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Research article

Optimizing boron and zinc application strategies to enhance seed yield and quality traits in finger millet (*Eleusine coracana* (L.) Gaertn.)

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Abstract

Boron (B) and zinc (Zn) deficiencies are widespread in Indian soils, limiting both seed yield and quality in finger millet (*Eleusine coracana* L. Gaertn.). To address this, a two-year field study was conducted across two post-rainy seasons under semi-arid conditions. The experiment evaluated the effects of boron (B), zinc (Zn), B + Zn application along with absolute control (no micronutrient application) as foliar sprays at panicle initiation (PI), 50% flowering (FL), PI + FL and soil application (SA). The combined foliar application of B + Zn at PI and PI + FL stages consistently resulted in superior plant growth, reflected in increased plant height, number of productive tillers, and ear dry weight. It significantly outperformed individual nutrient treatments and the control. This treatment also recorded the highest seed and stover yields, harvest index, and improved seed quality traits such as germination, field emergence, and seedling vigor indices. Foliar feeding proved more effective than soil application, with sprays during early reproductive stages delivering the most pronounced benefits. However, economic analysis based on the benefit-cost (BC) ratio revealed that zinc applied alone at PI and PI + FL stages offered greater profitability compared to combined nutrient applications. This suggests that while B + Zn foliar sprays optimize biological performance, zinc-alone treatments are more cost-efficient. Overall, the findings underscore that synchronizing foliar applications of boron and zinc at key growth stages is a practical and scalable strategy to enhance seed yield potential and seed vigor in finger millet under semi-arid, micronutrient-deficient conditions.

Keywords: Boron, Finger millet, Foliar spray, Seed quality, Seed yield, Soil application, Zinc

Introduction

Finger millet, an annual herbaceous cereal, is a vital crop for resource-poor communities in Africa and Asia, providing essential nutrients, including high-quality protein and minerals, surpassing other major cereals like rice, wheat and maize (Abioye *et al*., 2022). Finger millet ranks as the third most significant millet crop after pearl millet and sorghum. It is cultivated across various Indian states, thriving from the coastal lowlands of Andhra Pradesh to altitudes of 8,000 feet in the Himalayas (Hariprasanna, 2023). Its geographical adaptability is remarkable, allowing it to flourish in a wide range of environmental conditions. Notably, finger millet performs well at higher elevations compared to many other tropical cereals. This crop is particularly vital in drought-prone regions, serving as a staple food source and playing a crucial role in food security (Singh *et al*., 2024). The grains are highly valued for their nutritional content, especially their calcium levels, which range from 250 to 350 mg/kg, 20 to 30 times higher than that of other cereals.

In addition to its well-known benefits for sustainability and human nutrition, finger millet also serves as a highly nutritious forage crop for livestock across several African and Asian countries. Additionally, finger millet straw provides excellent fodder, containing up to 61% total digestible nutrients (Gupta *et al*., 2017). Recent studies have emphasized its key attributes- adaptability, forage potential and nutritive value (Gowda *et al*., 2015; Baath *et al*., 2018; Kumar *et al*., 2021). In India, the dry stover left after harvesting finger millet panicles is widely used as a valuable fodder source in dryland regions. Beyond India, finger millet straw is also utilized as livestock forage in the USA, various African nations, and Ireland. Compared to conventional fodder crops like maize and sorghum, finger millet forage offers superior micronutrient content, particularly calcium, phosphorus and potassium. It contains approximately 61% total digestible nutrients,

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105 to 156 g/kg crude protein, 598 to 734 g/kg neutral detergent fibre (NDF), 268 to 382 g/kg acid detergent fibre (ADF), 597 to 730 g/kg *in-vitro* digestibility and 387 to 552 g/kg NDF digestibility (Backiyalakshmi *et al*., 2021). These nutritional metrics highlight finger millet's potential as a robust and sustainable forage option for livestock production systems.

In India, finger millet is cultivated over approximately 1.19 million hectares, producing around 1.98 million tons with an average yield of 1,661 kg per hectare (Pramanick *et al*., 2024). Karnataka is the leading state in both area and production, accounting for 56.21 and 59.52%, respectively, followed by Tamil Nadu (9.94 and 18.27%), Uttarakhand (9.40 and 7.76%), and Maharashtra (10.56 and 7.16%) (Kumar *et al*., 2024). The All India Coordinated Research Project on Small Millets has successfully released numerous improved varieties of finger millet to benefit farmers. Quality seeds are crucial as they carry the genetic potential of these enhanced varieties, ensuring that all farmers have access to seeds with high vigor and viability (Joshi and Braun, 2022). Research focused on specialized seed production practices is essential for optimizing technology that increases both seed yield and seedling vigor.

Micronutrients such as zinc and boron significantly contribute to plant nutrition during seed production, leading to improved seed set and quality (Bordolui and Mukherjee, 2022). Zinc is an essential micronutrient crucial for the growth and development of crop plants. It plays a key role as a component of carbonic anhydrase and aldolase, both of which are vital for carbon metabolism. Furthermore, zinc is integral to various biomolecules, including lipids and proteins, and serves as a cofactor for auxins, significantly influencing nucleic acid degradation. As a necessary component of many enzymes, zinc is vital for their activation. A deficiency in zinc can hinder carbohydrate digestion, damage pollen tubes, and ultimately reduce crop yields and seed quality. Many studies have demonstrated the effectiveness of zinc application in enhancing crop yield and quality. For instance, application of zinc has been shown to promote growth and yield of finger millet (Manjunath and Debbarma, 2023). Boron is another essential micronutrient critical for the growth of crop plants. Boron deficiency ranks as the second most significant micronutrient constraint in crop production, following zinc (Ahmad *et al*., 2012). It plays a crucial role in various biological processes, including the development of pollen tubes, maintenance of membrane integrity, pollination and seed setting. The primary functions of boron involve the breakdown of nucleic acids, carbohydrates, proteins, indole acetic acid, and phenols, all of which contribute to the synthesis of plant cell walls and the preservation of membrane integrity. Additionally, boron is vital for cellular division and regulates carbohydrate and protein metabolism, influencing the reproductive phase and seed development. A deficiency of boron in the soil can lead to erratic seedling growth and reduced photosynthesis (Safdar *et al*. 2023).

