



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating: 5.20
www.agronomyjournals.com
2025; 8(7): 793-797
Received: 13-04-2025
Accepted: 18-05-2025

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Growth and yield of finger millet (*Eleusine coracana* L.) varieties as influenced by zinc fortification

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DOI: <https://www.doi.org/10.33545/2618060X.2025.v8.i7j.3289>

Abstract

A field experiment entitled 'Response of finger millet (*Eleusine coracana* L.) varieties to zinc fortification' was conducted during the kharif seasons of 2023 and 2024 at the College Farm, N. M. College of Agriculture, Navsari Agricultural University, Navsari, to evaluate the impact of zinc application through soil and foliar modes on the growth, yield and quality of finger millet. The experiment was laid out in a factorial randomized block design with three varieties (V₁: WN-259, V₂: GNN-7, V₃: GN-8) and nine zinc fortification treatments, ranging from control to combinations of soil and foliar applications of ZnSO₄. Results revealed that zinc fortification significantly influenced crop performance, with the treatment F₉ (Soil application of ZnSO₄ @ 25 kg/ha + foliar spray @ 1% at tillering and panicle initiation stages) recording the highest plant height (98.39 cm), dry matter accumulation (5654 kg/ha), tillers (54/m²), panicle length (9.75 cm), fingers per panicle (8.68), grain yield (1924 kg/ha) and straw yield (4811 kg/ha), followed closely by F₈ (same soil dose + 0.5% foliar spray). Thus, combined soil and foliar application of ZnSO₄, particularly at 25 kg/ha soil + 1% foliar spray, proved most effective in enhancing finger millet performance under the agro-climatic conditions of South Gujarat.

Keywords: Finger millet, zinc fortification, nutrient application through soil, foliar application

Introduction

Finger millet (*Eleusine coracana* L.) known as 'ragi', is one of India's oldest crops, dating back to 2300 BC in Karnataka. Though originally from Africa, it has been widely domesticated in India and is nutritionally superior to rice and wheat, rich in protein, calcium, iron, and dietary fiber. Globally, millet cultivation declined by 29% from 1963 to 2021, though Africa's area grew by 61%. India remains a top producer, contributing over 50% of global finger millet, especially in semi-arid regions. In Gujarat, it is mainly grown in Dangs, Valsad, and Navsari, covering 10.5 thousand hectares. The 2023 International Year of Millets highlighted their nutritional value, and biofortification efforts have led to nutrient-rich crop varieties. Agronomic biofortification using advanced fertilizers and foliar application improves nutrient uptake. Zinc, a key micronutrient for plants and humans, is deficient in 49% of Indian soils and 24% in Gujarat. Enhancing zinc in finger millet can address malnutrition and improve yields, prompting the proposed field experiment.

Materials and Methods

The present investigation entitled 'Response of finger millet (*Eleusine coracana* L.) varieties to zinc fortification' was carried out during kharif season for two successive years viz., 2023 and 2024 to evaluate the impact of zinc application through soil and foliar mode on growth characteristics and yield attribute in finger millet. A research experiment was conducted over two consecutive kharif seasons (2023-24 and 2024-25) to study the response of different finger millet varieties to zinc fortification, aiming to improve crop nutrition and address zinc deficiencies in human diets. The experiment included three finger millet varieties i.e. WN-259 (V₁), GNN-7 (V₂), and GN-8 (V₃) as the main plot treatments and nine zinc fortification treatments as sub-treatments, which combined soil and foliar applications of zinc sulfate (ZnSO₄) at varying rates as T₁: control (no application), T₂: soil application at 12.5 kg/ha, T₃: soil application at 25.0 kg/ha, T₄: Foliar application at 0.5% at tillering and panicle initiation stages

