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RESEARCH ARTICLE

Enhancement of productivity and nutrient content in pearl millet by agronomic fortification

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Abstract

Field level experiment was conducted at the Agricultural College and Research Institute, Madurai, Tamil Nadu Agricultural University (TNAU), India during the rabi season of 2022 and 2023. The objective was to develop a compendium technology to enhance iron (Fe) and zinc (Zn) content, enhance the yield in pearl millet through agronomic fortification using a Factorial Randomized Block Design. The study involved a bio-fortified hybrid (ICMH 1202) and CO 10 of TNAU variety, with three replications. The treatments included soil application of Zn in chemical and microbial forms, their combination and supplementation of Zn and Fe in chemical form through foliar with the combination of CO 10 and ICMH 1202. The results revealed that cultivation of CO 10 with $ZnSO_4$ at 25 kg ha^{-1} (100 % recommended dose) applied to the soil, combined with foliar supplementation of 0.5 % of $ZnSO_4$), 0.5 % of $FeSO_4$ and nano-urea (@ 2 mL L^{-1} of water), in combination with other agronomic practices, achieved higher yield (3245 kg ha^{-1}), net income (Rs. 42155 ha^{-1}) and BCR of 2.18. This treatment also recorded Fe content of 119.85 ppm and Zn content of 39.29 ppm. Similarly, cultivation of ICMH 1202 under the same treatment achieved a yield of 2917 kg ha^{-1} and recorded higher Fe (178.11 ppm) and Zn (49.76 ppm) content in the grain. Increasing Zn and Fe application levels enhanced their total content in pearl millet grains. External application of Zn and Fe is essential for achieving optimal nutrient levels in bio-fortified hybrids, particularly under micronutrient-deficient soil conditions.

Keywords: agronomic fortification; Fe content; productivity; Zn content

Introduction

The production of food crops has significantly increased since the Green Revolution. Yet, the nutritious value of crops could not keep up with the population's increasing needs. Malnutrition, the monster of hidden hunger, has already attained the status of the utmost significance through the interventions of Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs) (1). Around 45 % of mortality within the age of five is caused by malnutrition (2). One of the many micronutrients necessary for optimum health is Zn, which is typically insufficient in the average person's diet. Zn deficiency can cause immune system dysfunction, growth restrictions in children and negative pregnancy outcomes in women (3). Similarly, anaemia and neurological disorders are just two examples of the physiological issues brought on by a diet low in Fe (4).

Until recently, production of crops has primarily focused on boosting yield of crops and agricultural productivity compared to increasing nutritional security. Micronutrient deficiencies in plants can result in micronutrient deficiencies in individuals through consumption of plant parts and value-added products as food. Zn is a vital trace element needed by both humans and plants. Semi-arid and dry climates restrict Zn uptake in plants by low solubility and higher fixation of Zn in the soil. Zn deficiency in soil hampers agricultural production and affects health of the people health, making bio fortification in agricultural production is essential (5).

Zn is essential for the synthesis of chlorophyll, enzymes and regulation of plant growth hormones. It also played a role in the synthesis of the enzymes and proteins required for plant growth. Zn helps in the formation of seeds and their maturation. Fe plays an essential role in both humans and plants. It involved in chlorophyll production and provided green colour and is needed for photosynthesis. Fe also plays an important role in enzymes production that are supporting in plant growth and metabolism (6).

Bio fortification and agronomic fortification are ways to enhance the nutrient content in the plant and enhance the availability to the human. Agronomic bio fortification is the simplest, quickest and most frequently acknowledged method to reach the rural people who are the most impoverished and to provide micronutrients, vitamins, folic acids and energy rich foods. Agronomic bio fortification involves enhancing the level of nutrients, vitamins and minerals in crops through the implementation of suitable agricultural practices. This method serves as an efficient approach for supplementing micronutrient and improving diet condition (1).

Typically, the common mechanism for unlocking various micronutrients in the soil and rhizosphere involves pH reduction facilitated by microbes. Decrease in soil pH at the level of one unit which can increase Zn availability by a hundredfold (7). Potential microbes release organic acids that provide both organic ions and protons, acting as chelating agents in the rhizosphere. Zn-solubilising microbes play several mechanisms on availability of Zn in the soil (8). In addition to reducing pH, soil microbes perform other functions to mobilize Zn to plant parts. The production of Zn-binding compounds supports for the increase in bioavailability of Zn in the rhizosphere, ultimately absorbed by the roots and transported to various plant parts (8, 9). Employing agronomic methods for bio fortifying food crops is a practical and economical approach (10). Overall, agronomic bio fortification supports to enhance the healthy life of people in the world, mainly susceptible groups' needs of micronutrient. With this background, an agronomic bio fortification study was conducted in pearl millet with the objectives to increase the nutrient level and improve the productivity of pearl millet under irrigated conditions.

