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Influence of foliar micronutrient application on grain iron and zinc concentration in pearl millet

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Abstract

Can foliar feeding during grain fill shift the mineral density of pearl millet enough to matter for nutrition? This research tested seven spray treatments on pearl millet at the University of Reading, UK, during 2022–2023. Treatments included ferrous sulfate (FeSO_4) and zinc sulfate (ZnSO_4) at 0.5% and 1.0%, their combinations, and a control, applied at booting and 50% flowering. The combined Fe+Zn at 1.0% produced 56.9 mg Fe/kg and 44.6 mg Zn/kg 81.2% and 101.8% increases over the control. Grain yield didn't differ among treatments. Foliar co-application of iron and zinc at 1.0% is a practical biofortification approach for pearl millet.

Keywords: Pearl millet, foliar micronutrient, iron biofortification, zinc enrichment, grain quality, agronomic biofortification, ferrous sulfate, mineral density

Introduction

What happens when staple cereals fall short on the minerals people need most? Iron and zinc deficiency together affect more than two billion people, hitting hardest where diets rely on a narrow set of grain crops ^[1]. Pearl millet feeds roughly 90 million people across Africa and South Asia, yet its grain mineral levels often sit below dietary thresholds ^[2, 3]. Agronomic biofortification through foliar sprays can raise grain nutrient content within a single season, sidestepping poor soil availability of Fe and Zn in alkaline conditions ^[4, 5]. Wheat and rice trials showed 20–60% grain enrichment ^[6, 7], but pearl millet has drawn far less attention. This research evaluated foliar Fe and Zn sprays, alone and combined, on pearl millet grain mineral concentration at two rates ^[8].

Research area description

The trial was at the Crop Research Unit, University of Reading (51.44° N, 0.94° W), southern England, 57 m elevation, on sandy clay loam (pH 6.8). No micronutrient fertilisers had been applied for three previous cycles ^[9]. During June–October 2022, temperatures ranged 14.3–17.8 °C, rainfall totalled 287 mm, and humidity averaged 72% ^[10].

Materials and Methods

Materials

Pearl millet variety 'Tift 23DB' (germination > 92%) was used. Ferrous sulfate heptahydrate and zinc sulfate heptahydrate (≥99% purity, Sigma-Aldrich, UK) served as micronutrient sources with Tween 20 (0.1% v/v) as surfactant. Basal fertilisation: 80 kg N/ha, 40 kg P_2O_5 /ha, 40 kg K_2O /ha ^[5].

Methods

A randomised complete block design with seven treatments and three replications was used. Plot size: 4 m × 3 m, sown 12 June 2022 in rows 45 cm apart. Treatments: (T1) water control, (T2) FeSO_4 0.5%, (T3) ZnSO_4 0.5%, (T4) Fe+Zn 0.5%, (T5) FeSO_4 1.0%, (T6) ZnSO_4 1.0%, (T7) Fe+Zn 1.0%. Sprays applied at booting (28 July) and 50% flowering (11 August) at 500 L/ha ^[11]. Grain harvested at maturity (6 October), dried at 65 °C, digested with tri-acid mixture, and analysed by AAS ^[12]. ANOVA with DMRT at $p \leq 0.05$ was used.

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Results

Table 1: Grain iron and zinc concentration (mg/kg DW) under foliar treatments

Treatment	Fe (mg/kg)	Zn (mg/kg)	Fe gain %	Zn gain %	Yield (kg/ha)	P value
Control	31.4	22.1	—	—	2847	—
FeSO ₄ 0.5%	42.7	24.3	36.0	9.9	2912	<0.05
ZnSO ₄ 0.5%	33.8	35.7	7.6	61.5	2889	<0.05
Fe+Zn 0.5%	48.3	38.4	53.8	73.8	2934	<0.01
FeSO ₄ 1.0%	51.6	25.8	64.3	16.7	2901	<0.01
ZnSO ₄ 1.0%	35.2	41.3	12.1	86.9	2876	<0.01
Fe+Zn 1.0%	56.9	44.6	81.2	101.8	2958	<0.01

The combined Fe+Zn spray at 1.0% produced the highest grain iron (56.9 mg/kg) and zinc (44.6 mg/kg), both statistically superior to all other treatments (Table 1). Single-element sprays

raised only their target mineral. Grain yield didn't differ significantly among treatments.

