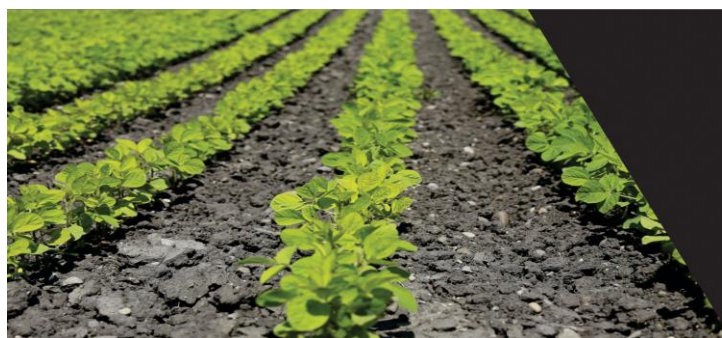




International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(6): 922-926
Received: 22-05-2026
Accepted: 25-06-2026

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Iron and zinc agronomic fortification enhances nutrient content and uptake in finger millet (*Eleusine coracana* L.) under south Gujarat condition

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i6l.5808>

Abstract

A field experiment was conducted during the *kharif* season of 2024 and 2025 at the College Farm, N. M. College of Agriculture, Navsari Agricultural University, Navsari, to study the Agronomic fortification of finger millet (*Eleusine coracana* L.) with iron and zinc under south Gujarat condition. The experiment was laid out in a randomized block design comprising fourteen treatments, including a recommended dose of fertilizers (RDF) control, separate soil applications of iron sulfate (FeSO_4) and zinc sulfate (ZnSO_4) at @ 25 kg ha^{-1} and @ 50 kg ha^{-1} and combined soil application of both micronutrients. These soil treatments were evaluated both with and without additional foliar interventions using @ 0.5% FeSO_4 and ZnSO_4 at critical growth stages of tillering and panicle initiation. An absolute control was maintained alongside the nutrient combinations for comparison. The baseline experimental soil was clayey in texture and slightly alkaline in nature exhibiting a normal electrical conductivity range, low in organic carbon, low available nitrogen, medium in available phosphorus and fairly high in available potassium. The macroclimate of the study region was a typical tropical monsoon type. The results revealed that combined soil and foliar application of Fe and Zn significantly improved nutrient enrichment and uptake by finger millet. Treatment T_{11} (RDF + soil application of FeSO_4 @ 25 kg ha^{-1} + ZnSO_4 @ 25 kg ha^{-1} + foliar application of FeSO_4 @ 0.5% and ZnSO_4 @ 0.5% at tillering and panicle initiation stages) recorded the highest Fe concentration in grain (36.79 ppm) and straw (23.21 ppm) as well as Zn concentration in grain (24.69 ppm) and straw (19.38 ppm). The same treatment also produced maximum total uptake of nitrogen (49.50 kg ha^{-1}), P_2O_5 (20.04 kg ha^{-1}), K_2O (126.61 kg ha^{-1}), iron (191.31 g ha^{-1}) and zinc (147.69 g ha^{-1}) and realized the highest economic returns. Treatment T_{13} remained statistically at par with T_{11} for several nutrient parameters. The study concluded that integrated soil and foliar fortification with Fe and Zn is an efficient agronomic strategy to improve nutritional quality, nutrient uptake and profitability of finger millet under South Gujarat conditions.

Keywords: Finger millet, agronomic biofortification, iron, zinc, nutrient uptake

Introduction

Finger Millet (*Eleusine coracana* L. Gaertn.), a member of the Poaceae family and Chloridoideae subfamily, is a vital sustenance crop originating from the Ethiopian Highlands and introduced to India approximately 4000 years ago (Dida *et al.*, 2008) [3]. It ranks third among India's millets in both area (1.29 million ha) and production (2.19 million tonnes), following after sorghum and pearl millet. Finger millet is small-seeded minor cereal with light brown to brick red coloured or dark brown seed coat, which is highly rich in phyto-chemicals such as a phytochemical such as polyphenols and dietary fibers. Finger millet is a good source of nutrients especially fiber and antioxidants which makes it easily and slowly digestible. Consequently, finger millet efficiently helps in controlling the blood glucose levels in diabetic patients. Therefore, finger millet is considered to be ideal food for diabetic individuals due to its low sugar content and slow release of glucose into the body (Kang *et al.* 2008) [7].