Materials and Methods

Field experiment was conducted at field level during 2022 and 2023(two years) rabi season in the farm located at Agricultural College and Research Institute, Madurai, Tamil Nadu Agricultural University, India.The soil Zn (13.68 ppm) and Fe (21.12 ppm) content level were low, with the texture of red sandy loam.

Field experiment was conducted in the treatment combinations of composite (CO 10) (C_1) and hybrids (ICMH 1202) (C_2) as main factor and sources, forms and quantity of Zn and Fe as sub factors and replicated thrice under Factorial Randomized Block Design. The treatments of sub-factor include

L_1- 100 % recommended quantity of (RQ) of Zn through chemical form of fertilizer (CF) of $ZnSO_4$ @ 25 kg ha^{-1}

L_2 – 125 % RQ of Zn through CF of $ZnSO_4$ @ 31.25 kg ha^{-1}

L_3- 100 % RQ of Zn through CF of $ZnSO_4$ @ 25 kg ha^{-1}+ 0.5 % spray of $FeSO_4$ + biological form (BF) (*Bacillus megaterium* @ 500 mL ha^{-1}) through soil application

L_4– 125 % RQ of Zn through CF of $ZnSO_4$ @ 31.25 kg ha^{-1}+ 0.5 % spray of $FeSO_4$ + BF (*Bacillus megaterium* @ 500 mL ha^{-1}) through soil application

L_5- 100 % RQ of Zn CF of $ZnSO_4$ @ 25 kg ha^{-1} through soil and foliar application of $ZnSO_4$ @ 0.5 % + 0.5 % spray of $FeSO_4$

L_6- 100 % RQ of Zn CF of $ZnSO_4$ @ 25 kg ha^{-1} through soil and foliar application $ZnSO_4$ @ 0.5 % + BF through soil application + 0.5 % spray of $FeSO_4$

L_7- 100 % RQ of Zn through chemical form $ZnSO_4$ @ 25 kg ha^{-1} through soil and foliar application $ZnSO_4$ @ 0.5 % + 0.5 % spray of $FeSO_4$ + Nano urea foliar spray (@ 2 mL L^{-1} of water)

L_8- Foliar application $ZnSO_4$ @ 0.5 % + 0.5 % spray of $FeSO_4$ + Nano urea foliar spray (@ 2 mL L^{-1} of water)

Field was prepared to the level of fine tilth and layouts were formed and seeds of main factor were dippled and irrigated as per the agronomic practices for irrigated pearl millet. Pre-emergence herbicide of pendimethalin was applied @ 1.1 kg ha^{-1} on 5 DAS. The recommended fertilizer dose of 70:35:35 N, P_2O_5, K_2O kg ha^{-1} was adopted in all the treatments. 25 percent of nitrogen and 100 % phosphorus and potassium of recommended dose was applied as basal; remaining 75 % of N was top dressed at 15 DAS and 30 DAS by two splits. Irrigated the field based on the crop appearance and weather condition without any moisture stress. The quantity of Zn was applied at the time of sowing as per the treatments. Biological form was applied on soil at 7 DAS. Foliar application of micronutrient was done at 25 DAS and nano urea at 35 DAS by knapsack sprayer with 500 L of spray volume. Pest and disease were managed by spraying required pesticides and fungicides on 20 and 40 DAS by preventive methods.

The performance was assessed by the observation on growth and yield parameters at respective stages and presented in the Table 1. Initial soil and post-harvest soil were analysed. Initial soil having the status of soil organic carbon (low (4.50 g kg^{-1})), soil available N (low (70 kg ha^{-1})), P (medium (94 kg ha^{-1})) and K (high (237 kg ha^{-1}) and Zn and Fe at low status (13.05 ppm and 20.89 ppm respectively). Nutrient content in grain was analyzed and presented in Fig. 1. The methodology adhered to the protocols of Eviati et al. for chemical analyses (11). The nutrient content of grain samples was analysed using the AAS 271-Atomic Absorption Spectrophotometer. The influence of treatments also evaluated by calculating economics and presented in Table 2.