or T₅: Foliar application at 1% at tillering and panicle initiation stages, T₆: soil application at 12.5 kg/ha along with foliar application at 0.5% or T₇: soil application at 12.5 kg/ha along with foliar application at 1% at tillering and panicle initiation stages, T₈: soil application at 25.0 kg/ha along with foliar application at 0.5% or T₉: soil application at 25.0 kg/ha along with foliar application at 1% at tillering and panicle initiation stages and combinations of both methods. The study followed a Randomized Block Design with factorial arrangements with treatments being randomly assigned across experimental units. The primary objective was to assess how zinc fortification impacts plant growth and yield, while also determining which variety and zinc application method yields the best results. The research aimed to provide insights into how different zinc treatments affect plant height, tillering, panicle length and grain yield with the goal of enhancing finger millet as a biofortified crop. The results of this experiment would help identify the most effective zinc application strategies to improve both crop growth and productivity, benefiting farmers and consumers, especially in zinc-deficient regions.

Results and Discussion

Zinc fortification had a profound and statistically significant influence on the growth and yield performance of finger millet across all observed parameters. Among the different treatments evaluated the application of ZnSO₄ at 25 kg/ha to the soil along with a 1% foliar spray at the critical growth stages of tillering and panicle initiation (treatment F₉) consistently resulted in superior plant performance. In terms of vegetative growth, F₉ produced the tallest plants at all growth stages, reaching a maximum height of 100.94 cm at harvest, whereas the control treatment (F₁), which received no zinc supplementation, recorded the shortest height of 79.10 cm. Likewise, leaf area per plant, which is crucial for photosynthesis and biomass accumulation, was also markedly increased under zinc fortification with F₉ recording 805.53 cm² at 90 days after

sowing (DAS) significantly higher than the control which showed the lowest leaf area at all stages. Similarly, dry matter accumulation was greatest in F₉, with 1375 kg/ha recorded at 30 DAS and consistently higher values at subsequent growth stages highlighting the role of zinc in enhancing metabolic activity, nutrient utilization and overall biomass production.

In terms of reproductive development, F₉ produced the highest number of panicles per square meter (55.19) significantly more than the control (39.74) suggesting improved transition from vegetative to reproductive stages under zinc-enriched conditions. Yield attributes were also markedly improved by zinc application. F₉ resulted in the highest number of grains per panicle (2220) followed by F₈, while the control had the lowest grain count (1802) indicating that zinc plays a critical role in enhancing grain set and filling. Panicle weight and test weight also improved significantly with zinc fortification, with F₉ registering the highest test weight of 2.92 g compared to 2.37 g in the control reflecting better grain quality and nutrient translocation. Grain yield under F₉ was the highest across both years and pooled data (1984, 1865 and 1924 kg/ha) followed closely by F₈, while the control recorded the lowest yield (1575 kg/ha) which can be attributed to zinc deficiency affecting plant metabolism and reproductive efficiency. Similarly, straw yield was also significantly higher under F₉ (up to 4959 kg/ha) compared to F₁ (as low as 3923 kg/ha) indicating that zinc also supports vegetative biomass production. Finally, the harvest index (HI) which represents the efficiency of the plant in allocating biomass to economic yield was highest under F₉ (28.70%) showing better partitioning of assimilates toward grain development. Overall, the study clearly demonstrated that zinc fortification particularly the combined application through soil and foliar spray at appropriate stages significantly enhanced both growth and yield parameters in finger millet with treatment F₉ proving to be the most effective while the control (F₁) consistently showed the poorest performance due to the absence of zinc nutrition.

