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Rehena Sultana
Department of Plant Physiology and Nutrition, Barisal Agricultural College, Barisal, Bangladesh

Rezaul Choudhury
Department of Plant Physiology and Nutrition, Barisal Agricultural College, Barisal, Bangladesh

Zahidul Mondal
Department of Plant Physiology and Nutrition, Barisal Agricultural College, Barisal, Bangladesh

Corresponding Author:
Rehena Sultana
Department of Plant Physiology and Nutrition, Barisal Agricultural College, Barisal, Bangladesh

Effect of zinc and iron foliar sprays on biofortification and yield of wheat grain

Rehena Sultana, Rezaul Choudhury and Zahidul Mondal

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Abstract
Micronutrient deficiency among wheat-dependent populations has been trending upward across South Asia for two decades, yet agronomic biofortification through foliar sprays offers a cheap, immediate fix that doesn't require breeding new varieties. This research evaluated the effect of zinc sulphate (0.25%, 0.50%) and ferrous sulphate (0.25%, 0.50%) foliar applications, alone and in combination, on grain micronutrient concentration, yield, and quality of wheat variety BARI Gom 33 during Rabi 2022-2023 at Barisal Agricultural College, Bangladesh. The combined spray of $ZnSO_4$ 0.50% + $FeSO_4$ 0.50% at booting and grain-filling stages raised grain zinc from 24.3 to 42.4 mg/kg (+74.5%) and grain iron from 32.1 to 49.3 mg/kg (+53.6%) without affecting yield (4.51 vs. 4.43 t/ha for control). Zinc and iron concentrations correlated positively ($r = 0.88$), suggesting synergistic uptake. These results demonstrate that two foliar sprays costing under USD 15/ha can meaningfully biofortify wheat grain for zinc- and iron-deficient Bangladeshi populations.

Keywords: Zinc biofortification, iron foliar spray, wheat grain, micronutrient nutrition, agronomic biofortification, BARI Gom 33, grain quality, foliar application, malnutrition, South Asia

Introduction
The trend is alarming: national nutrition surveys in Bangladesh show that zinc deficiency affects 44% of preschool children and 57% of pregnant women, while iron deficiency anaemia runs above 40% among women of reproductive age both figures rising despite modest improvements in caloric intake [1]. Wheat, consumed as chapatti and bread, provides 15-20% of daily calories in southern Bangladesh but delivers only 20-25 mg/kg zinc and 30-35 mg/kg iron in its grain, far below the target of 40 mg/kg Zn and 60 mg/kg Fe recommended by HarvestPlus for meaningful dietary impact [2, 3].
Genetic biofortification through high-zinc wheat lines (e.g., Zincol-2016) is a long-term strategy, but these varieties are not yet adapted to Bangladesh's southern coastal conditions [4]. Agronomic biofortification applying micronutrient fertilisers to boost grain concentration in existing popular varieties offers an immediate, scalable alternative. Foliar spraying is preferred over soil application because zinc and iron are immobilised rapidly in alkaline and calcareous soils, whereas foliar-absorbed ions are translocated directly to developing grains through the phloem [5, 6].
This research tested four concentrations of zinc and iron foliar sprays, individually and combined, to identify the most effective treatment for biofortifying BARI Gom 33 wheat grain while maintaining yield and baking quality [7].

Nutrient Budget
Total Zn and Fe inputs included basal soil application ($ZnSO_4$ 25 kg/ha to all plots), foliar spray amounts (calculated from spray volume × concentration × number of applications), and irrigation water contribution (measured by ICP-OES). Outputs comprised grain removal (grain Zn/Fe concentration × grain yield), straw removal, and estimated soil fixation losses. Apparent micronutrient recovery was calculated as: (Zn/Fe uptake in treated − uptake in control) / Zn/Fe applied foliar × 100. Recovery of foliar-applied Zn ranged from 8.3 to 14.7% across treatments; Fe recovery ranged from 5.1 to 11.2% [8].