Globally, India is a leading producer of millets alongside nation like Nigeria, Niger, Mali, Burkina Faso, Chad and China. India contributes more than 50 per cent of the world production with an area of 1.2 million ha and a production of 1.75 million tonnes and productivity of 1.7 tonnes ha^{-1} , respectively. In Gujarat, finger millet is the most important traditional millet crop grown over an area of 11,000 ha. with a productivity of 1435 kg ha^{-1} and provides vital food and nutritional security to the marginal farmers in the rainfed dry lands and hilly tribal areas of the Dangs,

Valsad and Navsari districts of South Gujarat and Panchmahal district of middle Gujarat. (Intwala *et. al.*,2017) ^[5]. In 2025, 1,165 kg of finger millet was harvested per hectare in the region with the Dang district taking the lead in millet farming in the state over the past few years. (Anon.,2025). Agronomic biofortification is an effective and accessible way to reach the poor rural masses for enhancing the concentration of essential minerals (Zn and Fe) in their diets. The attempt to alleviate Zn and Fe deficiencies in human beings through biofortification is a continuum of the soil–plant–animal-human pathway. Therefore, equal importance must be placed on understanding micronutrient concentrations in soil, uptake by plants and accumulation in edible plant parts, and their ultimate bioavailability and absorption in the human body for alleviating Zn and Fe deficiencies in human beings. Therefore, the attempts at increasing Zn and Fe in food crops required a broader, comprehensive understanding of the role and behaviour of both these nutrients across the integrated soil, plants and human body matrix.

Materials and Methods

The field experiment was conducted during *kharif* 2023-24 and 2024-25 at the College Farm, N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat. The experimental soil was clayey in texture, moderately alkaline in reaction and low to medium in available micronutrient status. The experiment was laid out in a Randomized Block Design (RBD) with three replications and fourteen treatments consisting of different combinations of soil and foliar application of iron sulphate (FeSO₄) and zinc sulphate (ZnSO₄) viz., T₁: RDF, T₂: RDF + soil application of FeSO₄ @ 25 kg ha⁻¹, T₃:RDF + soil application of FeSO₄ @ 25 kg ha⁻¹ + foliar application of FeSO₄ @ 0.5% at tillering and panicle initiation stage, T₄: RDF + soil

application of FeSO₄ @ 50 kg ha⁻¹, T₅: RDF + soil application of FeSO₄ @ 50 kg ha⁻¹ + foliar application of FeSO₄ @ 0.5% at tillering and panicle initiation stage, T₆: RDF + soil application of ZnSO₄ @ 25 kg ha⁻¹, T₇:RDF + soil application of ZnSO₄ @ 25 kg ha⁻¹ + foliar application of ZnSO₄ @ 0.5% at tillering and panicle initiation stage, T₈: RDF + soil application of ZnSO₄ @ 50 kg ha⁻¹, T₉: RDF + soil application of ZnSO₄ @ 50 kg ha⁻¹ + foliar application of ZnSO₄ @ 0.5% at tillering and panicle initiation stage,T₁₀: RDF + soil application of FeSO₄ @ 25 kg ha⁻¹ + ZnSO₄ @ 25 kg ha⁻¹, T₁₁: RDF + soil application of FeSO₄ @ 25 kg ha⁻¹ + ZnSO₄ @ 25 kg ha⁻¹ + foliar application of FeSO₄ @ 0.5% and ZnSO₄ @ 0.5% at tillering and panicle initiation stage,T₁₂: RDF + soil application of FeSO₄ @ 50 kg ha⁻¹ + ZnSO₄ @ 50 kg ha⁻¹,T₁₃: RDF + soil application of FeSO₄ @ 50 kg ha⁻¹ + ZnSO₄ @ 50 kg ha⁻¹ + foliar application of FeSO₄ @ 0.5% and ZnSO₄ @ 0.5% at tillering and panicle initiation stage,T₁₄: Control. Finger millet variety GN-8 was used in the study. The recommended dose of fertilizer comprising 40 kg N and 20 kg P₂O₅ ha⁻¹ was applied through conventional fertilizers. Soil application of FeSO₄ and ZnSO₄ was carried out as per treatment at sowing, whereas foliar sprays were imposed at the designated critical growth stages of tillering and panicle initiation. The initial and final soil samples were analysed for available N, P₂O₅, K₂O and micronutrients, viz. Zn and Fe as per the standard procedures. The plant samples of both the grain and straw of finger millet was analysed for both macronutrient and micronutrient uptake. The two years experimental pooled mean data were subjected to statistical analysis as per procedure described by Gomez and Gomez (1984) ^[4]. Differences among the means and treatments were compared by the least significant difference (LSD) at P≤0.05.