Table 1. Effect of combination treatments of variety, forms and levels of micronutrient on plant growth and yield parameters and yield of pearl millet (pooled mean of two years)

Treatments	Plant height at 50 % flowering (cm)	Flower initiation (DAS)	Plant height at harvest (cm)	Number of tillers (plant^{-1})	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
$C_1 L_1$	136	47	188	4.02	2446	5612
$C_1 L_2$	142	47	197	4.19	2582	5694
$C_1 L_3$	146	46	198	4.34	2632	5886
$C_1 L_4$	148	46	201	4.36	2891	5954
$C_1 L_5$	149	48	206	4.91	2930	5786
$C_1 L_6$	152	48	208	5.12	3096	5896
$C_1 L_7$	156	49	214	5.46	3254	6152
$C_1 L_8$	148	48	207	5.24	3076	6021
$C_2 L_1$	94	45	124	2.71	2076	5142
$C_2 L_2$	92	45	128	2.74	2221	5312
$C_2 L_3$	95	45	129	2.84	2276	5462
$C_2 L_4$	98	45	131	2.87	2432	5691
$C_2 L_5$	101	47	139	3.09	2546	5328
$C_2 L_6$	99	45	142	3.12	2881	5672
$C_2 L_7$	114	46	145	3.15	2938	5924
$C_2 L_8$	109	45	138	2.94	2762	5842
SEd	4	NS	3	0.42	24	32
CD(P=0.05)	9		7	0.91	53	67

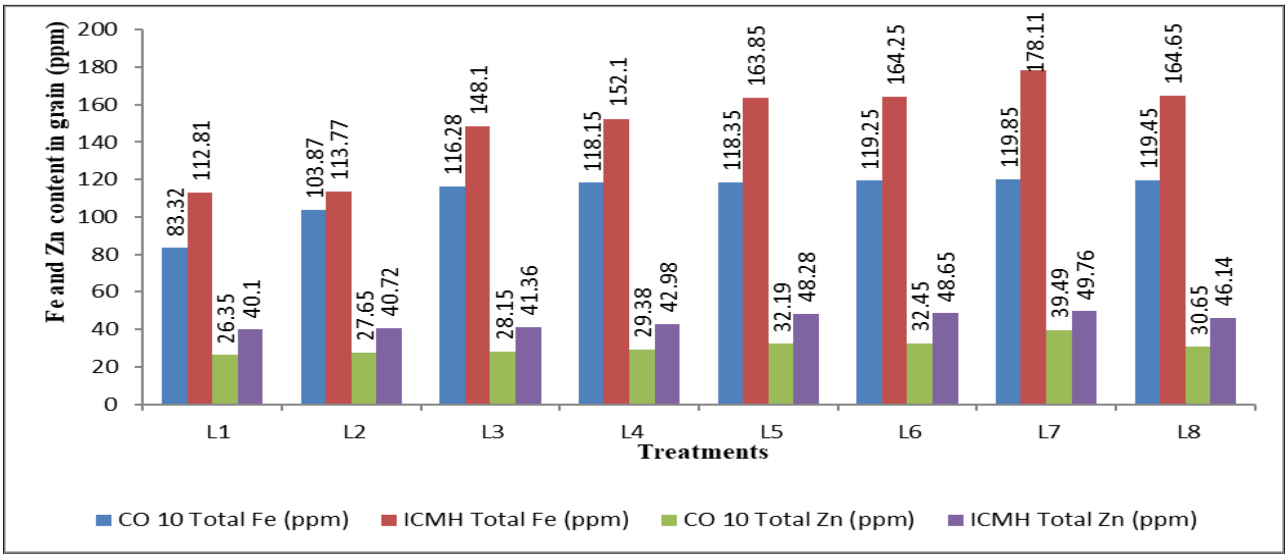

Fig. 1 Effect of treatment combinations of variety, forms and levels of micronutrient on Fe and Zn nutrient content in grain.

