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Response of pearl millet (*Pennisetum glaucum* L.) hybrids to micronutrient application under irrigated condition

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Abstract

The present investigation was carried out at the Regional Agricultural Research Station, Vijayapur, during the *kharif* seasons of 2021, 2022, and 2023 on sandy loam soil. The experiment followed a split-plot design, with two pearl millet hybrids as main plot treatments [M1: MPMH 17 and M2: HHB 299] and nine micronutrient application treatments as sub-plots. The sub-plot treatments included: T₁ - RDF (control), T₂ - RDF + soil application of ZnSO₄ at 25 kg/ha, T₃ - RDF + 0.5% ZnSO₄ foliar spray at 20-25 DAS, T₄ - RDF + soil application of FeSO₄ at 20 kg/ha, T₅ - RDF + 0.5% FeSO₄ foliar spray at tillering stage (20-25 DAS), T₆ - RDF + 0.5% MnSO₄ foliar spray at tillering stage (20-25 DAS), T₇ - RDF + 0.2% CuSO₄ foliar spray at tillering stage (20-25 DAS), T₈ - RDF + 0.2% Borax foliar spray at tillering stage (20-25 DAS), and T₉ - RDF + ZnSO₄ (25 kg/ha) + FeSO₄ (20 kg/ha) + 0.2% Borax. Each treatment was replicated three times.

The pooled data over three years revealed that among the main plot treatments, the hybrid M2 (HHB 299) produced significantly greater plant height, grain yield, and net returns (170.4 cm, 2308 kg/ha, and ₹29,488/ha, respectively) compared to M1 (MPMH 17), which recorded 167.8 cm, 2119 kg/ha, and ₹25,790/ha, respectively. Among the sub-plot treatments, T₉ (RDF + ZnSO₄ 25 kg/ha + FeSO₄ 20 kg/ha + 0.2% Borax) achieved significantly higher grain yield, gross returns, and net returns (2308 kg/ha, ₹50,637, and ₹30,345/ha, respectively), and was statistically on par with T₂ and T₄.

The interaction of M2T₉ was found to be the most effective combination, recording the highest grain yield, gross, and net returns (2602 kg/ha, ₹53,276, and ₹32,884/ha, respectively). Overall, the study demonstrated that biofortified pearl millet hybrids responded positively to soil application of micronutrients.

Keywords: Pearl millet, micronutrient, biofortification, foliar, soil, zinc, ferrous, manganese, copper, boron

1. Introduction

Pearl millet [*Pennisetum glaucum* (L.)] ranks as the fourth most important cereal crop in India after rice, wheat, and sorghum. Commonly known as *bajra*, it is a drought-tolerant crop predominantly cultivated under rainfed conditions on marginal lands with low input management. Nutritionally, pearl millet grains are comparable to, and often superior to, other major cereals in terms of protein, energy, vitamins, and minerals^[10]. They are also rich in dietary fiber, phytochemicals, micronutrients, and nutraceuticals, earning them the designation of “nutricereal” (Gazette of India, No. 133, dated 13th April 2018).

Pearl millet is increasingly used in the preparation of health foods due to its high content of insoluble dietary fiber and gluten-free nature. It contains around 4% linoleic acid in its total fatty acids, which plays a vital role in physiological functions such as platelet aggregation, cholesterol reduction, and immune system enhancement. Additionally, pearl millet is a good source of micronutrients like iron (Fe), zinc (Zn), and magnesium (Mg), as well as essential amino acids such as lysine, threonine, methionine, and cystine, which support body growth.

However, its productivity is often limited by abiotic stresses, including drought, poor soil fertility, high soil pH, and elevated temperatures. These conditions restrict nutrient uptake by roots and hinder the availability of nutrients in forms suitable for plant absorption during different growth stages.