Table 1: Iron (Fe) content in grain and straw of finger millet as influenced by different treatments

Treatments	Iron (Fe) content (ppm)					
	Grain			Straw		
	2024	2025	Pooled	2024	2025	Pooled
T ₁ : RDF	26.92	27.34	27.13	19.59	18.86	19.23
T ₂ : RDF + Soil application of FeSO ₄ @ 25 kg ha ⁻¹	32.84	33.14	32.99	20.50	19.89	20.20
T ₃ : T ₂ + Foliar application of FeSO ₄ @ 0.5% at tillering and panicle initiation stage	34.20	34.19	34.20	22.23	22.11	22.17
T ₄ : RDF + Soil application of FeSO ₄ @ 50 kg ha ⁻¹	32.62	32.10	32.36	20.76	20.59	20.68
T ₅ : T ₄ + Foliar application of FeSO ₄ @ 0.5% at tillering and panicle initiation stage	32.90	33.25	33.08	21.73	21.67	21.70
T ₆ : RDF + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹	29.08	29.67	29.38	20.27	19.91	20.09
T ₇ : T ₆ + Foliar application of ZnSO ₄ @ 0.5% at tillering and panicle initiation stage	30.18	29.86	30.02	19.97	20.05	20.01
T ₈ : RDF + Soil application of ZnSO ₄ @ 50 kg ha ⁻¹	28.78	29.06	28.92	20.33	20.67	20.50
T ₉ : T ₈ + Foliar application of ZnSO ₄ @ 0.5% at tillering and panicle initiation stage	29.86	29.17	29.52	20.43	19.94	20.19
T ₁₀ : RDF + Soil application of FeSO ₄ @ 25 kg ha ⁻¹ + ZnSO ₄ @ 25 kg ha ⁻¹	33.86	32.80	33.33	22.25	22.20	22.23
T ₁₁ : T ₁₀ + Foliar application of FeSO ₄ @ 0.5% and ZnSO ₄ @ 0.5% at tillering and panicle initiation stage	37.14	36.43	36.79	23.29	23.13	23.21
T ₁₂ : RDF + Soil application of FeSO ₄ @ 50 kg ha ⁻¹ + ZnSO ₄ @ 50 kg ha ⁻¹	32.00	31.48	31.74	21.65	21.84	21.74
T ₁₃ : T ₁₂ + Foliar application of FeSO ₄ @ 0.5% and ZnSO ₄ @ 0.5% at tillering and panicle initiation stage	35.87	34.92	35.40	22.17	22.13	22.15
T ₁₄ : Control	25.58	24.81	25.19	17.64	17.61	17.63
SEm±	1.39	1.23	0.93	0.75	0.69	0.51
CD (P=0.05)	4.03	3.58	2.63	2.18	2.00	1.44
CV (%)	7.61	6.81	7.23	6.24	5.77	6.01

Year	SEm±	0.35	0.19
	CD (P=0.05)	NS	NS
Y x T	SEm±	1.31	0.72
	CD (P=0.05)	NS	NS

Results and Discussion

Iron content in grain and straw (%)

Iron concentration in grain and straw exhibited a significant

response to agronomic fortification with Fe and Zn. RDF + soil application of FeSO₄ @ 25 kg ha⁻¹ + ZnSO₄ @ 25 kg ha⁻¹ + foliar application of FeSO₄ @ 0.5% and ZnSO₄ @ 0.5% at tillering and

panicle initiation stage (T_{11}) exhibited the highest pooled values (36.79 ppm in grain and 23.21 ppm in straw) and remained statistically at par with T_{13} and T_3 (grain) and with T_{10} , T_3 and T_{13} (straw), while the absolute control registered the lowest values; the remaining treatments showed intermediate performance. The enhanced iron concentration reflects improved micronutrient availability and translocation under integrated agronomic fortification, supported by efficient uptake and redistribution of Fe towards developing plant parts. These findings are in agreement with the results of Vijayakumar *et al.* (2020) ^[14] and Khobragade *et al.* (2022) ^[18].