Table 1: Growth attributing characteristics of finger millet as influenced by different treatments

Treatment	Plant height at harvest (cm)			Leaf area at 90 DAS (cm ²)			Dry matter accumulation at harvest (kg/ha)		
	2023	2024	Pooled	2023	2024	Pooled	2023	2023	2023
Varieties									
V ₁	85.37	80.27	82.82	655.35	732.23	663.79	5114	4969	5041
V ₂	87.77	82.68	85.23	673.81	763.72	726.20	5132	5041	5085
V ₃	89.71	84.61	87.16	688.69	784.99	729.41	5145	5057	5101
SEm±	1.44	1.44	1.02	11.09	16.00	9.73	63.3	73.3	48.43
CD at 5%	NS	NS	2.86	NS	NS	27.30	NS	NS	135.98
Zinc fortification									
F ₁	79.70	74.60	77.15	611.78	653.17	632.48	4858	4665	4763
F ₂	82.66	77.56	80.11	634.53	700.25	367.39	4897	4786	4843
F ₃	83.69	78.69	81.14	642.44	716.61	679.53	4985	4876	4930
F ₄	84.00	78.90	81.45	644.85	758.48	709.20	5077	4930	5005
F ₅	85.97	80.87	83.42	659.91	769.07	709.45	5013	4887	4948
F ₆	86.99	81.89	84.44	667.78	772.57	718.43	4977	4825	4902
F ₇	87.21	82.11	84.66	669.48	774.05	721.03	5209	5052	5132
F ₈	97.43	92.33	94.88	747.95	835.52	805.18	5508	5570	5539
F ₉	100.94	95.84	98.39	774.84	863.12	805.53	5640	5609	5624
SEm±	2.50	2.50	1.77	19.20	27.72	16.86	109.70	127.0	83.89
CD at 5%	7.10	7.10	4.96	54.49	78.66	47.28	312	361	236
CV%	8.56	9.10	8.82	8.56	10.94	9.98	6.41	7.58	7.01

Where; V₁: WN-259, V₂: GNN-7 and V₃: GN-8

F₁: Control

F₂: Soil application of ZnSO₄ @ 12.5 kg/ha

F₃: Soil application of ZnSO₄ @ 25.0 kg/ha

F₄: Foliar application of ZnSO₄ @ 0.5% at tillering and panicle initiation stage

F₅: Foliar application of ZnSO₄ @ 1% at tillering and panicle initiation stage

F₆: Soil application of ZnSO₄ @ 12.5 kg/ha + Foliar application of ZnSO₄ @ 0.5% at tillering and panicle initiation stage

F₇: Soil application of ZnSO₄ @ 12.5 kg/ha + Foliar application of ZnSO₄ @ 1% at tillering and panicle initiation stage

F₈: Soil application of ZnSO₄ @ 25 kg/ha + Foliar application of ZnSO₄ @ 0.5% at tillering and panicle initiation stage

F₉: Soil application of ZnSO₄ @ 25 kg/ha + Foliar application of ZnSO₄ @ 1% at tillering and panicle initiation stage

Table 2: Yield attributing characteristics of finger millet as influenced by different treatments

Treatment	Number of panicles at harvest			Panicle weight at harvest (g)			Test weight (g)		
	2023	2024	Pooled	2023	2024	Pooled	2023	2023	2023
Varieties									
V ₁	42.81	41.94	42.38	4.59	4.47	4.52	2.55	2.48	2.55
V ₂	44.56	43.61	44.09	4.65	4.58	4.61	2.58	2.55	2.56
V ₃	45.98	45.03	45.50	4.77	4.64	4.71	2.66	2.58	2.62
SEm±	1.83	1.01	0.73	0.07	0.06	0.05	0.04	0.03	0.02
CD at 5%	5.18	NS	2.04	NS	NS	0.13	NS	NS	0.07
Zinc fortification									
F ₁	38.67	37.98	38.32	4.33	4.20	4.26	2.40	2.34	2.37
F ₂	40.83	39.88	40.35	4.46	4.34	4.40	2.48	2.41	2.45
F ₃	41.58	40.63	41.11	4.51	4.39	4.45	2.51	2.44	2.47
F ₄	41.81	40.86	41.33	4.53	4.41	4.47	2.51	2.45	2.48
F ₅	43.24	42.29	42.77	4.56	4.49	4.53	2.53	2.49	2.56
F ₆	43.99	43.04	43.52	4.62	4.50	4.58	2.57	2.50	2.54
F ₇	44.15	43.20	43.68	4.66	4.56	4.59	2.59	2.53	2.55
F ₈	51.61	50.66	51.14	5.10	5.03	5.06	2.84	2.80	2.82
F ₉	54.17	53.22	53.70	5.26	5.17	5.21	2.92	2.87	2.90
SEm±	1.83	1.74	1.26	0.12	0.11	0.08	0.06	0.06	0.04
CD at 5%	5.18	4.94	3.54	0.34	0.31	0.23	0.18	0.16	0.12
CV%	12.32	12.01	12.17	7.78	7.18	7.49	7.52	6.90	7.22