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Micronutrients—required in very small amounts for plant growth and development—include zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), and boron (B). Over the past four decades, their importance has gained recognition, especially following the identification of widespread micronutrient deficiencies, particularly zinc, in intensively cultivated soils across India. Zinc plays a key role in crop growth and development [1]; iron is vital for both plants and humans as it forms part of macromolecules involved in respiration, photosynthesis, chlorophyll synthesis, nitrogen fixation, and metabolism [6]; manganese acts as an enzyme activator in plant metabolism and chlorophyll synthesis; copper is essential for chlorophyll formation, protein synthesis, and respiration; and boron contributes to critical plant functions such as meristem activity, carbohydrate metabolism and translocation, RNA and cytokinin synthesis, pollen development, and seed formation [3]. In the present study, two hybrids were evaluated—HHB 299, a biofortified hybrid containing 73 ppm Fe and 41 ppm Zn, and MPMH 17, a non-biofortified hybrid with 51 ppm Fe and 35 ppm Zn. Since biofortified hybrids can absorb sufficient micronutrients when available in the soil, this study was undertaken to assess the impact of micronutrient application on the growth and yield performance of biofortified and non-biofortified pearl millet hybrids.

2. Materials and Methods

The field experiment was carried out during the *kharif* seasons of 2021, 2022, and 2023 at the Regional Agricultural Research Station, Vijayapur, located in the Northern Dry Zone (Zone-3) of Agro-climatic Region-II of Karnataka. The experimental site lies at 16°49' N latitude, 75°43' E longitude, and an altitude of 593 meters above mean sea level, with an average annual rainfall ranging from 550 to 680 mm. The soil of the experimental field was sandy loam in texture, alkaline in reaction (pH 8.21), and had a medium organic carbon content of 0.7% (Table 1).

The experiment followed a split-plot design with two main plot treatments and nine sub-plot treatments, replicated three times. Each plot measured 4.0 m in length and 5.0 m in width, resulting in a total of eighteen treatment combinations. The main plot treatments consisted of two pearl millet hybrids—M1: MPMH 17 and M2: HHB 299—while the sub-plot treatments comprised nine micronutrient application regimes:

T₁ - Control (RDF only),

T₂ - Soil application of ZnSO₄ at 25 kg/ha,

T₃ - 0.5% ZnSO₄ foliar spray at 20-25 DAS,

T₄ - Soil application of FeSO₄ at 20 kg/ha,

T₅ - 0.5% FeSO₄ foliar spray at tillering stage (20-25 DAS),

T₆ - 0.5% MnSO₄ foliar spray at tillering stage (20-25 DAS),

T₇ - 0.2% CuSO₄ foliar spray at tillering stage (20-25 DAS),

T₈ - 0.2% Borax foliar spray at tillering stage (20-25 DAS), and

T₉ - Combined application of ZnSO₄ (25 kg/ha) + FeSO₄ (20 kg/ha) + 0.2% Borax.

A recommended dose of fertilizers (60:30:0 kg NPK/ha) was uniformly applied across all treatments. Prior to sowing, the field was prepared and farmyard manure (2.5 t/ha) was incorporated into the soil. Fertilizers and micronutrients were applied as per the respective treatments at the time of sowing. Seeds were sown at a rate of 4 kg/ha, maintaining a spacing of 45 × 15 cm between rows and plants. Rows were marked using a 45 cm marker, and seeds were placed manually to ensure uniform plant spacing. Foliar applications of micronutrients were carried out as per treatment requirements using a knapsack sprayer.

Table 1: Initial properties of the soil samples of the experimental field

Soil Properties	Texture	pH	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Mn (mg/g)	Fe (mg/g)	Zn (mg/g)	Cu (mg/g)
Result	Sandy loam soil	8.21	0.7	210	22	405	1.6	9.2	0.7	0.3
Critical level	-	Alkaline	0.5	-	10	120	2.0	4.0	0.6	0.2

From each plot, five plants were randomly selected for recording various growth and yield parameters. Observations were taken on growth attributes such as plant height (cm) and the total and effective number of tillers per plant, as well as on yield components including 1000-grain weight, grain yield, and dry fodder yield (kg/ha). Harvesting of both gross and net plots was carried out carefully to avoid any mixing of produce between treatments. The grain from each net plot was threshed, cleaned, and weighed to determine grain yield, which was then converted to kilograms per hectare. Dry fodder yield was measured by weighing the remaining dry fodder (after removal of ear heads) from each net plot and converting it to a hectare basis. The recorded experimental data were statistically analyzed using the MSTAT-C software package.