Zinc content in grain and straw (%)

Zinc concentration in grain and straw responded significantly to agronomic fortification with Fe and Zn, wherein RDF + soil

application of $\text{FeSO}_4 @ 25 \text{ kg ha}^{-1} + \text{ZnSO}_4 @ 25 \text{ kg ha}^{-1}$ + foliar application of $\text{FeSO}_4 @ 0.5\%$ and $\text{ZnSO}_4 @ 0.5\%$ at tillering and panicle initiation stage (T_{11}) registered the highest pooled values (24.69 ppm in grain and 19.38 ppm in straw), it is found to be statistically at par with treatment T_{13} (grain) and with treatments T_{13} , T_{10} , T_9 , T_7 and T_6 (straw), whereas the absolute control exhibited the lowest value. The simultaneous inclusion of iron may further support metabolic vigor and root activity, facilitating greater zinc mobilization and accumulation in the grain and straw. Such integrated nutrient delivery appears to be highly effective in enhancing zinc loading efficiency and achieving superior agronomic fortification in finger millet. These findings are in agreement with the results of Teklu *et al.* (2023) ^[13], Reddy *et al.* (2025) and Waghmare (2025) ^[15].

Table 2: Zinc content in grain and straw of finger millet as influenced by different treatments

Treatments		Zn content (ppm)					
		Grain			Straw		
		2024	2025	Pooled	2024	2025	Pooled
T_1 : RDF		17.31	17.46	17.39	12.84	13.26	13.05
T_2 : RDF + Soil application of $\text{FeSO}_4 @ 25 \text{ kg ha}^{-1}$		19.21	19.64	19.43	15.14	15.37	15.26
T_3 : T_2 + Foliar application of $\text{FeSO}_4 @ 0.5\%$ at tillering and panicle initiation stage		19.32	19.69	19.51	16.00	16.33	16.17
T_4 : RDF + Soil application of $\text{FeSO}_4 @ 50 \text{ kg ha}^{-1}$		19.24	18.79	19.01	14.79	15.21	15.00
T_5 : T_4 + Foliar application of $\text{FeSO}_4 @ 0.5\%$ at tillering and panicle initiation stage		19.58	19.98	19.78	15.54	16.08	15.81
T_6 : RDF + Soil application of $\text{ZnSO}_4 @ 25 \text{ kg ha}^{-1}$		21.12	21.48	21.30	18.72	17.20	17.96
T_7 : T_6 + Foliar application of $\text{ZnSO}_4 @ 0.5\%$ at tillering and panicle initiation stage		22.96	22.62	22.79	18.26	18.72	18.49
T_8 : RDF + Soil application of $\text{ZnSO}_4 @ 50 \text{ kg ha}^{-1}$		21.11	20.56	20.84	17.24	17.63	17.44
T_9 : T_8 + Foliar application of $\text{ZnSO}_4 @ 0.5\%$ at tillering and panicle initiation stage		21.62	21.54	21.58	18.81	18.61	18.71
T_{10} : RDF + Soil application of $\text{FeSO}_4 @ 25 \text{ kg ha}^{-1} + \text{ZnSO}_4 @ 25 \text{ kg ha}^{-1}$		22.18	22.34	22.26	18.55	19.10	18.83
T_{11} : T_{10} + Foliar application of $\text{FeSO}_4 @ 0.5\%$ and $\text{ZnSO}_4 @ 0.5\%$ at tillering and panicle initiation stage		24.64	24.73	24.69	19.60	19.15	19.38
T_{12} : RDF + Soil application of $\text{FeSO}_4 @ 50 \text{ kg ha}^{-1} + \text{ZnSO}_4 @ 50 \text{ kg ha}^{-1}$		20.97	21.58	21.28	16.23	16.74	16.49
T_{13} : T_{12} + Foliar application of $\text{FeSO}_4 @ 0.5\%$ and $\text{ZnSO}_4 @ 0.5\%$ at tillering and panicle initiation stage		23.18	23.56	23.37	18.62	19.10	18.86
T_{14} : Control		15.96	15.81	15.88	12.78	12.24	12.51
SEm $\pm$		0.84	0.78	0.57	0.62	0.71	0.47
CD (P=0.05)		2.44	2.27	1.63	1.79	2.07	1.34
CV (%)		7.05	6.55	6.80	6.44	7.36	6.92
Year	SEm $\pm$	0.22			0.18		
	CD (P=0.05)	NS			NS		
Y x T	SEm $\pm$	0.82			0.67		
	CD (P=0.05)	NS			NS		