A zinc and boron concentration of < 0.6 and < 0.5 ppm in soil is considered deficient for zinc and boron, respectively and accordingly, 36.5, 23.2 and 8.7% of the soil samples of India were classified as Zn, B and Zn + B deficient (Shukla *et al*., 2021). Soil deficiency gets manifested in plant uptake, and any concentration in plants below a critical level is counterproductive to the crop. As soil-applied zinc fertilizer gets precipitated while reacting with phosphorus, plant availability is hampered (Maharajan *et al*., 2023). In the case of boron, too, the recommended rate of application is low (1 kg/ha) and its uptake by plants is moderated by many soil properties. For both these nutrients, quick deficiency correction in crops is attempted through foliar applications. With this background in view, this study aims to evaluate the role of micronutrient management, specifically zinc (Zn) and boron (B), in enhancing seed production in finger millet, a crop valued for its nutritional resilience. The research will also examine the impact of different approaches, such as foliar spray and soil application of these micronutrients, to determine optimal timing for nutrient delivery. By optimizing these practices, seed farmers can improve both the quantity and quality of seed production, contributing to better agricultural outcomes and food security, particularly in micronutrient-deficient millet-growing regions.

Materials and Methods

***Experimental site*:** The experiment was carried out at the Research Farm, ICAR- Indian Institute of Millets Research, Hyderabad, located at 17.3850°N, 78.4867°E and an altitude of 505 m. Physicochemical analysis of the experimental sandy loam soil indicates its moderately alkaline non-saline nature (Table 1) that was rated as low for organic carbon and available Nitrogen (N), medium for available Phosphorus (P) and Potassium (K) and deficient for Diethylenetriamine-pentaacetic acid (DTPA) extractable Zn and 0.02 M hot Calcium Chloride ($CaCl_2$) extractable B.

***Treatment details*:** Field experiments were conducted for two consecutive post-rainy seasons (October-March) of 2020-21 (year 1) and 2021-22 (year 2) to assess the impact of two modes (foliar sprays and soil application) of boron and zinc fertilization on growth, yield attributes, seed yield and seedling vigor in finger millet (cv. VL347). The experiments were laid out in split plot design (SPD) with three replications. The treatments formed by combination of micronutrient in main plot [M1: Boron (B), M2: Zinc (Zn), M3: Boron + Zinc and M4: Control (no micronutrient)

Table 1. Physiochemical properties of experimental soil (Mean of two years)

Particulars	Value	Method employed
A. Mechanical analysis		
Sand (%)	78%	Bouyoucos hydrometer (Piper, 1966)
Silt (%)	12%	
Clay (%)	10%	
Soil texture	Sandy loam	
B. Physical analysis		
Soil pH (1:2 soil suspension)	8.14	pH meter (Jackson, 1973)
E.C (dSm^{-1} at 25^{0}C)	0.11	Conductivity bridge method (Jackson, 1973)
C. Chemical analysis		
Organic carbon (%)	0.36	Walkley and Black (1934) method (Jackson, 1973)
Available N (kg ha^{-1})	174.7	Alkaline permanganate method (Subbaiah and Asija, 1956)
Available P (kg ha^{-1})	13.5	Olsen's method (Olsen, 1954)
Available K (kg ha^{-1})	273.7	Flame photometry (Jackson, 1973)
DTPA extractable zinc	0.42	Lindsay and Norvell (1978)
0.02M hot $CaCl_2$ –B	0.38	Parker and Gardner (1981)

and four stages of application of micronutrient (s) in sub-plot *i.e.* [S1: foliar spray at panicle initiation (PI) at 77 days after sowing (DAS), S2: foliar spray at 50% flowering (FL) at 93 DAS, S3: foliar spray at both PI + FL, and S4: soil application before sowing (SA)] forming a total of 16 treatment combinations: M1S1, M1S2, M1S3, M1S4; M2S1, M2S2, M2S3, M2S4; M3S1, M3S2, M3S3, M3S4; and M4S1, M4S2, M4S3, M4S4. For soil application in S4, 15 kg/ha of $ZnSO_4.7H_2O$ and 1 kg/ha of $Na_2[B_4O_5(OH)_4].8H_2O$ were used in the study and were applied as basal before sowing along with the recommended dose of NPK fertilizers. In foliar spray treatments, boron ($Na_2[B_4O_5(OH)_4]\cdot 8H_2O$) and zinc ($ZnSO_4.7H_2O$) were applied at 0.5% and 1% concentrations, respectively.

***Layout and design*:** The experiments were laid out in split plot design, with a gross plot size of 15.75 m^2 each and a spacing of 60 x 10 cm. All phosphorus (P) and potassium (K) fertilizers, as single super phosphate and muriate of potash, respectively, along with 50% nitrogen (N) through prilled urea, were applied as a basal dose uniformly before sowing to all the treatments and the remaining N was top-dressed at 30 days after sowing. Crop received an irrigation immediately after sowing, and further irrigations followed at 30 DAS, PI (77 DAS), FL (93 DAS), milking (105 DAS) and soft dough stages (115 DAS) of seed formation. Thus crop received around 6 irrigations by the flood method.

***Observations recorded*:** The observations were recorded for the characters *viz.,* plant height (PHT) (cm), productive tillers per plant (PTL), ear dry weight (EDW) (g), fingers per panicle (FGR), hundred seed weight (HSW) (mg), seed yield per plant (YPN) (g), seed yield per plot (YPT) (g), stover dry weight (STV) (g), seed germination (SG) (%), field emergence (FE) (%), shoot length (SL) (cm), root length (RL) (cm), seedling dry weight (SDW) (mg), seedling vigor index 1 (SVI1) and seedling vigor index 2 (SVI2). The growth and yield traits *viz.,* PHT, PTL, EDW, FGR, YPN, STV were recorded for every five randomly selected plants in each treatment and their average was computed. Seed yield per net-plot (YPT) and hundred seed weight (HSW) were recorded after harvest. To record HSW, a hundred seeds were randomly selected with four replicates representing each treatment combination and weighed to obtain seed test weight in milligrams (mg).

The seed germination tests were conducted as per the rules of the International Seed Testing Association (ISTA, 2015) specified for finger millet. The top of paper (TP) method was followed, where seeds were placed on top of germination paper in petri plates. A total of 4 replications of 100 seeds each were placed, after which they were kept in a germinator maintained at 25 ± 5°C. Germination counts were taken on 8th day and the seedlings were evaluated for other traits, which include root and shoot length, seedling dry weight, which was recorded from ten randomly selected seedlings and the dry weights were taken after drying them at 80°C for 24 hours. The recorded data were computed to evaluate seedling vigor indices by adopting the formulae: [Seedling vigor index 1 = Germination (%) x Seedling length (cm)] and [Seedling vigor index 2 = Germination (%) x Seedling dry weight (g)] given by Abdul Baki and Anderson (1973) and expressed as an index number.

