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EFFECT OF ZINC BIOFORTIFICATION ON YIELD, NUTRIENT UPTAKE AND ECONOMICS OF PEARL MILLET

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Pearl millet is an indispensable and widely cultivated dual purpose (food and fodder) crop, across the length and breadth of arid and semi-arid regions of India. It is the world's hardiest crop among the cereals (Rinku *et al*., 2016) cultivated in 6.93 million hectares producing 8.61 million tonnes with a productivity of 1243 kg ha^{-1}. It covers about 10.5% of irrigated area (DAC & FW, 2019). It is the fourth most important cereal in India in terms of cultivated area after rice, wheat and sorghum (Singh *et al*., 2017). Its grain is more nutritious and contains 60-78% carbohydrates,11-19% protein, 3.0-4.6% fat and has also good amount of phosphorus and iron apart from high content of calcium, potassium, magnesium, zinc (Zn) and manganese, riboflavin, thiamine, niacin, lysine and tryptophan (Reddy *et al*., 2016). Zn is one of the essential micronutrients required relatively in small concentrations (5-100 mg kg^{-1}) for healthy growth and reproduction of plants. It is also an essential nutrient for human health and critical for many biological functions apart from strong influence on fertility and healthy growth of hair and nails. Low availability of nutrients in grain particularly micronutrients leads to increased malnutrition. Zinc deficiency, especially in infants and young children under five years of age, has received global attention. Zinc deficiency is the fifth leading cause of death and disease in the developing world. According to the World Health Organization, about 8,00,000 people die annually due to zinc deficiency, of which 4,50,000 are children under the age of five. Nearly 49% of the global population does not meet their daily recommended intake of 15 mg day^{-1} of zinc for an adult and is one of the leading risk factors associated with diseases such as diarrhea and retarded growth contributing to the death of 8,00,000 people each year (Patil *et al*., 2017). The solubility of zinc is highly dependent on soil pH and moisture and hence, arid and semi-arid areas of Indian agro-ecosystems are often deficient in zinc. There are several approaches adopted to eliminate micronutrient malnutrition. Bio-fortification is a process of increasing the density of vitamins and minerals in crops through plant breeding, transgenic techniques, or agronomic practices. Agronomic bio-fortification is a promising and cost - effective measure to increase zinc concentration in cereal grains and to address Zn malnutrition (Rakshit *et al*., 2013). Agronomic bio-fortification is a short-term solution to enhance micronutrient availability and mainly to complement genetic bio-fortification through breeding. Among different inorganic sources of zinc, zinc sulphate ($ZnSO_4$) is the most widely used due to its high solubility and lower cost. Foliar application of micronutrients is more beneficial than soil application (Bozorgi *et al*., 2011). Apart from direct application of micronutrients, application of enriched manures is also one of the viable options which directly supply and also solubilize the native reserves of micronutrient elements and render them available to plants. Further, the beneficial effect of these materials on soil structure, nutrient retention capacity and their bio-regulatory roles in soil and productivity, quality and nutrient uptake is considerable. Integrated use of micronutrients in combination with organic manures serves as a better option due to high chelation and slow availability which prevents micronutrient losses through precipitation, fixation, oxidation and leaching. Organic fertilisers serve as a source of micronutrients and complexing agent. Zinc enriched organics provide beneficial effect on plant growth enriched nutrients for a longer time (Mansuri *et al*., 2019). Keeping these points in view, present experiment was carried out to find out the effect of agronomic zinc biofortification on yield, nutrient uptake and monetary returns of pearl millet.

The experiment was carried during rainy season, 2019 on sandy loam soils at College Farm College of Agriculture, Rajendranagar, Hyderabad, Professor Jayashankar Telangana State Agricultural University. The farm is geographically located at 17º 32' N latitude, 78º 41' E longitude at an altitude of 541.6 m above mean sea level. The soil of the experimental site was non-saline (0.31 dsm^{-1}) neutral in reaction (pH-7.1), low in organic carbon (0.47%) and available nitrogen (150.5 kg ha^{-1}), high in available P_2O_5 (82.3 kg ha^{-1}) and K_2O (351.3 kg ha^{-1}) and low in available DTPA extractable zinc (0.52 ppm). The experiment was laid out in randomized block design with 14 treatments (Table 1) and replicated thrice. A total of 628.2 mm of rainfall was received over thirty eight rainy days during crop growth period. Uniform dose of RDF (60:30:20 kg N, P_2O_5 and