3. Results and Discussion

3.1 Growth attributes

The pooled data over three years on the effect of micronutrient application on growth parameters of pearl millet hybrids are presented in Table 2. The results indicated that micronutrient application had a significant effect on plant height, as well as on the total and effective number of tillers per plant.

Among the main plot treatments, the hybrid M2 (HHB 299) recorded a significantly greater plant height (170.4 cm) compared to M1 (MPMH 17), which attained 167.8 cm. However, the difference between the two hybrids for total and effective tillers per plant was found to be statistically non-significant.

In the sub-plot treatments, T₉ (RDF + ZnSO₄ 25 kg/ha + FeSO₄ 20 kg/ha + 0.2% Borax) showed significantly higher values for plant height, total tillers, and effective tillers per plant (175.3 cm, 3.69, and 2.87, respectively). This treatment was statistically at par with T₂ (RDF + soil application of ZnSO₄ at 25 kg/ha) and T₄ (RDF + soil application of FeSO₄ at 20 kg/ha), which recorded plant heights of 172.6 cm and 172.2 cm, total tillers of 3.57 each, and effective tillers of 2.67 and 2.66, respectively. The control treatment (T₁) recorded the lowest values for all growth parameters (163.7 cm plant height, 3.23 total tillers, and 2.40 effective tillers per plant).

Regarding interaction effects, the combination M2T₉ exhibited significant superiority, recording the highest plant height, total tillers, and effective tillers per plant (176.8 cm, 3.76, and 2.93, respectively).

The improved growth under micronutrient application could be attributed to the vital roles these nutrients play in various physiological and biochemical processes—such as enzyme activation, regulation of plant hormones, and enhancement of protein synthesis—which collectively promote better plant development. Similar findings have been reported earlier in foxtail millet [13] and pearl millet [5,14].

3.2 Yield attributes and yield

The pooled data over three years on yield attributes of pearl millet as affected by micronutrient application are presented in Table 3. Among the hybrids, M2 (HHB 299) recorded a significantly higher 1000-seed weight (12.92 g) due to its bolder grains compared to M1 (MPMH 17), which recorded 12.09 g.

In the sub-plot treatments, T₉ (RDF + ZnSO₄ 25 kg/ha + FeSO₄ 20 kg/ha + 0.2% Borax) produced the highest 1000-seed weight (12.96 g). Grain and dry fodder yields were also significantly

higher in the hybrid HHB 299 (2308 and 6027 kg/ha, respectively) among the main plot treatments. Similarly, among the sub-plots, treatment T₉ resulted in the highest grain and fodder yields (2582 and 6267 kg/ha, respectively). This treatment was statistically at par with T₂ (RDF + ZnSO₄ 25 kg/ha) and T₄ (RDF + FeSO₄ 20 kg/ha), which recorded 2450 and 2375 kg/ha grain yield, and 6119 and 6026 kg/ha dry fodder yield, respectively. The lowest yields for all parameters were observed in the control treatment (T₁).

The superior performance under micronutrient application, particularly with zinc and iron, could be attributed to their role in enhancing chlorophyll synthesis and photosynthetic efficiency, which promote the translocation of assimilates to developing sink organs. The combined application of RDF with zinc has been reported to improve physiological and molecular processes in pearl millet, resulting in higher grain yield^[4,9]. The notable increase in yield may also be linked to zinc's involvement in the biosynthesis of indole acetic acid, which facilitates the initiation of reproductive primordia and stimulates photosynthetic activity^[12].

3.3 Economics

Significantly higher gross returns, net returns, and benefit-cost (B:C) ratio were recorded in the biofortified pearl millet hybrid HHB 299 (₹47,321 gross returns/ha, ₹29,488 net returns/ha, and

B:C ratio of 2.65) compared to the non-biofortified hybrid MPMH 17 (₹43,422 gross returns/ha, ₹25,790 net returns/ha, and B:C ratio of 2.46) (Table 4).