Table 2. Effect of boron and zinc and their modes of application at different stages of crop on plant growth traits in finger millet

Treatments	PHT		PTL		FGR		EDW	
	Yr.1	**Yr.2**	**Yr.1**	**Yr.2**	**Yr.1**	**Yr.2**	**Yr.1**	**Yr.2**
Main plots (Micronutrients) (M)								
M_1 (Boron 0.5%)	71.6	76.5	7.8	13.7	7.06	7.08	7.04	6.71
M_2 (Zinc 1%)	73.3	83.4	11.4	15.6	7.30	8.00	6.95	8.25
M_3 (Boron 0.5% + Zinc 1%)	75.1	87.1	14.0	18.4	7.39	8.64	7.64	10.4
M_4 (Control)	63.7	70.7	6.6	12.0	6.22	6.45	4.98	5.75
SEM (±)	0.36	0.36	0.25	0.20	0.08	0.06	0.29	0.04
CD (P<0.05)	1.75	1.79	1.24	0.98	0.38	0.29	1.41	0.20
Sub plots (Modes and stages) (S)								
S_1 (Foliar spray at PI)	71.9	81.8	10.3	15.4	6.97	7.95	6.85	8.25
S_2 (Foliar spray at FL)	69.3	71.8	9.4	12.8	6.53	6.39	6.10	6.14
S_3 (Foliar spray at PI and FL)	73.1	87.2	11.1	17.5	7.58	8.67	7.34	9.49
S_4 (Soil application BS)	69.4	76.8	9.06	14.0	6.89	7.14	6.32	7.21
SEM (±)	0.63	0.18	0.39	0.14	0.13	0.07	0.19	0.04
CD (P<0.05)	2.48	0.72	1.53	0.56	0.52	0.28	0.78	0.16

PHT: Plant height (cm); PTL: Productive tillers per plant; FGR: Fingers per panicle; EDW: Ear dry weight (g); PI: Panicle initiation stage; FL: Flowering stage; BS: Before sowing; Yr.1: Year 1; Yr.2: Year 2

***Field emergence*:** The field emergence (FE) of seeds was tested by sowing the seeds in four replications of 50 seeds in cement pots (45 cm diameter) filled with red and black soils mixed in a 1:1 ratio. After 20 days, the seedlings that emerged with leaves above the soil surface were counted and expressed as a percentage.

***Economic analysis*:** To estimate the economic feasibility of micronutrients application (Zn and B), an economic analysis was carried out. The total expenses for growing finger millet included the costs of a package of practices followed for its production, along with the costs incurred through the micronutrients supplemented in the form of soil application and foliar sprays. Gross income was computed according to the breeder seed price specified by the Indian Council of Agricultural Research. Further, net income was obtained by eliminating the total expenditure incurred from gross returns. The benefit-cost ratio was calculated as the ratio of total gross income generated to the total cost of cultivation incurred.

***Statistical analysis*:** The data were transformed to arc-sine values wherever necessary, and the analysis was performed in split plot design for the two years' data separately using the statistical software package Statistix 8.1. (2003).

Results and Discussion

***Growth and yield parameters*:** The treatments with micronutrients zinc (Zn), boron (B) or (B + Zn) had a marked influence on plant growth and yield attributes of finger millet (Table 2). The mean values across two years of treatment M3 (B + Zn) resulted in the production of markedly taller plants (81.1 cm) than Zn (78.4 cm) and B (74.1 cm) and control (67.2 cm). Zinc foliar spray through its improved availability in leaves enhanced the photosynthetic activity contributing towards increased vegetative growth which is evident with the increased plant height, and this effect is further enhanced with application of boron, influencing vegetative growth due to increased nitrogen uptake thereby increasing the plant height (Chowdary and Patra, 2019) which is further validated from the results of Manjunath and Debbarma (2023); Oluoch *et al*., (2024) in finger millet on application of Zn and B. Further, the combination of B + Zn (M3) followed by Zn (M2) and B (M1) had significant effects on productive tillers per plant (PTL) and fingers per panicle (FGR) during both years. The M3 treatment recorded the highest PTL (16) and FGR (8) on a mean basis, followed by M2 (13.5 and 7.65) and M1 (10.75 and 7.07), and the least being (9.3 and 6.3) the control (M4). Ear dry weight (EDW)

Table 3. Effect of boron and zinc and their modes of application at different stages of crop on seed yield and stover traits in finger millet

Treatments	YPN		YPT		HSW		STV		HI	
	Yr.1	**Yr.2**	**Yr.1**	**Yr.2**	**Yr.1**	**Yr.2**	**Yr.1**	**Yr.2**	**Yr.1**	**Yr.2**
Main plots (Micronutrients) (M)										
M_1 (Boron 0.5%)	26.3	37.9	1270	1754	181	217	53.9	53.1	32.6	41.4
M_2 (Zinc 1%)	31.9	50.7	1400	2133	180	236	54.1	62.2	36.8	44.9
M_3 (Boron 0.5% + Zinc 1%)	38.5	73.6	1568	2216	182	271	56.4	79.1	40.6	48.0
M_4 (Control)	23.5	34.6	1131	1525	168	212	41.5	42.5	35.9	44.5
SEM (±)	1.03	0.38	22.5	63.9	1.43	0.53	0.42	0.44	0.75	0.40
CD (P<0.05)	5.05	1.90	110.1	313	7.02	2.63	2.04	2.19	3.70	1.40
Sub plots (Modes and stages) (S)										
S_1 (Foliar spray at PI)	32.4	52.6	1411	1929	175	236	54.6	60.4	36.7	46.3
S_2 (Foliar spray at FL)	27.4	39.7	1260	1759	169	225	49.6	55.1	35.2	40.8
S_3 (Foliar spray at PI and FL)	33.7	58.2	1392	2073	185	243	53.7	65.0	38.5	46.8
S_4 (Soil application BS)	26.7	46.4	1286	1869	182	231	48.0	56.3	*35.5*	*44.9*
SEM (±)	0.94	0.41	48.4	44.5	1.84	0.37	1.17	0.27	0.58	0.38
CD (P<0.05)	3.68	1.62	188.7	173.6	7.20	1.44	4.57	1.08	2.28	1.51

YPN: Yield per plant (g); YPT: Yield per plot (g); HSW: Hundred seed weight (mg); STV: Stover dry weight per plant (g); HI: Harvest index (%); PI: Panicle initiation stage; FL: Flowering stage; BS: Before sowing; Yr.1: Year 1; Yr.2: Year 2

Table 4. Effect of boron and zinc and their modes of application at different stages of crop on seed physiological quality traits in finger millet