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K_2O ha$^{-1)}$ was applied to all treatments. N through urea was applied in 2 equal splits (50% as basal dose and remaining 50% at tillering stage). Entire P_2O_5 through Single Super phosphate) and K_2O through muriate of potash were applied as basal. Required quantity of well decomposed farmyard manure @ 5 t ha^{-1} was applied as per the treatments (T_2 and T_9) 15 days prior to sowing of the crop and thoroughly incorporated in the soil and required quantity of well-prepared vermicompost @ 2 t ha^{-1} was applied as per the treatments (T_3 and T_{10}) as basal and thoroughly incorporated in the soil. Vermicompost @ 2 t ha^{-1} was incubated for enrichment with 21% $ZnSO_4$ @ 12.5 kg ha^{-1} (T_6 and T_{13}) and 25 kg ha^{-1} (T_7 and T_{14}) at room temperature for 15 days by proper moistening and later it was applied as per the treatments as basal one day before sowing and incorporated in the soil. The nutrient content of organics is detailed in Table 2.

Table 1. Treatment details

T_1 - RDF (60:30:20 kg ha^{-1} N, P_2O_5, K_2O) alone
T_2 - RDF + FYM @ 5 t ha^{-1}
T_3 - RDF + Vermicompost @ 2 t ha^{-1}
T_4 - RDF + 12.5 kg ha^{-1} $ZnSO_4$ (Basal)
T_5 - RDF + 25 kg ha^{-1} $ZnSO_4$ (Basal)
T_6 - RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ (Basal)
T_7 - RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ (Basal)
T_8 - RDF + Foliar spray @ 0.5% $ZnSO_4$ at Tillering + Heading + Milking stage
T_9 - RDF + FYM @ 5 t ha^{-1}+Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage
T_{10} - RDF + Vermicompost @ 2 t ha^{-1}+Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage
T_{11} - RDF + 12.5 kg ha^{-1} $ZnSO_4$ (Basal)+ Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage
T_{12} RDF + 25 kg ha^{-1} $ZnSO_4$ (Basal) + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage
T_{13} - RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ (Basal)+ Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage
T_{14} - RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ (Basal)+ Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage

The required quantity of 21% $ZnSO_4$ (Zinc sulphate heptahydrate - $ZnSO_4.7H_2O$) @ 12.5 kg ha^{-1} and 25 kg ha^{-1} was applied as per the treatments (T_6, T_7, T_{13} and T_{14}) as basal one day after single super phosphate application. For foliar application, 21% $ZnSO_4$ at 0.5% concentration was sprayed as per treatments. The pearl millet crop (PHB-3) was sown on 22nd July, 2019 adopting a spacing of 45 cm × 15 cm. The weather conditions during the crop growth period were conducive for normal growth and development and no serious incidence of pest and disease was noticed.

Table 2. Nutrient content (%) of organic manures

Organic manure	Nutrient content			
	N (%)	P (%)	K (%)	Zn (ppm)
Farmyard manure	0.56	0.28	0.52	24.2
Vermicompost	1.28	0.56	0.62	46.8
Enriched vermicompost @12.5 kg ha^{-1} 121212.5vermicompost @1212.5 kg ha^{-1}	1.64	0.68	0.76	54.5
Enriched vermicompost @ 25 kg ha^{-1}	1.68	0.69	0.82	57.8

Nutrient analysis *viz*; N, P, K and zinc was done following standard procedures. Nutrient uptake at harvest (N, P, K and Zn) was calculated as a product of corresponding nutrient content and dry matter accumulation. Data on nutrient uptake and crop parameters (collected from five randomly selected representative plants) were statistically analysed as per the procedure laid by Gomez and Gomez (1984). LSD values at p=0.05 were used to determine the significance of difference between treatment means.