Total Uptake of NPK (kg ha^{-1})

The pooled data in Table 3 revealed that integrated agronomic fortification strategies significantly influenced the total macronutrient uptake of finger millet. The treatment T_{11} (RDF + soil application of $\text{FeSO}_4 @ 25 \text{ kg ha}^{-1} + \text{ZnSO}_4 @ 25 \text{ kg ha}^{-1}$ + foliar application of $\text{FeSO}_4 @ 0.5\%$ and $\text{ZnSO}_4 @ 0.5\%$ at tillering and panicle initiation stage) consistently maximized accumulation, yielding the highest total nitrogen (49.50 kg ha^{-1}), phosphorus (20.04 kg ha^{-1}) and potassium ($126.61 \text{ kg ha}^{-1}$) uptake. This treatment significantly outperformed the recommended dose of fertilizers alone (T_1) and the unfertilized control (T_{14}), which recorded the lowest overall nutrient accumulation. The marked enhancement in total N uptake under T_{11} is attributed to the synergistic action of zinc and iron, which optimizes root elongation, photosynthetic efficiency, and enzyme activation, thereby accelerating nitrogen translocation into both grain and straw. Continuous nutrient availability throughout the crop cycle favored higher biomass production and a consequently greater removal of nitrogen by the plant, corroborating the findings of Teklu *et al.* (2023) ^[13] and Waghmare (2025) ^[15].

Similarly, the higher total P_2O_5 uptake under T_{11} is due to

improved phosphorus acquisition and utilization efficiency facilitated by balanced iron and zinc nutrition, which enhanced root growth, rhizosphere nutrient mobilization, and overall dry matter production. Split delivery via soil and foliar modes guaranteed uninterrupted nutrient supply during critical growth stages, promoting greater phosphorus absorption as documented by Shivay *et al.* (2015) ^[11], Roy *et al.* (2018) ^[10] and Vijayakumar *et al.* (2020) ^[14].

Furthermore, the elevated total K_2O uptake under T_{11} resulted from improved root proliferation, cellular nutrient absorption, and photosynthetic capacity driven by adequate micronutrient supply, which regulates vital metabolic activities and creates favorable cellular gradients for potassium translocation from the soil to the grain and straw. Delivering foliar sprays at tillering and panicle initiation stages ensured timely availability during high-demand growth phases, maximizing potassium utilization. These results are in strong agreement with Shivay *et al.* (2015) ^[11] and Dholariya *et al.* (2020) ^[2] who reported analogous beneficial impacts of micronutrient applications on macronutrient uptake and overall crop productivity.

Table 3: Pooled Nitrogen, Phosphorous and potash uptake (kg ha⁻¹) by finger millet crop as influenced by different treatments