Treatments	SG *		FE		SVI1		SVI2	
	Yr.1	**Yr.2**	**Yr.1**	**Yr.2**	**Yr.1**	**Yr.2**	**Yr.1**	**Yr.2**
Main plots (Micronutrients) (M)								
M_1 (Boron 0.5%)	95 (77)	88 (70)	93 (75)	82 (65)	1153	889	193	247
M_2 (Zinc 1%)	95 (78)	93 (75)	92 (74)	87 (69)	1125	1099	200	328
M_3 (Boron 0.5% + Zinc 1%)	96 (79)	94 (76)	93 (75)	88 (71)	1249	1226	232	379
M_4 (Control)	94 (76)	83 (66)	91 (72)	79 (63)	992	784	148	183
SEM (±)	0.55	0.70	0.39	0.34	13.4	7.35	3.63	3.21
CD (P<0.05)	2.46	3.10	1.73	1.53	59.3	32.5	16.0	14.2
Sub plots (Modes and stages) (S)								
S_1 (Foliar spray at PI)	94 (76)	93 (75)	92 (73)	84 (67)	1121	1056	194	303
S_2 (Foliar spray at FL)	93 (74)	83 (66)	90 (72)	78 (62)	1040	834	167	239
S_3 (Foliar spray at PI and FL)	97 (81)	94 (77)	95 (77)	91 (73)	1240	1175	218	328
S_4 (Soil application BS)	*95* (78)	87 (69)	93 (74)	82 (65)	*1118*	932	*194*	*266*
SEM (±)	0.48	0.65	0.27	0.29	13.3	6.15	5.27	2.45
CD (P<0.05)	1.85	2.49	1.03	1.11	50.6	23.5	20.1	9.35

* Values in parenthesis are arcsine transformed; SG: Seed germination (%); FE: Field emergence (%); SVI1: Seedling vigor index 1; SVI2: Seedling vigor index 2; PI: Panicle initiation stage; FL: Flowering stage; BS: Before sowing; Yr.1: Year 1; Yr.2: Year 2

improved due to B + Zn application marginally during year 1 (Yr. 1) and significantly during year 2 (Yr. 2) over control, B and Zn individual applications, respectively.

Regarding stages of micronutrient application, foliar spray at 50% flowering (FL) stage was markedly inferior to all other treatments for PHT, PTL, FGR and EDW, with the exception during Yr. 1 at par values with that of soil application (SA) of micronutrients (Table 2). Further, foliar spray at panicle initiation (PI) stage and PI + FL stages were found to be markedly superior to SA and FL stage applications, respectively, during Yr.2 of the study. On average, EDW increased by 11.6 and 11.45% with PI and PI + FL stage applications as compared to SA and PI stage applications, respectively.

Interaction effects of these micronutrients and crop stages of application revealed that B + Zn (M3) at two stages (S3), i.e., panicle initiation (PI) and flowering (FL), proved to be effective in improving plant growth and yield attributes. Zn is one of the major essential micronutrients that is required for optimum crop growth (Rion *et al*., 2022) and optimal concentrations of Zn in plants promote balanced metabolism through activation of various enzymatic reactions (Kumar *et al*., 2012). Zn, being one of the chief components for the growth of chloroplasts, its availability in required concentrations enhances the rate of photosynthesis, nitrogen fixation, growth and ultimately the yield of the crop. Numerous studies reported increased crop yields, along with seed enrichment and biofortification, through foliar application among the varied modes of Zn applications such as soil incorporation, foliar spray, or seed treatment (Hidoto *et al*., 2017). Besides Zn, another vital micronutrient that positively influences plant height and other vegetative growth-related traits is B, which is efficient in transferring sugars or energy that fuels plant growth (Qamar *et al*., 2016). Both Zn and B play an integral role in basic plant processes that include photosynthesis, protein synthesis and chlorophyll synthesis (Cakmak, 2008) that ultimately enhance the crop growth and productivity. Enhanced vegetative growth trends were recorded in crops like finger millet (Pradhan *et al*., 2016) and cotton (Ahmed *et al*., 2019), on application of Zn through foliar spray, and similar observations with B were reported by Srilekha *et al*. (2024) in finger millet. Therefore, the observed significant effects of Zn and B could be attributed to the increased availability and utilization of these nutrients at appropriate stages of crop growth.

Yield, harvest index and yield attributes: Individual application of either B (M1) or Zn (M2) or in combination of B + Zn (M3) had markedly enhanced the YPN, YPT, STV, HSW and HI over the control (M4) during both years, except B application during Yr.1 (Table 3). The enhanced seed yield was due to a concomitant increase in PTL and FGR. The combined foliar spray B + Zn (M3) gave the highest YPN and YPT (56 and 1892), followed by Zn (41 and 1767) and B (32 and 1512) and the least being (29 and 1328), the control (M4). Such positive effects of B and Zn could be attributed to the important role of boron in sexual reproduction when compared to the vegetative growth (Goldbach *et al*., 2007). It directly influences the pollen grain germination, pollen tube formation and ultimately final seed set and yield (Davarpanah *et al*., 2016). Similarly, Zn, being one of the chief elements for various physiological processes, helps in preventing sterility and promoting seed production in crops (Solanki *et al*., 2016), which is vital for pollen viability and spore formation.

Regarding modes/methods of micronutrient application, foliar sprays (S1–S3) proved superior to soil application (S4) and further, within times of foliar sprays, spraying at both stages, *i.e*., PI + FL (S3), appeared to be significantly superior (Table 3). Interaction effects on seed yield indicate that soil application of Zn is inferior to its foliar spray at PI or PI + FL stages, while for B and B + Zn applications, time or method of application had no impact (Fig 1). Spraying B at the FL stage had a similar effect to SA. The combination of B + Zn (M3) foliar spray at PI stage (S1) showed on par seed yield with PI + FL (S3). B (Yr. 2), Zn and B + Zn application during both the years (Yr. 1 and 2) showed significant improvement in STV and HI over control (Fig 1). Further, the data indicate that Zn and B + Zn application brought 14.4 and 7.1% improvement in YPN and 8.7 and 16.5% improvement in STV over B and Zn application alone, respectively. The improvement in seed yield could be ascribed to the combined impact of increased FGR and HSW.