Among the sub-plot treatments, T₉ (RDF + ZnSO₄ 25 kg/ha + FeSO₄ 20 kg/ha + 0.2% Borax) recorded significantly higher gross and net returns (₹50,637 and ₹30,345 per ha, respectively). This treatment was statistically on par with T₂ (RDF + soil application of ZnSO₄ at 25 kg/ha) and T₄ (RDF + soil application of FeSO₄ at 20 kg/ha), which recorded gross returns of ₹47,925 and ₹47,020 per ha, and net returns of ₹29,381 and ₹29,351 per ha, respectively. The highest B:C ratio was observed in T₄ (2.66), while the lowest was recorded in the control treatment (T₁) with 2.41.

Regarding interaction effects, the combination M2T₉ proved to be superior, recording significantly higher grain yield, gross returns, and net returns (2602 kg/ha, ₹53,276, and ₹32,884 per ha, respectively). It was statistically at par with M2T₂ (2441 kg/ha, ₹49,975 and ₹31,331 per ha, respectively) and M2T₄ (2389 kg/ha, ₹48,986 and ₹31,217 per ha, respectively).

The enhanced economic performance observed with micronutrient application can be attributed to their essential roles in key physiological and biochemical processes within the plant—such as enzyme activation, hormone regulation, and protein synthesis—which collectively improve plant growth, productivity, and ultimately profitability^[2, 7, 8, 11].

Table 2: Effect of micronutrient application on growth attributes of biofortified and non-biofortified pearl millet hybrid (Pooled data of three years 2021, 2022 and 2023)

Treatments	Plant height (cm)			Total number of tillers/plant			Effective number of tillers/plant		
	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean
T ₁ : Control	162.3	165.0	163.7	3.18	3.27	3.23	2.40	2.40	2.40
T ₂ : ZnSO ₄ at 25 kg/ha	171.1	174.0	172.6	3.58	3.56	3.57	2.64	2.69	2.67
T ₃ : 0.5% ZnSO ₄ at 20-25 DAS	166.8	167.6	167.2	3.33	3.38	3.36	2.38	2.49	2.44
T ₄ : FeSO ₄ at 20 kg/ha	170.9	173.4	172.2	3.58	3.56	3.57	2.69	2.62	2.66
T ₅ : 0.5% FeSO ₄ at 20-25 DAS	165.8	168.4	167.1	3.42	3.44	3.43	2.56	2.51	2.54
T ₆ : 0.5% MnSO ₄ at 20-25 DAS	166.0	168.7	167.4	3.42	3.42	3.42	2.62	2.58	2.60
T ₇ : 0.2% CuSO ₄ at 20-25 DAS	167.5	170.6	169.1	3.44	3.49	3.47	2.62	2.60	2.61
T ₈ : 0.2% Borax at 20-25 DAS	165.8	168.8	167.3	3.44	3.49	3.47	2.56	2.56	2.56
T ₉ : ZnSO ₄ + FeSO ₄ + 0.2% Borax	173.7	176.8	175.3	3.62	3.76	3.69	2.80	2.93	2.87
Mean	167.8	170.4	169.1	3.45	3.48	3.47	2.59	2.60	2.60
	S.E.m. ±	CD at 5%		S.E.m. ±	CD at 5%		S.E.m. ±	CD at 5%	
Main plot	0.6	1.8		0.02	NS		0.01	NS	
Sub plot	1.3	3.8		0.06	0.17		0.05	0.15	
M X S	1.7	5.0		0.04	0.12		0.07	0.21	
S X M	1.7	5.1		0.08	0.23		0.06	0.18	

Note: RDF is common to all the treatments.