Treatments		Nitrogen uptake (kg ha ⁻¹)			P2O5 uptake (kg ha ⁻¹)			K2O uptake (kg ha ⁻¹)		
		Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T ₁ : RDF		15.04	10.21	25.25	4.51	5.23	9.74	8.01	74.74	82.76
T ₂ : RDF + Soil application of FeSO ₄ @ 25 kg ha ⁻¹		16.85	12.20	29.05	5.37	6.23	11.60	8.93	85.12	94.06
T ₃ : T ₂ + Foliar application of FeSO ₄ @ 0.5% at tillering and panicle initiation stage		18.15	13.65	31.47	5.99	6.84	12.66	9.34	91.59	100.93
T ₄ : RDF + Soil application of FeSO ₄ @ 50 kg ha ⁻¹		15.61	11.31	26.92	5.03	5.72	10.74	8.07	79.95	88.02
T ₅ : T ₄ + Foliar application of FeSO ₄ @ 0.5% at tillering and panicle initiation stage		17.11	12.44	29.51	5.82	6.41	12.22	9.05	88.20	97.25
T ₆ : RDF + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹		18.21	13.70	31.91	7.51	7.09	14.60	9.42	91.74	101.16
T ₇ : T ₆ + Foliar application of ZnSO ₄ @ 0.5% at tillering and panicle initiation stage		19.52	15.16	34.68	7.97	7.52	15.49	10.12	96.99	107.11
T ₈ : RDF + Soil application of ZnSO ₄ @ 50 kg ha ⁻¹		17.38	12.81	30.19	6.74	6.76	13.50	8.71	89.62	98.32
T ₉ : T ₈ + Foliar application of ZnSO ₄ @ 0.5% at tillering and panicle initiation stage		18.92	13.57	32.49	7.89	7.33	15.21	9.99	97.15	107.14
T ₁₀ : RDF + Soil application of FeSO ₄ @ 25 kg ha ⁻¹ + ZnSO ₄ @ 25 kg ha ⁻¹		19.88	16.66	35.87	8.75	7.78	15.87	9.74	100.29	110.04
T ₁₁ : T ₁₀ + Foliar application of FeSO ₄ @ 0.5% and ZnSO ₄ @ 0.5% at tillering and panicle initiation stage		26.30	23.20	49.50	10.41	9.63	20.04	12.05	114.56	126.61
T ₁₂ : RDF + Soil application of FeSO ₄ @ 50 kg ha ⁻¹ + ZnSO ₄ @ 50 kg ha ⁻¹		18.53	16.01	34.54	7.48	7.04	14.51	10.00	97.33	107.33
T ₁₃ : T ₁₂ + Foliar application of FeSO ₄ @ 0.5% and ZnSO ₄ @ 0.5% at tillering and panicle initiation stage		23.78	21.31	45.09	9.82	8.90	18.55	11.72	113.67	125.40
T ₁₄ : Control		9.47	6.60	16.07	2.99	3.42	6.40	5.24	53.80	59.04
SEm±		0.57	0.42	1.00	0.24	0.20	0.44	0.27	2.85	3.10
CD (P=0.05)		1.62	1.18	2.84	0.68	0.56	1.24	0.77	8.08	8.79
CV (%)		7.66	7.17	7.58	8.52	7.10	7.87	7.17	7.66	7.56
Year	SEm±	0.22	0.16	0.38	0.09	0.08	0.17	0.10	1.08	1.18
	CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y x T	SEm±	0.80	0.59	1.42	0.34	0.28	0.62	0.39	4.03	4.38
	CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4: Pooled Iron and Zinc uptake (g ha⁻¹) by finger millet crop as influenced by different treatments