Soil is graded as deficient for both B and Zn. Response to SA of 15 kg/ha Zn was distinct as compared to 1 kg/ha B. Binding of a small quantity of B applied in the clay mineral complex of soil and its interaction with other nutrients and time taken for transformation might be the reason for poor response to SA of B. Under Zn-deficient conditions, due to lower levels of stigma exudates, it can result in poor fertilization and finally reduced seed yields (Davarpanah *et al*., 2016). Harris and Mathuma (2015) observed that zinc is involved in RNA metabolism, encouraging the formation of carbohydrates, proteins and DNA, increasing seed formation, seed dry weight, total number of seeds and final seed yield per plant. Correspondingly, Tahir *et al*. (2012) in their study on wheat reported increased yield, and a reduction in the number of unfertile tillers due to the foliar spray of boron carried out at the booting stage of the plant growth and further played a prominent role in the seed setting of wheat. The increased test weight of the seeds from the crop plants subjected to foliar sprays with boron could be attributed to the role of boron in seed setting and sugar translocation (Rehman *et al*., 2012). Zinc similarly influences the rate of photosynthesis and the rate of translocation of assimilates from the source to the sink (Rahman *et al*., 2020). In conformity, a significant increase in the seed test weight was observed in finger millet (Prashantha and Chikkaramappa, 2017) due to boron treatments in accordance with the current study. In case of zinc micronutrient sprays significant increase in seed test weight was recorded in crops like finger millet (Oluoch *et al*., 2024), pearl millet (Jitarwal *et al*., 2024) and barnyard millet (Gajalakshmi *et al*., 2022).

Among the stages of application, foliar spray at PI (S1) proved the best and little improvement was seen with foliar spray at both S3 (PI + FL) stages (Table 3). Foliar spray at S1 and S3 on a two-year mean basis indicated the enhancement of YPT by 5.9 and 9.8% and STV by 25.7 and 13.8%, respectively, over soil application. Further, S3

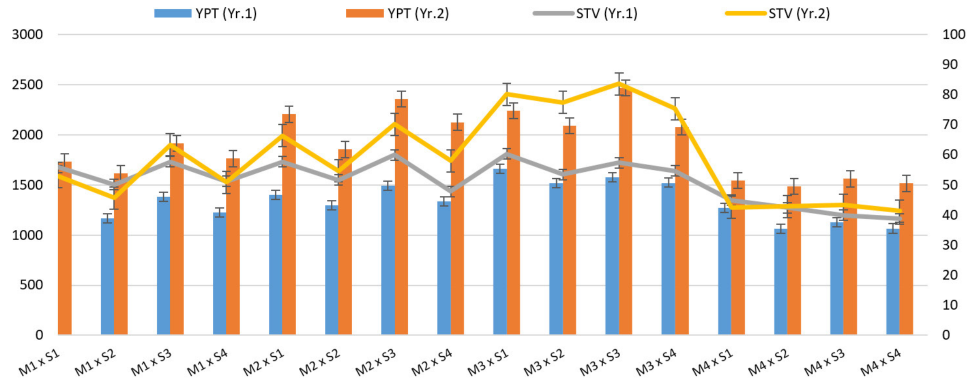

Fig 1. Interaction effects of micronutrients (M) with modes and stages (S) of application on seed yield and stover yield in finger millet during Yr.1 and Yr.2 [YPT: Yield per plot (g); STV: Stover dry weight per plant (g); Yr.1: Year 1; Yr.2: Year 2; M1 : Boron (0.5%); M2 : Zinc (1%); M3 : Boron (0.5%) + zinc (1%); M4 : Control (water spray) and no soil application; S1: Foliar spray panicle initiation (PI); S2: Foliar spray 50% flowering (FL); S3: Foliar spray at PI + FFL; S4: Soil application before sowing]

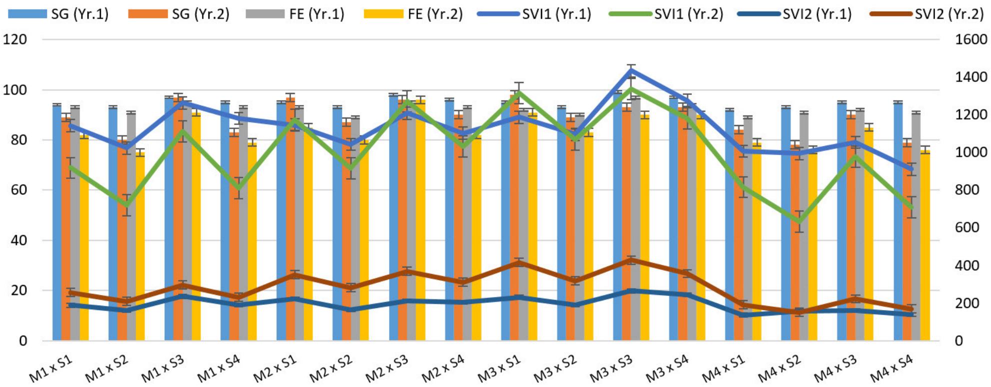

Fig 2. Interaction effects of micronutrients (M) with modes and stages (S) of application seed physiological quality traits in finger millet Yr.1 and Yr.2 [SG: Seed germination (%); FE: Field emergence (%); SVI1: Seedling vigor index1; SVI2: Seedling vigor index2; Yr.1: Year 1; Yr.2: Year 2; M1: Boron (0.5%); M2: Zinc (1%); M3: Boron (0.5%) + zinc (1%); M4: Control (water spray) and no soil application; S1: Foliar spray panicle initiation (PI); S2: Foliar spray 50% flowering (FL); S3: Foliar spray at PI + FFL; S4: Soil application before sowing]

(PI + FL) stage foliar sprays had brought a 3.7 % increase in seed yield (YPT) over S1 (PI) stage application. Foliar spray at FL did not bring any yield improvement over SA. This was due to the fact that most of the macro nutrients uptake is completed by the flowering stage and thus, foliar applied nutrients have little interaction with other nutrients in boosting plant activities and on the contrary, their application at the PI stage had given scope for boosting metabolic activities of the plant and thus improved performance. The interaction effect of micronutrients and their mode of application indicates that combined application of B + Zn at the PI stage and PI + FL stages brought 13.7% and 9.9% improvement in seed (YPT) yield as compared to the SA and foliar spray at the PI stage (Fig 1). Zinc and boron, therefore, play an essential role in many of the physiological processes that include chlorophyll formation, stomatal regulation, and starch utilization, all of which ultimately contribute to the final seed yield. Parallel findings where application of boron resulted in enhanced plant height, number of leaves per plant, number of cobs and finally adding to improved grain yield were recorded in maize Kanshouwa and Mehera (2023). Similarly, on application of zinc positive growth trends and enhanced yields were observed in finger millet (Reddy, 2023) and pearl millet (Jitarwal *et al*., 2024).