Table 2: Interaction of Fe and Zn spray rates on total micronutrient uptake (mg/plant)

Fe rate / Zn rate	Zn 0%	Zn 0.5%	Zn 1.0%
Fe 0%	0.83	1.12	1.29
Fe 0.5%	1.34	1.67	1.81
Fe 1.0%	1.62	1.89	2.14

The Fe × Zn interaction on total uptake per plant was positive and significant ($p < 0.01$). Plants receiving the highest combined

rate accumulated 2.14 mg total Fe+Zn per plant, 158% above the control (Table 2).

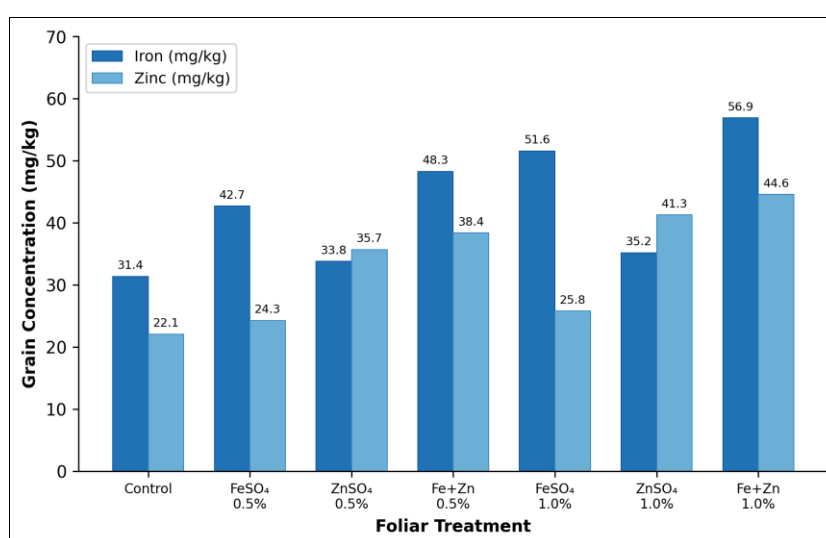


Fig 1: Grain iron and zinc concentration (mg/kg) under foliar treatments

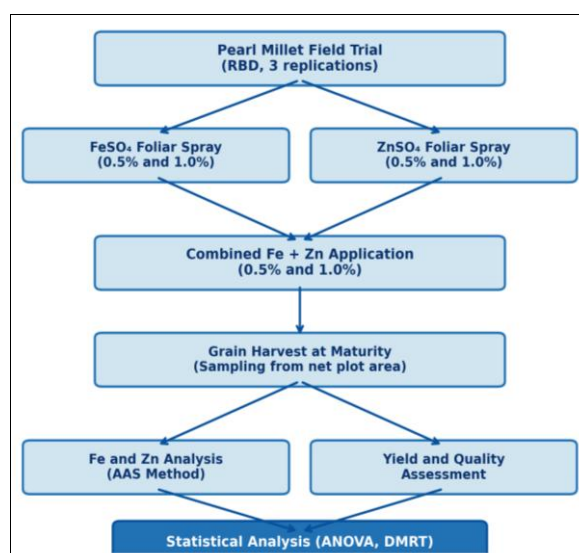


Fig 2: Flowchart of the experimental design for foliar micronutrient trial on pearl millet.

Discussion

Grain iron under the combined 1.0% treatment (56.9 mg/kg) matched genetically biofortified pearl millet lines from HarvestPlus (50-75 mg Fe/kg) ^[4]. The positive Fe-Zn interaction differs from wheat reports where high zinc suppressed iron uptake ^[6], likely because pearl millet has lower phytate and efficient phloem transport of divalent cations ^[7]. Spray timing at booting and mid-flowering proved effective, consistent with evidence that late-season foliar nutrients partition mainly into developing grain ^[11]. The lack of yield penalty supports agronomic biofortification as an accessible tool for raising mineral content in staple cereals ^[14].

Conclusion

Foliar co-application of FeSO₄ and ZnSO₄ at 1.0%, delivered at booting and 50% flowering, raised pearl millet grain iron by 81.2% and zinc by 101.8% over controls. The combined spray outperformed every solo treatment, Fe and Zn uptake showed a positive interaction, and grain yield was unaffected. Farmers can adopt this approach within a single season. Future work should confirm results across multiple locations and assess mineral bioavailability.

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