Table 3: Effect of micronutrient application on yield attributes of biofortified and non-biofortified pearl millet hybrid (Pooled data of three years 2021, 2022 and 2023)

Treatments	1000 seed weight (g)			Grain yield (kg/ha)			Dry fodder yield (kg/ha)		
	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean
T ₁ : Control	11.70	12.32	12.01	1893	2073	2116	5508	5759	5634
T ₂ : ZnSO ₄ at 25 kg/ha	12.30	13.14	12.72	2243	2441	2450	6056	6181	6119
T ₃ : 0.5% ZnSO ₄ at 20-25 DAS	11.77	12.77	12.27	2050	2207	2132	5704	5933	5819
T ₄ : FeSO ₄ at 20 kg/ha	12.37	13.15	12.76	2202	2389	2375	5937	6114	6026
T ₅ : 0.5% FeSO ₄ at 20-25 DAS	11.98	12.85	12.42	2061	2227	2260	5612	5912	5762
T ₆ : 0.5% MnSO ₄ at 20-25 DAS	12.04	13.03	12.54	2094	2266	2207	5828	5930	5879
T ₇ : 0.2% CuSO ₄ at 20-25 DAS	12.09	12.89	12.49	2106	2310	2165	5802	6005	5904
T ₈ : 0.2% Borax at 20-25 DAS	11.98	12.75	12.37	2080	2259	2189	5747	6022	5885
T ₉ : ZnSO ₄ + FeSO ₄ + 0.2% Borax	12.53	13.38	12.96	2347	2602	2582	6147	6387	6267
Mean	12.09	12.92	12.51	2119	2308	2275	5816	6027	5922
	S.E.m. ±	CD at 5%		S.E.m. ±	CD at 5%		S.E.m. ±	CD at 5%	
Main plot	0.10	0.31		33	101		40	119	
Sub plot	0.17	0.50		45	141		82	238	
M X S	0.30	0.91		54	164		55	168	
S X M	0.25	0.76		50	151		111	337	

Note: RDF is common to all the treatments.

Table 4: Effect of micronutrient application on economics in biofortified and non-biofortified pearl millet hybrid (Pooled data of three years 2021, 2022 and 2023)

Treatments	Gross returns (Rs./ha)			Net returns (Rs./ha)			B-C ratio		
	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean
T ₁ : Control	38,618	42,343	40,481	21,949	25,474	23,712	2.31	2.51	2.41
T ₂ : ZnSO ₄ at 25 kg/ha	45,874	49,975	47,925	27,430	31,331	29,381	2.48	2.67	2.58
T ₃ : 0.5% ZnSO ₄ at 20-25 DAS	42,109	45,188	43,649	24,973	27,852	26,413	2.45	2.60	2.53
T ₄ : FeSO ₄ at 20 kg/ha	45,054	48,986	47,020	27,485	31,217	29,351	2.56	2.75	2.66
T ₅ : 0.5% FeSO ₄ at 20-25 DAS	42,171	45,697	43,934	25,133	28,459	26,796	2.47	2.64	2.56
T ₆ : 0.5% MnSO ₄ at 20-25 DAS	42,938	46,479	44,709	25,731	29,072	27,402	2.49	2.66	2.58
T ₇ : 0.2% CuSO ₄ at 20-25 DAS	43,301	47,464	45,383	25,982	29,945	27,964	2.49	2.70	2.60
T ₈ : 0.2% Borax at 20-25 DAS	42,736	46,478	44,607	25,619	29,161	27,390	2.49	2.67	2.58
T ₉ : ZnSO ₄ + FeSO ₄ + 0.2% Borax	47,997	53,276	50,637	27,805	32,884	30,345	2.37	2.61	2.49
Mean	43,422	47,321	45,372	25,790	29,488	27,639	2.46	2.65	2.56
	S.E.m. ±		CD at 5%	S.E.m. ±		CD at 5%	S.E.m. ±		CD at 5%
Main plot	626		1882	626		1882	0.03		0.09
Sub plot	834		2514	834		2514	0.06		0.18
M X S	1699		5091	1699		5091	0.08		0.23
S X M	1465		4398	1465		4398	0.07		0.21

Note: RDF is common to all the treatments.

4. Conclusion

The present study demonstrated that, between the two hybrids, the biofortified HHB 299 was significantly superior to the non-biofortified MPMH 17 in terms of grain and dry fodder yield. Additionally, HHB 299 produces bold, dark gray grains, which are visually more attractive. Among the nutrient management treatments, the combined application of RDF + ZnSO₄ (25 kg/ha) + FeSO₄ (20 kg/ha) + 0.2% Borax outperformed other treatments, resulting in higher yields and greater net returns.

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