***Seed quality*:** During both the years of study, B and Zn individually and in combination (B + Zn) were at par and significantly increased the seed germination (SG), field emergence (FE), and seedling vigor indices (SVI1 and SVI2) values (Table 4). The M3 combined treatment (B + Zn) application during both years, on average, showed the highest SG (95%), followed by Zn

Table 5. Benefit-cost (BC) ratio on effect of boron and zinc, and its mode of application across growth stages for breeder seed production (per ha) in finger millet

Treatments	**Cost of cultivation**	**Total returns**		**Net returns**		**BC Ratio**	
	Yr.1 and 2	**Yr.1**	**Yr.2**	**Yr.1**	**Yr.2**	**Yr.1**	**Yr.2**
Main plots (Micronutrients) (M)							
M_1 (Boron 0.5%)	47865	76495	99245	28630	51380	1.6	2.1
M_2 (Zinc 1%)	45163	82730	119977	37567	74814	1.8	2.7
M_3 (Boron 0.5% + Zinc 1%)	49188	91400	128990	42212	79802	1.9	2.6
M_4 (Control)	43215	66172	85187	22957	41972	1.5	2.0
Sub plots (Modes and stages) (S)							
S_1 (Foliar spray at PI)	46089	83402	109747	37313	63658	1.8	2.4
S_2 (Foliar spray at FL)	46089	74730	100082	28641	53993	1.6	2.2
S_3 (Foliar spray at PI and FL)	48963	82230	117967	33267	69004	1.7	2.4
S_4 (Soil application BS)	44290	75485	105667	31195	61377	1.7	2.4
Interaction (M x S)							
M1 x S1	47653	78965	98015	31312	50362	1.7	2.1
M1 x S2	47653	70415	90250	22762	42597	1.5	1.9
M1 x S3	52090	82782	109810	30692	57720	1.6	2.1
M1 x S4	44065	73595	98935	29530	54870	1.7	2.2
M2 x S1	44776	83780	124532	39004	79757	1.9	2.8
M2 x S2	44776	77087	104350	32312	59574	1.7	2.3
M2 x S3	46336	88650	132892	42314	86556	1.9	2.9
M2 x S4	44765	77752	118290	32987	73525	1.7	2.6
M3 x S1	48713	97005	130335	48292	81622	2.0	2.7
M3 x S2	48713	88030	122400	39317	73687	1.8	2.5
M3 x S3	54211	91955	142090	37744	87879	1.7	2.6
M3 x S4	45115	88580	121152	43465	76037	2.0	2.7
M4 x S1	43215	73795	86042	30580	42827	1.7	2.0
M4 x S2	43215	63165	83377	19950	40162	1.5	1.9
M4 x S3	43215	65550	87060	22335	43845	1.5	2.0
M4 x S4	43215	62197	84352	18982	41137	1.4	2.0

PI: Panicle initiation stage; FL: Flowering stage; BS: Before sowing; Yr.1: Year 1; Yr.2: Year 2

(94%) and B (91.5%), with control (M4) being the least (88.5%). The micronutrient sprays positively enhanced the overall seed quality in terms of SG, FE and SVI1 and SVI2. Similarly, the combination of B + Zn (M3) showed significant improvement for FE, followed by Zn (M2) and B (M1) compared to the control (M4). The significant influence of zinc and boron on seed germination and seedling vigor could be presumed due to the role of zinc in many of the physiological processes of seedling development, including protein synthesis, cell elongation and multiplication (Cakmak, 2000). Similarly, boron is involved in carbon metabolism and cell division of newly developing tissues (Rahman *et al.*, 2020).

Among the stages of micronutrients application, foliar spray at S3 (PI + FL) stage resulted in significantly higher SG (95%), FE (93%), SVI1 (1207) and SVI2 (273) traits followed by SA (S4) and PI stage (S1) for SG and FE traits, whereas PI stage (S1) and SA (S4) for SVI (Table 4). Interaction effects confirm that combined foliar treatment M3 (B + Zn) at S3 (PI + FL) stage was found to give the best results SG (96), FE (93.5), SVI1 (1386) and SVI2 (346), followed by S4 (Fig 2). Zinc plays an integral role in the biosynthesis of the plant growth-promoting hormone auxin Indole acetic acid (IAA). It is also a major component of chief enzymes such as carbonic anhydrase, alcohol dehydrogenase, glutamic dehydrogenase, etc., attributing to seed germination and vigor (Boonchuay *et al*., 2013). Also, zinc content has been found to be higher in the newly developed radicles and coleoptiles, indicating the involvement of zinc in early seedling development. Similar observations with Zn and B applied together were recorded in maize (Wasaya *et al*., 2017).

***Economic analysis*:** Application of two micronutrients (B + Zn) at both the stages PI and FL (M3 x S3) resulted in the highest cost of cultivation and also gave the maximum yields among all the other treatments. However, the benefit-cost (BC) ratio for M3 treatment at S3 was lower when compared to the individual application of Zn at (PI + FL) stages (M2 x S3) that showed the highest BC ratio (1.9 and 2.9) when calculated with the price of 'breeder seed class' over two years (Table 5). Although the gross and net returns generated from (M3 x S3) are higher in comparison with the other treatments, the two chemical costs involved outweigh the final benefits incurred. Therefore, Zn (M2) applied at S3 (PI+FL) and S1 (PI) stages recorded the highest BC ratio with at par values, this was followed by combined treatment (B + Zn) at PI (M3 x S1) and SA (M3 x S4) stages, while the control consistently recorded the lowest BC ratio. These findings are in corroboration with Wasaya *et al*. (2017) in maize, where Zn and B foliar application was found to be profitable by generating increased returns and profits as indicated by the BC ratios and hence is economically a feasible option.

Conclusion

This study demonstrates that the integrated application of boron and zinc, particularly through foliar sprays at the panicle initiation stage, significantly enhances the seed yield and quality of finger millet. Combined foliar application of boron (0.5%) and zinc (1%) was superior to individual and soil applications, reflecting their synergistic role in enhancing growth, yield attributes, germination, and seedling vigor. Among the application modes/stages, foliar spray at panicle initiation was most effective, with performance comparable to combination spray at panicle initiation and 50% flowering, indicating this stage as critical for micronutrient intervention. Although combined boron and zinc application resulted in the highest seed yields, it also incurred the greatest cultivation cost, leading to a comparatively lower benefit–cost ratio. In contrast, individual zinc application at panicle initiation and 50% flowering recorded the highest BC ratio over two years. Overall, the results highlight the superiority of foliar application (PI or PI + FL) over soil application and emphasize the importance of precise timing in micronutrient delivery. The findings are anticipated to offer practical insights for refining seed production protocols, improving seed yield and seedling vigor, and supporting sustainable agriculture practices, particularly in micronutrient-deficient millet-growing regions. Future research should focus on exploring the long-term effects of these micronutrient applications and their interactions with other agronomic practices.

