be recommended for maximizing productivity and profitability of sorghum under semi-arid conditions. However, where the cost or availability of foliar micronutrient sprays is a constraint, treatments involving soil application of $ZnSO_4$ and $FeSO_4$ alone also produced substantial yield improvements over RDF and control."

References

[1] United States Department of Agriculture, Foreign Agricultural Service. (2024a). World agricultural production (Circular Series WAP 03-25, March 2025). United States Department of Agriculture.

[2] International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). (2011). ICRISAT annual report and institutional information. ICRISAT, Hyderabad, India.

[3] Department of Agriculture and Farmers Welfare. (2024b). Unified portal for agricultural statistics. Government of India. https://upag.gov.in

[4] World Health Organization (WHO). (2002). The world health report 2002: Reducing risks, promoting healthy life. World Health Organization, Geneva, Switzerland.

[5] Brown, K. H., Wuehler, S. E., & Peerson, J. M. (2001). The importance of zinc in human nutrition and estimation of the global prevalence of zinc deficiency. Food and Nutrition Bulletin, 22, 113–125.

[6] Müller, O., & Krawinkel, M. (2005). Malnutrition and health in developing countries. Canadian Medical Association Journal, 173, 279–286.

[7] Swaminathan, C., & Kannan, K. (2001). Range management. Agroforestry Systems, 22, 208–211.

[8] Rout, G. R., & Sahoo, S. (2015). Role of iron in plant growth and metabolism. Reviews in Agricultural Science, 3, 1–24.

[9] Tandon, H. L. S. (1995). Micronutrient research and agricultural production. Fertiliser Development and Consultation Organisation, New Delhi, India.

[10] Cakmak, I., Kalayci, M., & Kaya, Y. (2010). Biofortification and localization of zinc in wheat grain. Journal of Agricultural and Food Chemistry, 58, 9092–9102.

[11] Zaheer, I. E., Ali, S., Saleem, M. H., Arslan, M., Ali, Q., & Abbas, Z. (2020). Zinc-lysine supplementation mitigates oxidative stress in rapeseed (Brassica napus L.) by preventing phytotoxicity of chromium when irrigated with tannery wastewater. Plants, 9(9), 1145.

[12] Hafeez, B., Khanif, Y. M., Samsuri, A. W., Radziah, O., Zakaria, W., & Saleem, M. (2013). Direct and residual effect of zinc on zinc-efficient and zinc-inefficient rice genotypes grown under submerged acidic conditions. Australian Journal of Crop Science, 7(12), 1773–1779.

[13] Association of Official Agricultural Chemists (AOAC). (1960). Official methods of analysis (18th ed.). Association of Official Agricultural Chemists, Washington, DC.

[14] Choudhary, B. L., Sharma, P. K., Mandeewal, R. L., Verma, B. L., & Dudwal, M. (2021). Response of iron and zinc on yield attributes, yield and economics of wheat (Triticum aestivum L.). International Journal of Plant & Soil Science, 33(16), 29–35.

Publication History

Received	17.06.2026
Revised	14.07.2026
Accepted	16.07.2026
Online	02.08.2026