Table 2. Effect of treatment combinations of variety, forms and levels of micronutrient application on economics (pooled mean of two years)

Treatments	Gross income (Rs. ha^{-1})	Cost of cultivation (Rs. ha^{-1})	Net income (Rs. ha^{-1})	BCR
C_1 L_1	63596	32200	31396	1.98
C_1 L_2	67132	34075	33057	1.97
C_1 L_3	68432	33475	34957	2.04
C_1 L_4	75166	34775	40391	2.16
C_1 L_5	76180	33075	43105	2.30
C_1 L_6	80496	33425	47071	2.41
C_1 L_7	84604	33725	50879	2.51
C_1 L_8	79976	33675	46301	2.37
C_2 L_1	53976	32020	21956	1.69
C_2 L_2	57746	33895	23851	1.70
C_2 L_3	59176	33295	25881	1.78
C_2 L_4	63232	34595	28637	1.83
C_2 L_5	66196	32895	33301	2.01
C_2 L_6	74906	33065	41841	2.27
C_2 L_7	76388	33545	42843	2.28
C_2 L_8	71812	33495	38317	2.14

The data on growth and yield parameters were compiled, tabulated and subjected for statistical analysis (12). AGRES statistical software v 7.01 was employed to assess the treatment effect, with a critical difference (CD) at p = 0.05 % level for comparison of data at significance level.

Results and Discussion

Growth and yield parameters

The growth and yield parameters observed during the two year study were pooled and are presented in Table 1. Among main factors, CO 10 was performed at higher level of growth, yield and yield factors. This might be due to the genetic potential of the composite CO 10 pearl millet, which produces a higher grain yield compared to traditional varieties. This makes it an attractive option for farmers seeking better productivity, known for its ability to withstand dry conditions, making it suitable for semi-arid and arid regions. It also has improved resistance to common pests and diseases affecting pearl millet, leading to more stable yields.

Among sub factors, 100 % RQ of Zn applied in chemical form of $ZnSO_4$ @ 25 kg ha^{-1} at soil and foliar application $ZnSO_4$ @ 0.5 % + 0.5 % spray of $FeSO_4$ + Nano urea foliar spray (@ 2 mL L^{-1}) recorded the higher performance on growth, yield and yield factors. This might be due to the addition of required micronutrient and uptake by the crop and their contribution on support to physiological process of the crop and to enhance the yield and yield factors. Enhancing the quantity of supply through soil in chemical, biological and foliar supported on improvement in growth and yield factors and achieved higher yield and productivity.

Bio-fortification of Fe and Zn by agronomic methods can improve chlorophyll content (13). Treatments with Fe and Zn resulted in higher chlorophyll content. Zn and Fe function as catalytic enzymes and proteins, thus promoting chlorophyll synthesis (14). Fe plays on various physiological processes and chlorophyll formation (15). Zn enhances the functional role of enzymes and synthesis of chlorophyll (16).

The treatment combination of CO 10 + 100 % RQ of Zn through chemical form $ZnSO_4$ @ 25 kg ha^{-1} through soil and foliar application $ZnSO_4$ @ 0.5 % + 0.5 % spray of $FeSO_4$ + Nano urea foliar spray (@ 2 mL L^{-1} of water) recorded the higher growth and yield (3254 kg ha^{-1}), might be due to the enhancement of required nutrient availability to the crop. Additional supplementation of nutrient in the form of chemical, biological and foliar added incremental in the quantity of nutrient uptake by the plant. Fe is involved in plant growth and development, playing a key role in chlorophyll production, respiration and photosynthesis (17). Foliar Zn sprays influenced grain Zn content under field conditions significantly, whereas soil Zn applications at sowing had minimal effect (18). Applying micronutrient fertilizers directly to the soil or plants is an effective way to combat malnutrition in developing countries and can also improve grain yield and quality (19).

The increase in yield was matched by notable rises in the potassium and Zn levels in the grain when it reached maturity. Both applying Zn to the soil and priming the seeds by Zn led to significant boosts in grain Zn concentration. When these methods were used together, the Zn level of grain enhanced to 27 mg kg^{-1}, a notable increase compared to the control group (20). The results indicated that application of Zn in soil is a more effective method for enhancing both wheat yield and Zn concentration. Wheat crops treated with 40 kg of $FeSO_4$ ha^{-1} showed increased yield of grain (2975 kg ha^{-1}) and Fe concentration of (432.23 mg kg^{-1}) compared to untreated crops. Similarly, application of 40 kg of $ZnSO_4$ ha^{-1} achieved higher grain yield (2971 kg ha^{-1}) in wheat (21).