Treatments		Pooled Iron uptake (g ha ⁻¹)			Pooled Zinc uptake (g ha ⁻¹)		
		Grain	Straw	Total	Grain	Straw	Total
T ₁ : RDF		39.87	70.58	110.46	25.55	47.93	73.48
T ₂ : RDF + Soil application of FeSO ₄ @ 25 kg ha ⁻¹		54.21	83.24	137.47	31.92	62.89	94.98
T ₃ : T ₂ + Foliar application of FeSO ₄ @ 0.5% at tillering and panicle initiation stage		59.52	95.48	154.91	33.96	69.56	103.53
T ₄ : RDF + Soil application of FeSO ₄ @ 50 kg ha ⁻¹		49.56	79.27	128.82	29.12	57.51	86.63
T ₅ : T ₄ + Foliar application of FeSO ₄ @ 0.5% at tillering and panicle initiation stage		54.58	88.87	143.45	32.64	64.78	97.41
T ₆ : RDF + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹		51.44	87.63	139.07	37.31	78.33	115.64
T ₇ : T ₆ + Foliar application of ZnSO ₄ @ 0.5% at tillering and panicle initiation stage		54.46	89.12	143.57	41.34	82.38	123.71
T ₈ : RDF + Soil application of ZnSO ₄ @ 50 kg ha ⁻¹		48.75	86.53	135.28	35.12	73.57	108.69
T ₉ : T ₈ + Foliar application of ZnSO ₄ @ 0.5% at tillering and panicle initiation stage		52.32	88.81	141.13	38.26	81.48	120.59
T ₁₀ : RDF + Soil application of FeSO ₄ @ 25 kg ha ⁻¹ + ZnSO ₄ @ 25 kg ha ⁻¹		60.29	100.20	160.49	40.28	84.88	125.15
T ₁₁ : T ₁₀ + Foliar application of FeSO ₄ @ 0.5% and ZnSO ₄ @ 0.5% at tillering and panicle initiation stage		77.58	113.73	191.31	52.07	95.62	147.69
T ₁₂ : RDF + Soil application of FeSO ₄ @ 50 kg ha ⁻¹ + ZnSO ₄ @ 50 kg ha ⁻¹		56.23	89.76	145.99	37.68	73.02	110.37
T ₁₃ : T ₁₂ + Foliar application of FeSO ₄ @ 0.5% and ZnSO ₄ @ 0.5% at tillering and panicle initiation stage		71.15	114.67	185.81	47.00	94.42	141.42
T ₁₄ : Control		26.36	46.65	73.01	16.62	33.11	49.73
SEm±		1.58	2.40	4.21	1.06	1.93	3.09
CD (P=0.05)		4.48	6.82	11.96	3.00	5.49	8.76
CV (%)		7.15	6.68	7.26	7.27	6.64	7.06
Year	SEm±	0.60	0.91	1.59	0.40	0.73	1.17
	CD (P=0.05)	NS	NS	NS	NS	NS	NS
Y x T	SEm±	2.23	3.40	5.96	1.50	2.74	4.37
	CD (P=0.05)	NS	NS	NS	NS	NS	NS

Iron and Zinc Uptake

The total iron (Fe) and zinc (Zn) uptake by the grain, straw, and whole crop of finger millet was significantly affected by the various iron and zinc agronomic fortification treatments (Table 4). A critical appraisal of the pooled data revealed that treatment T₁₁ (RDF + soil application of FeSO₄ @ 25 kg ha⁻¹ and ZnSO₄ @ 25 kg ha⁻¹ + foliar application of FeSO₄ @ 0.5% and ZnSO₄ @

0.5% at the tillering and panicle initiation stage) recorded the highest total Fe uptake (191.31 g ha⁻¹) and total Zn uptake (147.69 g ha⁻¹). While T₁₁ proved significantly superior to most treatments, it remained statistically at par with T₁₃ regarding both total Fe (185.81 g ha⁻¹) and total Zn uptake (141.42 g ha⁻¹). These were sequentially followed by treatments T₁₀ and T₇ whereas the absolute minimum total Fe (73.01 g ha⁻¹) and Zn (49.73 g ha⁻¹)

uptake values were consistently observed under the unfertilized control (T₁₄).

The profound enhancement in micronutrient uptake under T₁₁ can be ascribed to the synergistic advantage of combining basal soil applications with targeted foliar sprays. Soil-applied FeSO₄ and ZnSO₄ likely enriched the rhizosphere, maintaining a steady baseline availability of Fe and Zn during early vegetative growth to promote robust root proliferation and enhanced nutrient absorption. Concurrently, foliar interventions at critical physiological phases—namely tillering and panicle initiation facilitated rapid, direct nutrient entry through the foliage when crop demand peaks. Because iron is essential for chlorophyll biosynthesis, electron transport, and respiratory metabolism, and zinc plays a key regulatory role in enzyme activation, protein synthesis, and membrane stability, their optimal supply enhanced overall photosynthetic efficiency, assimilate production, and dry matter accumulation. This synchronized source-to-sink translocation resulted in substantially higher micronutrient accumulation in both the grain and straw. These findings align with similar beneficial effects of integrated Fe and Zn fertilization on nutrient uptake and agronomic biofortification reported by Niyigaba *et al.* (2019)^[9], Jalal *et al.* (2020)^[6], Vijayakumar *et al.* (2020)^[14] and Khobragade *et al.* (2022)^[8].