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References

Abdul-Baki, A. A. and J. D. Anderson. 1973. Vigor determination in soybean seed by multiple criteria. *Crop Science* 13(6): 630-633.

Abioye, V. F., G. O. Babarinde, G. O. Ogunlakin, J. A. Adejuyitan, S. J. Olatunde and A. O. Abioye. 2022. Varietal and processing influence on nutritional and phytochemical properties of finger millet: A review. *Heliyon* 8(12): e12064.

Ahmad, W., M. H. Zia, S. S. Malhi, A. Niaz and S. Ullah. 2012. Boron deficiency in soils and crops: a review. In: *Crop Plant*. pp. 65-97. DOI:10.5772/36702.

Ahmed, N., M. Abid, M. A. Ali, S. Masood, A. Rashid, S. Noreen and S. Hussain. 2019. Zinc application enhances biological yield and alters nutrient uptake by cotton (*Gossypium hirsutum* L.). *Communications in Soil Science and Plant Analysis* 50(3): 265-272.

Baath, G. S., B. K. Northup, P. H. Gowda, A. C. Rocateli and K. E. Turner. 2018. Adaptability and forage characterization of finger millet accessions in US southern great plains. *Agronomy Journal* 177:1-9.

Backiyalakshmi, C., C. Babu, D. Naresh Reddy, V. Padmakumar, K. V. S. V. Prasad, V. C. R. Azevedo and M. Vetriventhan. 2021. Assessing forage potential of the global collection of finger millet (*Eleusine coracana* (L.) Gaertn.) germplasm conserved at the ICRISAT gene bank. *Agronomy* 11(9): 1706.

Boonchuay, P., I. Cakmak, B. Rerkasem and C. Prom-U-Thai. 2013. Effect of different foliar zinc application at different growth stages on seed zinc concentration and its impact on seedling vigor in rice. *Soil Science and Plant Nutrition* 59(2):180-188.

Bordolui, S. K. and A. Mukherjee. 2022. Eminent roles of micro-nutrients in quality seed production. *International Journal of Plant and Soil Science* 34(23): 324-342.

Cakmak, I. 2000. Possible roles of zinc in protecting plant cells from damage by reactive oxygen species. *New Phytologist* 146(2):185-205.

Cakmak, I. 2008. Enrichment of cereal grains with zinc: agronomic or genetic biofortification? *Plant and Soil* 302(1):1-17.

Chowdary, K. A and B. C. Patra. 2019. Effect of micronutrient application with different sources of NPK on growth and yield of finger millet crop in red laterite zone. *Journal of Agricultural Science and Technology* 9: 403-416.

Davarpanah, S., A. Tehranifar, G. Davarynejad, J. Abadía and R. Khorasani. 2016. Effects of foliar applications of zinc and boron nano-fertilizers on pomegranate (*Punica granatum* cv. Ardestani) fruit yield and quality. *Scientia Horticulturae* 210: 57-65.

Gajalakshmi, R., T. Chitdeshwari, S. Maragatham and R. Ravikesavan. 2022. Zinc nutrition for improving the growth and yield of barnyard millet (*Echinochloa frumentacea* L.). *International Journal of Plant and Soil Science* 34(21): 657-664.

Goldbach, H. E., L. Huang and M. A. Wimmer. 2007. Boron functions in plants and animals: recent advances in Boron research and open questions. In: *Advances in Plant and Animal Boron Nutrition: Proceedings of 3rd International Symposium on All Aspects of Plant and Animal Boron Nutrition*. Dordrecht: Springer.

Gowda, P. H., P. V. V. Prasad, S. V. Angadi, U. M. Rangappa and P. Wagle. 2015. Finger millet: An alternative crop for the southern high plains. *American Journal of Plant Sciences* 6: 2686-2691.

Gupta, S. M., S. Arora, N. Mirza, A. Pande, C. Lata, S. Puranik, J. Kumar and A. Kumar. 2017. Finger millet: a 'certain' crop for an 'uncertain' future and a solution to food insecurity and hidden hunger under stressful environments. *Frontiers in Plant Science* 8: 643.

Hariprasanna, K. 2023. Small millets in India: current scenario and way forward. *Indian Farming* 73(1): 38-41.

Harris, K. D and V. Mathuma. 2015. Effect of foliar application of Boron and Zinc on growth and yield of tomato (*Lycopersicon esculentum* Mill.). *Asian Journal of Pharmaceutical Science and Technology* 5(2): 74-78.

Hidoto, L., W. Worku, H. Mohammed and T. Bunyamin. 2017. Effects of zinc application strategy on zinc content and productivity of chickpea grown under zinc deficient soils. *Journal of Soil Science and Plant Nutrition* 17(1): 112-126.

ISTA, 2015. *International Rules for Seed Testing.* International Seed Testing Association, Bassersdorf, Zurich.

Jackson, M. L. 1973. *Soil Chemical Analysis*. Prentice Hall of India, New Delhi. pp. 82-205.

Jitarwal, J., B. Mehera, P. Kumar, G. Mahala and R. K. Mund. 2024. Effect of zinc and panchagavya on growth and yield of pearl millet (*Pennisetum glaucum* L.). *International Journal of Plant and Soil Science* 36(6): 444-449.

Joshi, A. K. and H. J. Braun. 2022. Seed systems to support rapid adoption of improved varieties in wheat. In: *Wheat Improvement: Food Security in a Changing Climate*. Cham: Springer International Publishing. pp. 237-256.

Kanshouwa, C. M and B. Mehera. 2023. Effect of boron and panchagavya on growth and yield of baby corn (*Zea mays* L.). *International Journal of Plant and Soil Science* 35(13): 102-108.

Kumar, A., H. P. Yadav and D. Vart. 2012. Sustaining productivity of high yielding hybrids of pearl millet through zinc. *Forage Research* 38: 23-26.

Kumar, P., A. K. Sarawgi, B. K. Das, D. Sharma, V. Kumar and G. Vishwakarma. 2021. Adaptability and forage potential studies in finger millet (*Eleusine coracana* L) accessions. *Forage Research* 47(1): 58-63.

Kumar, B., M. Singh, A. Kumar, D. Kumar, A. K. Singh, R. Kumar and S. Kumar. 2024. Finger millet scientific cultivation and its uses in India. In: *Millets – Rediscover Ancient Grains*. Intech Open, London.