An overview of the data (Table 3) clearly indicated that zinc sources (organic and inorganic), levels and methods (foliar and soil) significantly influenced grain, stover yield ,nutrient uptake (N, P, K and Zn) at harvest and monetary returns. Crop fertilized with T_{14}-RDF and zinc enriched vermicompost @ 25 kg ha^{-1} along with 0.5% foliar spray of $ZnSO_4$ at tillering, heading and milking stages recorded significantly higher grain and stover yield (3193 and 5335 kg ha^{-1}) over RDF alone and was statistically on par with T_{12} -RDF + 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (3135 and 5318 kg ha^{-1}), T_{13-} RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (2981 and 5189 kg ha^{-1}) and T_7 – RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ (2928 and 5192 kg ha^{-1}). On the other hand, crop applied with T_1- RDF alone registered lowest grain and stover yield (2477 and 4678 kg ha^{-1}). Enhanced grain and stover yield could be ascribed to the adequate availability of zinc and favorable effect of enriched vermicompost that improved mineralization process with steady availability of nutrients for prolonged period and reflected in enhanced assimilatory surface and nutrient uptake (Fulpagare *et al*., 2018; Jain *et al*., 2018 and Singh *et al*., 2019).

Perusal of nutrient uptake data at harvest indicated (Table 4) that significantly higher nitrogen uptake by grain and straw was recorded in crop fertilized with T_{14} -RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$

+ Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (66.3 and 87.6 kg ha^{-1}) but, T_{14} was on par with T_{12} (RDF + 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (64.1 and 84.0 kg ha^{-1}) and followed by T_{13}-RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (59.4 and 77.5 kg ha^{-1}). While, the lowest nitrogen uptake was observed with T_1- RDF alone (40.0 and 51.9 kg ha^{-1}). Increased nitrogen uptake with zinc enriched vermicompost might be attributed to the solubilization of native nutrients, chelation of complex intermediate organic molecules produced during decomposition of added organic manures, improved the root growth, absorption of nutrients and thus, enhanced the nutrient content, grain and stover yield (Mansuri *et al*. 2019).

With respect to phosphorus uptake, a significantly higher uptake by grain and stover was observed with T_{14} -RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (13.20 and 18.85 kg ha^{-1}) followed by T_{13}-RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (11.73 and 17.30 kg ha^{-1}) and T_7- RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ (11.32 and 16.96 kg ha^{-1}) which were statistically comparable with each other. While, lowest phosphorous uptake by grain and stover was recorded with T_1-RDF alone (7.60 and 11.54 kg ha^{-1}). Improved P uptake might be ascribed to the solubilizing action of organic acids produced during decomposition of vermicompost that resulted in mineralization of the insoluble phosphates into soluble phosphate that increased the release of native P and favored root growth and dry matter production (Patil *et al*., 2017).

Data on potassium uptake indicated that T_{14} - RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage recorded highest potassium uptake by grain and stover (29.2 and 159.7 kg ha^{-1}) by grain but, it was on par withT_{12} - RDF + 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (27.8 and 152.4 kg ha^{-1}) and followed by T_{13} (RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (25.2 and 144.3 kg ha^{-1}).While, control treatment recorded lowest potassium uptake (17.7 and 113.4 kg ha^{-1}). Increased K uptake in plots supplied with zinc enriched vermicompost and recommended dose of NPK in conjunction with foliar spray of zinc was probably be due to the solubilization of native nutrients coupled with the adequate nutrient availability that led to better dry matter accumulation (grain and stover yield) and nutrient uptake (Togas *et al*., 2017).

An overview of data on zinc uptake by grain at harvest clearly revealed that it was highest was with crop applied with T_{14} - RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at

Table. 3. Effect of zinc biofortification on yield and nutrient (N, P, K and Zn) uptake of pearl millet