Economics

Economic parameters were calculated and presented in Table 2. Among the main factors, CO 10 achieved the highest gross income (Rs. 74438 ha^{-1}), net income (Rs. 40670 ha^{-1}) and BCR (2.20) compared to ICMH 1202. Among the sub factors, 100 % RQ of Zn in chemical form of $ZnSO_4$ @ 25 kg ha^{-1} at soil and foliar application $ZnSO_4$ @ 0.5 % + 0.5 % spray of $FeSO_4$ + Nano urea (@ 2 mL L^{-1} of water) recorded the highest net income (Rs. 46554 ha^{-1}) and BCR (2.37).

Treatment combination of CO 10 + 100 % RQ of Zn through chemical form $ZnSO_4$ @ 25 kg ha^{-1} through soil and foliar application $ZnSO_4$ @ 0.5 % + 0.5 % spray of $FeSO_4$ + Nano urea foliar spray (@ 2 mL L^{-1} of water) resulted in higher net income of Rs. 50879 ha^{-1} with the BCR of 2.51. Agronomic fortification of Zn and Fe influenced on enhanced growth, yield parameters and yield of crop (22, 23).

Nutrient Content

External application of Zn and Fe is important to achieve the potential level of nutrient content in bio fortified hybrid under deficit soil. Additional level of Zn and Fe application enhanced total content of Zn and Fe in grain of pearl millet (Fig. 1). Addition of Fe and Zn enhance the level of nutrient content in the grain. ICMH 1202 with the combination of 100 % recommended quantity of Zn as $ZnSO_4$ @ 25 kg ha^{-1} by soil and foliar spray of $ZnSO_4$ @ 0.5 %, 0.5 % spray of $FeSO_4$ and Nano urea (@ 2 mL L^{-1} of water) enhanced the level of Fe (178.11 ppm) and Zn (49.76 ppm) in the grain. Similarly, CO 10 composite with the combination of 100 % recommended quantity of Zn as $ZnSO_4$ @ 25 kg ha^{-1} by soil and foliar spray of $ZnSO_4$ @ 0.5 % + 0.5 % of $FeSO_4$ + Nano urea (@ 2 mL L^{-1} of water) enhanced the level of Fe (119.85 ppm) and Zn (39.49 ppm) in the grain.

Bio fortified hybrid supported to achieve a higher level of nutrient content. Zn application to the flag leaf, increased Zn concentration at the level of 17-33 %, while under spike Zn application, it increased by 30-37 %. Absorption was responsible for 68-90 % and 88-99 % of the applied Zn respectively in wheat (24). Fe-enhanced pearl millet boosted Fe absorption by 65 %, diminishing Fe deficiency, while Zn-enhanced wheat amplified Zn intake by 70 % (25). Incorporating Zn into fertilizer application under arid and semi-arid regions is crucial for human nutrition and well-being due to Zn essentiality role in human health (26).

Higher growth and yield (3254 kg ha^{-1}), net income (Rs. 50879 ha^{-1}) and BCR (2.51) resulted in the treatment combination of cultivation of CO 10, application of 100 % recommended quantity of Zn as $ZnSO_4$ @ 25 kg ha^{-1} at soil and foliar spray of $ZnSO_4$ @ 0.5 % + 0.5 % spray of $FeSO_4$ + Nano urea (@ 2 mL L^{-1} of water). The same trend also observed in the application of 100 % recommended quantity of Zn as $ZnSO_4$ @ 25 kg ha^{-1} at soil and foliar application of $ZnSO_4$ @ 0.5 % + 0.5 % spray of $FeSO_4$ + Nano urea (@ 2 mL L^{-1} of water on enhancement in the nutrient content of Fe and Zn in pearl millet. Application of nano urea favoured for the uptake of nutrient and higher Zn content in the grain. Among two composite and hybrids, ICMH 1202 responded at higher level to the application of Zn when compared to CO 10.

Conclusion

Adoption of compendium technology on cultivation of CO 10, application of recommended quantity of $ZnSO_4$ @ 25 kg ha^{-1} at soil and foliar spray of $ZnSO_4$ @ 0.5 % + 0.5 % spray of $FeSO_4$ + Nano urea foliar spray (@ 2 mL L^{-1} of water) in addition to other agronomic practices are important to achieve the productivity and enhance the nutrient content in pearl millet under irrigated conditions.

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Authors' contributions

AS was responsible for the execution of the research and analysis of nutrient content. VKS planned and conducted the research and was involved in manuscript preparation and editing. RR provided support for the analysis of nutrient content, while ST assisted with the analysis of physiological parameters. SJW contributed to documentation and manuscript preparation.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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