Lindsay, W. L. and W. L. Norvell. 1978. Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal* 42: 421-428.

Maharajan, T., T. P. A. Krishna, J. Shilpha and S. A. Ceasar. 2023. Effects of individual or combined deficiency of phosphorus and zinc on phenotypic, nutrient uptake, and molecular responses of finger millet (*Eleusine coracana*): A nutri-rich cereal crop. *Plants* 12(19): 3378.

Manjunath, N. S. and V. Debbarma. 2023. Effect of zinc and boron on growth, yield and economics of finger millet (*Eleusine coracana* L.). *International Journal of Plant and Soil Science* 35(18): 1497-1503.

Naz, R., M. S. Khan, A. Hafeez, M. Fazil, M. N. Khan, B. Ali, M. A. Javed, M. Imran, A. A. Shati, M. Y. Alfaifi and S. E. I. Elbehairi. 2022. Assessment of phytoremediation potential of native plant species naturally growing in heavy metal-polluted industrial soils. *Brazilian Journal of Biology* 84: 264473.

Olsen, S. R. 1954. *Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate* (No. 939). US Department of Agriculture.

Oluoch, V. O., A. N. Otinga and R. Njoroge. 2024. Effect of zinc-fertilizer on varietal performance of finger millet (*Eleusine coracana*) and soybean (*Glycine max*) in western Kenya. *Heliyon* 10(15): e29063.

Parker, D. R. and E. H. Gardner. 1981. The determination of hot-water-soluble boron in some acid Oregon soils using a modified azomethine-H procedure. *Communications in Soil Science and Plant Analysis* 12(12):1311-1322.

Piper, C. S. 1966. *Soil and Plant Analysis*. Hans Publishers, Bombay; Society of Agronomy, Madison, Wisconsin.

Pradhan, A., A. Sao, S. K. Nag and T. P. Chandrakar. 2016. Effect of zinc fertilization on growth and yield of finger millet (*Eleusine coracana* L. Gaertn.). *International Journal of Science, Environment and Technology* 5(3):1477-1487.

Pramanick, B., S. Choudhary, M. Kumar, S. K. Singh, R. K. Jha, S. K. Singh, S. H. Salmen, M. J. Ansari and A. Hossain. 2024. Can site-specific nutrient management improve the productivity and resource use efficiency of climate-resilient finger millet in calcareous soils in

India? *Heliyon* 10 (12): e32774.

Prashantha, G. M. and T. Chikkaramappa. 2017. Growth, yield and uptake of nutrients by finger millet (*Eleusine coracana* L.) in an alfisol of central dry zone of Karnataka as influenced by the application of zinc and boron. *Mysore Journal of Agricultural Sciences* 51(3): 680-685.

Qamar, J., A. Rehman, M. A. Ali, R. Qamar, K. Ahmed and W. Raza. 2016. Boron increases the growth and yield of mungbean. *Journal of Advanced Agriculture* 6(2): 3-6.

Rahman, M. H., M. A. Quddus, M. A. Satter, M. R. Ali, M. H. Sarker and T. N. Trina. 2020. Impact of foliar application of boron and zinc on growth, quality and seed yield of okra. *Journal of Energy and Natural Resources* 9(1): 1-9.

Reddy, Y. N. 2023. Effect of zinc and boron on physiological and yield attributing traits and the trait contribution to grain yield in popular finger millet (*Eleusine coracana* (L.) Gaertn.) cv. GPU-28. *Environment and Ecology* 41(1C): 671-678.

Rehman, A. U., M. Farooq, Z. A. Cheema and A. Wahid. 2012. Seed priming with boron improves growth and yield of fine grain aromatic rice. *Plant Growth Regulation* 68: 189-201.

Rion, M. S. I., A. Rahman, M. Khatun, H. M. Zakir, M. H. Rashid and Q. F. Quadir. 2022. Screening of zinc solubilizing plant growth promoting rhizobacteria (PGPR) as potential tool for biofortification in rice. *Journal of Experimental Agriculture International* 44(9): 132-143.

Safdar, M. E., R. Qamar, A. Javed, M. A. Nadeem, H. M. R. Javeed, S. Farooq, A. Głowacka, S. Michałek, M. S. Alwahibi, M. S. Elshikh and M. A. Ahmed. 2023. Combined application of boron and zinc improves seed and oil yields and oil quality of oilseed rape (*Brassica napus* L.). *Agronomy* 13(8): 2020.

Shukla, A. K., S. K. Behera, C. Prakash, A. Tripathi, A. K. Patra, B. S. Dwivedi, V. Trivedi, C. S. Rao, S. K. Chaudhari, S. Das and A. K. Singh. 2021. Deficiency of phyto-available sulphur, zinc, boron, iron, copper and manganese in soils of India. *Scientific Reports* 11(1): 19760.

Singh, B. D., G. J. Abhishek, P. Priya, S. Kumar, S. P. Shinde, S. Kumar, S. Bhushan, M. Behera, M. Vajha and A. K. Pandey. 2024. Millets as an ancient grain for modern food security and sustainable agriculture. *Journal of Scientific Research and Reports* 30(6): 706-714.

Solanki, M., N. Didwania and V. Nandal. 2016. Potential of Zinc solubilizing bacterial inoculants in fodder crops. *Momentum* 3: 1–4.

Srilekha, G. V., R. K. Panda, R. K. Nayak and M. Satapathy. 2024. Characterization of the morpho-physiology and yield of finger millet (*Eleusine coracana* L. Gaertn) under the influence of lime, compost, and micronutrients. *Environment and Ecology* 42(2B): 915-919.

Subbiah, B. V. and G. L. Asija. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Current Science* 25: 259-260.

Statistix 8.1. 2003. User's Manual. Analytical Software, Tallahassee, FL, USA.

Tahir, M., A. Ali, F. Khalid, N. Naeem, N. Fiaz and M. Waseem. 2012. Effect of foliar applied boron application on growth, yield and quality of maize (*Zea mays* L.): foliar applied boron for maize growth. *Pakistan Journal of Scientific and Industrial Research Series B: Biological Sciences* 55(3): 117-121.

Walkley, A. and I. A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science* 37(1): 29-38.

Wasaya, A., M. S. Shabir, M. Hussain, M. Ansar, A. Aziz, W. Hassan and I. Ahmad. 2017. Foliar application of zinc and boron improved the productivity and net returns of maize grown under rainfed conditions of Pothwar plateau. *Journal of Soil Science and Plant Nutrition* 17(1): 33-45.