Treatment	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	N uptake (kg ha^{-1})		P uptake (kg ha^{-1})		K uptake (kg ha^{-1})		Zn uptake (g ha^{-1})	
			Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
T_1	2477	4678	40.0	51.9	7.60	11.54	17.7	113.4	129.2	674.6
T_2	2570	4724	42.3	54.3	9.08	13.86	19.0	117.2	139.1	810.6
T_3	2667	4832	47.4	61.6	9.78	14.82	19.9	122.3	150.2	1008.0
T_4	2746	4908	49.9	64.6	8.97	13.09	21.0	129.1	168.1	1301.1
T_5	2897	5140	57.1	75.5	8.88	12.68	24.2	144.3	186.7	1548.2
T_6	2821	5020	52.7	72.2	10.63	15.90	23.2	136.8	175.8	1421.2
T_7	2928	5192	59.2	79.0	11.32	16.96	25.1	151.7	193.7	1802.3
T_8	2601	4812	42.3	54.1	7.98	11.87	17.6	118.6	138.9	764.6
T_9	2720	4928	48.0	62.3	9.52	14.29	20.2	124.1	156.2	923.0
T_{10}	2853	5009	52.8	68.8	10.46	15.61	22.3	130.9	168.9	1066.7
T_{11}	2890	5148	56.0	72.0	9.44	13.73	23.2	138.6	185.2	1359.6
T_{12}	3135	5318	64.1	84.0	9.82	13.47	27.8	152.4	211.5	1801.7
T_{13}	2981	5189	59.4	77.5	11.73	17.30	25.2	144.3	194.0	1484.6
T_{14}	3193	5335	66.3	87.6	13.20	18.85	29.2	159.7	221.3	1859.7
SEm $\pm$	91	107	1.76	3.38	0.36	0.66	0.87	4.53	3.22	65.53
CD (p=0.05)	265	311	5.11	9.83	1.06	1.93	2.53	13.15	9.35	190.47

Table 4. Monetary returns of Pearl millet as influenced by Zinc biofortification

Treatment	Cost of Cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B-C ratio
T_1	19350	54218	34868	2.80
T_2	24350	56117	31767	2.30
T_3	35350	58165	22815	1.65
T_4	19825	59828	40003	3.02
T_5	20300	63073	42773	3.11
T_6	35825	61447	25622	1.72
T_7	36300	63752	27452	1.76
T_8	20600	56839	36239	2.76
T_9	25600	59335	33735	2.32
T_{10}	36600	62142	25542	1.70
T_{11}	21075	62955	41880	2.99
T_{12}	21550	68018	46468	3.16
T_{13}	37075	64802	27727	1.75
T_{14}	37550	69195	31645	1.84

Tillering + Heading + Milking stage (221.3 g ha^{-1}) over rest of all treatments and was followed by T_{12} (RDF + 25 kg ha^{-1} $ZnSO_4$ T_5 + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (211.5 g ha^{-1}), T_{13} -RDF + Vermicompost enriched with 12.5 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (194.0 g ha^{-1}). While, lowest zinc uptake by grain was registered with T_1- RDF alone (129.2 g ha^{-1}).

On the other hand, highest zinc uptake by stover was recorded with T_{14} - RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (1859.7 g ha^{-1}), T_7 – RDF + Vermicompost enriched with 25 kg ha^{-1} $ZnSO_4$ (1802.3 g ha^{-1}) and T_{12} -RDF + 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage (1801.7 g ha^{-1}) which were statistically comparable with each other. The control plot with no Zinc application registered lowest Zn uptake (674.6 g ha^{-1}). The beneficial effect of enriched vermicompost could be attributed to the positive role of enriched vermicompost in mobilizing the native zinc. This might have increased the availability of Zn due to chelation and better nutrient distribution for longer period (Meena *et al.,* 2018).

With respect to monetary returns, highest gross returns (68018 **₹ ha^{-1}**), net returns (46468 **₹ ha^{-1}**) and B-C ratio (3.16) were accrued with T_{12} - RDF + 25 kg ha^{-1} $ZnSO_4$ + Foliar spray @ 0.5 % $ZnSO_4$ at Tillering + Heading + Milking stage over rest of the treatments. On account of improved grain and straw yield over rest of the treatments. On the other hand, higher cost under vermicompost applied treatments resulted in lower net returns and benefit- cost ratio.

Among the Zinc biofortification treatments, application of RDF (60:30:20 kg ha^{-1} N, P_2O_5 and K_2O) + enriched vermicompost with $ZnSO_4$ @ 25 kg ha^{-1} + foliar spray of $ZnSO_4$ @ 0.5% at tillering, heading and milking stages to pearl millet recovered higher grain zinc, grain, stover yield, macronutrient (N, P and K) uptake besides higher monetary returns.

Authors' contribution

Conceptualization of research work and designing of experiments (MMR); Execution of field/ lab experiments and data collection (UB); Analysis of data and interpretation (UB, MMR, BP); Preparation of manuscript (UB, MMR).

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