Conclusion

It can be concluded that for achieving superior grain quality of finger millet cv. GN 8, the crop should be fertilized with RDF (40:20 kg NP ha⁻¹) along with soil application of FeSO₄ @ 25 kg ha⁻¹ and ZnSO₄ @ 25 kg ha⁻¹ and two foliar sprays of FeSO₄ 0.5% + ZnSO₄ 0.5% at tillering and panicle initiation stage. Additionally, it also improved nutrient use efficiency and sustained soil fertility under south Gujarat condition.

References

1. Anonymous. Director of Agriculture, Gujarat State, Gandhinagar. Gujarat Government; 2025.
2. Dholariya HP, Zinzala VJ, Patel JV, Patel VM. Zinc nutrition in finger millet [*Eleusine coracana* (L.) Gaertn.] for better nutritional security. International Journal of Current Microbiology and Applied Sciences. 2020; Special Issue 11:1082–1086.
3. Dida MM, Wanyera N, Dunn ML, Bennetzen JL, Devos KM. Population structure and diversity in finger millet (*Eleusine coracana*) germplasm. Tropical Plant Biology. 2008;1:131–141.
4. Gomez KA, Gomez AA. Statistical procedures for agricultural research. New York: John Wiley & Sons; 1984.
5. Intwala CG, Patil HE, Patel BK, Patel JV. A high yielding finger millet variety (GNN-6) for cultivation in hilly region in South and Middle Gujarat. International Journal of Tropical Agriculture. 2017;35(4):771–776.
6. Jalal A, Shah S, Teixeira da Silva JA, Khan A, Shah T, Ilyas M, *et al.* Yield enhancement and biofortification of bread wheat through combined foliar application of zinc and iron fertilizers. Pakistan Journal of Botany. 2020;52(5):1843–1850.
7. Kang RK, Jain R, Mridula D. Impact of indigenous fiber rich premix supplementation on blood glucose levels in diabetics. American Journal of Food Technology. 2008;3(1):50–55.
8. Khobragade N, Patil KD, Dodake SB, Gavitt S, Jadhav A, Joke A, *et al.* Agronomic biofortification of finger millet with calcium and iron by using different sources in lateritic soils of Konkan. The Pharma Innovation Journal. 2022;11(1):864–866.
9. Niyigaba E, Twizerimana A, Mugenzi I, Ngnadong WA, Ye YP, Wu BM, *et al.* Winter wheat grain quality, zinc and iron concentration affected by a combined foliar spray of zinc and iron fertilizers. Agronomy. 2019;9(5):250.
10. Roy AK, Ali P, Lakra RK, Alam P, Mahapatra P, Narayan R. Effect of integrated nutrient management practices on nutrient uptake, yield of finger millet (*Eleusine coracana* L.) and post-harvest nutrient availability under rainfed condition of Jharkhand. International Journal of Current Microbiology and Applied Sciences. 2018;7(8):339–347.
11. Shivay YS, Prasad R, Singh RK, Pal M. 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.). Journal of Agricultural Science. 2015;7(2):161–173.
12. Szerement J, Szatanik-Kloc A, Mokrzycki J, Hersztek M. Agronomic biofortification with Se, Zn, and Fe: an effective strategy to enhance crop nutritional quality and stress defense—a review. Journal of Soil Science and Plant Nutrition. 2021. doi:10.1007/s42729-021-00719-2.
13. Teklu D, Gashu D, Joy EJM, Lark RM, Bailey EH, Wilson L, *et al.* Impact of zinc and iron agronomic biofortification on grain mineral concentration of finger millet varieties as affected by location and slope. Frontiers in Nutrition. 2023;10:1159833:1–9. doi:10.3389/fnut.2023.1159833.
14. Vijayakumar MR, Sivakumar, Tamilselvan N. Effect of zinc and iron application on yield attributes, available nutrient status and nutrient uptake of finger millet under rainfed condition. International Journal of Current Microbiology and Applied Sciences. 2020;9(5):3237–3246. doi:10.20546/ijcmas.2020.905.384.
15. Waghmare PK, Patel AP, Patel KG, Patel VM, Pital RR, Patange MJ. Growth and yield of finger millet (*Eleusine coracana* L.) varieties as influenced by zinc fortification. International Journal of Research in Agronomy. 2025;8(7):793–797.