Where; V₁: WN-259, V₂: GNN-7 and V₃: GN-8F₁: ControlF₂: Soil application of ZnSO₄ @ 12.5 kg/haF₃: Soil application of ZnSO₄ @ 25.0 kg/haF₄: Foliar application of ZnSO₄ @ 0.5% at tillering and panicle initiation stageF₅: Foliar application of ZnSO₄ @ 1% at tillering and panicle initiation stageF₆: Soil application of ZnSO₄ @ 12.5 kg/ha + Foliar application of ZnSO₄ @ 0.5% at tillering and panicle initiation stageF₇: Soil application of ZnSO₄ @ 12.5 kg/ha + Foliar application of ZnSO₄ @ 1% at tillering and panicle initiation stageF₈: Soil application of ZnSO₄ @ 25 kg/ha + Foliar application of ZnSO₄ @ 0.5% at tillering and panicle initiation stageF₉: Soil application of ZnSO₄ @ 25 kg/ha + Foliar application of ZnSO₄ @ 1% at tillering and panicle initiation stage**Table 3:** Grain yield, straw yield (kg/ha) and harvest index (%) of finger millet as influenced by different treatments

Treatment	Grain yield (kg/ha)			Straw yield (kg/ha)			Harvest index (%)		
	2023	2024	Pooled	2023	2024	Pooled	2023	2023	2023
Varieties									
V ₁	1680	1662	1671	4199	4154	4176	28.57	28.51	28.54
V ₂	1728	1680	1704	4320	4201	4261	28.67	28.53	28.60
V ₃	1766	1709	1738	4416	4273	4344	28.70	28.54	28.62
SEm±	32.82	31.56	22.77	82.06	78.91	56.92	3.81	2.01	2.91
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS
Zinc fortification									
F ₁	1569	1582	1575	3923	3954	3938	28.51	28.49	28.50
F ₂	1626	1595	1613	4066	3989	4034	28.52	28.50	28.51
F ₃	1644	1601	1620	4111	4002	4050	28.54	28.52	28.53
F ₄	1651	1651	1651	4128	4128	4128	28.54	28.53	28.53
F ₅	1689	1685	1695	4222	4211	4237	28.57	28.55	28.56
F ₆	1709	1692	1697	4263	4231	4242	28.60	28.59	28.59
F ₇	1712	1701	1702	4280	4253	4255	28.61	28.60	28.60
F ₈	1937	1782	1860	4843	4455	4649	28.70	28.67	28.68
F ₉	1984	1865	1924	4959	4663	4811	28.71	28.69	28.70
SEm±	56.84	54.67	39.43	142.14	136.68	98.60	0.40	0.20	0.31
CD at 5%	161.32	155.14	110.59	403.36	387.88	276.51	NS	NS	NS
CV%	9.89	9.74	9.82	9.89	9.74	9.82	3.80	2.01	2.90

Where; V₁: WN-259, V₂: GNN-7 and V₃: GN-8F₁: ControlF₂: Soil application of ZnSO₄ @ 12.5 kg/haF₃: Soil application of ZnSO₄ @ 25.0 kg/haF₄: Foliar application of ZnSO₄ @ 0.5% at tillering and panicle initiation stageF₅: Foliar application of ZnSO₄ @ 1% at tillering and panicle initiation stageF₆: Soil application of ZnSO₄ @ 12.5 kg/ha + Foliar application of ZnSO₄ @ 0.5% at tillering and panicle initiation stageF₇: Soil application of ZnSO₄ @ 12.5 kg/ha + Foliar application of ZnSO₄ @ 1% at tillering and panicle initiation stageF₈: Soil application of ZnSO₄ @ 25 kg/ha + Foliar application of ZnSO₄ @ 0.5% at tillering and panicle initiation stageF₉: Soil application of ZnSO₄ @ 25 kg/ha + Foliar application of ZnSO₄ @ 1% at tillering and panicle initiation stage

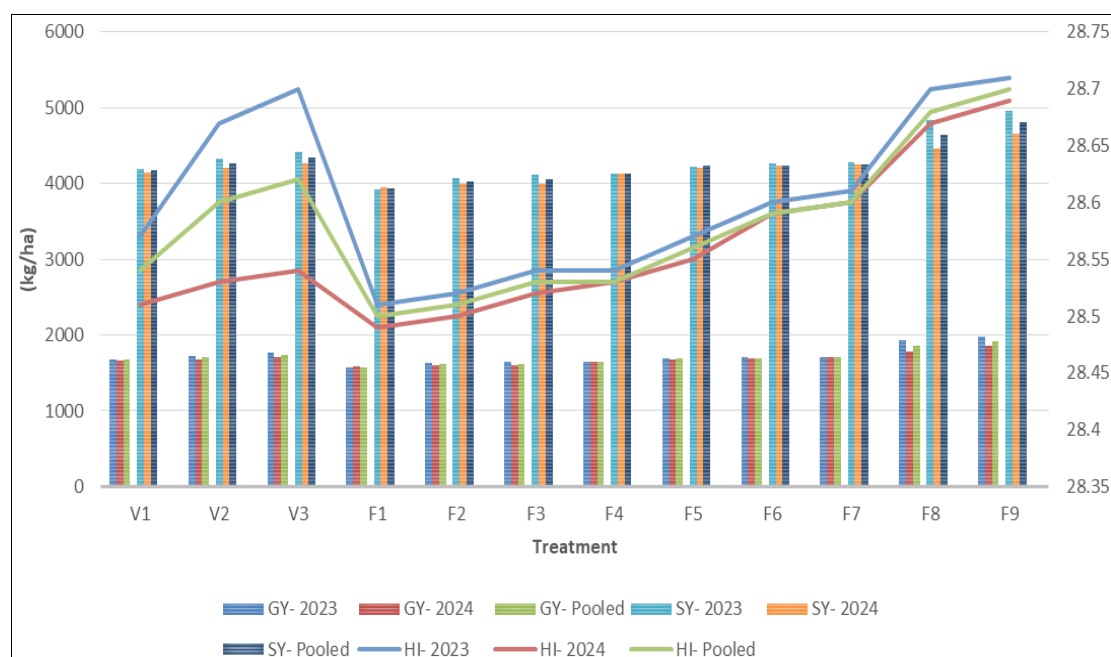


Fig 1: Grain yield, straw yield and harvest index (%) of finger millet as influenced by different treatments

Conclusion

Based on the results obtained over two years of investigation, it can be concluded that zinc fortification significantly improved the growth and yield of finger millet. The combination of soil application of ZnSO_4 at 25 kg/ha with foliar sprays of ZnSO_4 at either 1% or 0.5% during the tillering and panicle initiation stages was particularly effective. This treatment enhanced key growth parameters, such as plant height, tiller number, leaf area and dry matter accumulation as well as reproductive attributes like panicle number and grain yield. The positive effects of zinc fortification were plain across both years, demonstrating its potential to enhancement both the vegetative and reproductive performance of finger millet leading to higher overall productivity.

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