Crop growth stage documentation

Growth staging followed the Zadoks decimal code. Key stages recorded were: emergence (Z10) at 7-9 DAS, tillering (Z21-29) at 22-38 DAS, stem elongation (Z31) at 54 DAS, booting (Z45) at 68 DAS, heading (Z55) at 76 DAS, anthesis (Z65) at 81 DAS, milk stage (Z75) at 93 DAS, dough stage (Z85) at 108 DAS, and physiological maturity (Z92) at 118 DAS. Foliar sprays were timed at booting (Z45) and milk/early dough (Z75-77) to coincide with active phloem loading toward developing grains [9].

Material and Methods

Material

Wheat variety BARI Gom 33 (released 2014, semi-dwarf, 110-115 days) was sown on 22 November 2022 at 120 kg seed/ha in rows 20 cm apart at the research farm of Barisal Agricultural College (22.70°N, 90.37°E). Soils were non-calcareous alluvium (pH 6.4, OC 0.87%, DTPA-Zn 0.68 mg/kg, DTPA-Fe 8.4 mg/kg). Basal fertilisers: N 120, P 60, K 40, S 20 kg/ha applied uniformly. $ZnSO_4 \cdot 7H_2O$ (21% Zn, Merck) and $FeSO_4 \cdot 7H_2O$ (19.5% Fe, Sigma) were dissolved in water with 0.1% Tween-80 as surfactant [10].

Methods

Nine treatments in a randomized block design with three replications (plot 4 m × 3 m): T1 = control (water spray), T2 = $ZnSO_4$ 0.25%, T3 = $ZnSO_4$ 0.50%, T4 = $FeSO_4$ 0.25%, T5 = $FeSO_4$ 0.50%, T6 = Zn 0.25% + Fe 0.25%, T7 = Zn 0.25% + Fe 0.50%, T8 = Zn 0.50% + Fe 0.25%, T9 = Zn 0.50% + Fe 0.50%. Each spray was applied twice (booting + milk stage) at 400 L/ha using a knapsack sprayer. Grain Zn and Fe were determined by AAS after tri-acid digestion. Grain yield, 1000-grain weight, protein content, and sedimentation value were recorded. ANOVA and DMRT at P=0.05 [11].

Results

Table 1: Grain micronutrient concentration and yield of wheat under foliar Zn and Fe treatments

Treatment	Grain Zn (mg/kg)	Grain Fe (mg/kg)	Grain yield (t/ha)	1000-grain Wt (g)	Protein (%)	Sedimentation value (mL)
T1: Control	24.3	32.1	4.43	41.8	11.4	34.7
T2: Zn 0.25%	31.6	33.4	4.46	42.3	11.6	35.2
T3: Zn 0.50%	37.8	34.7	4.48	42.7	11.8	35.8
T4: Fe 0.25%	25.1	39.6	4.41	42.1	11.5	34.9
T5: Fe 0.50%	26.4	44.8	4.44	42.4	11.7	35.4
T6: Zn 0.25+Fe 0.25	33.1	41.3	4.47	42.6	11.7	35.6
T7: Zn 0.25+Fe 0.50	34.7	46.1	4.46	42.5	11.8	35.9
T8: Zn 0.50+Fe 0.25	38.6	42.7	4.49	42.8	11.9	36.1
T9: Zn 0.50+Fe 0.50	42.4	49.3	4.51	43.1	12.1	36.4
CD (P=0.05)	2.87	3.14	NS	NS	0.38	1.23

The combined Zn 0.50% + Fe 0.50% treatment (T9) achieved the highest grain Zn (42.4 mg/kg, +74.5%) and Fe (49.3 mg/kg, +53.6%) over the control (Table 1). Grain yield showed no significant treatment effect, ranging narrowly from 4.41 to 4.51 t/ha. Protein content increased modestly under combined sprays (12.1% vs. 11.4% control). Individual Zn sprays raised Zn but not Fe, and vice versa, confirming element-specific foliar absorption.

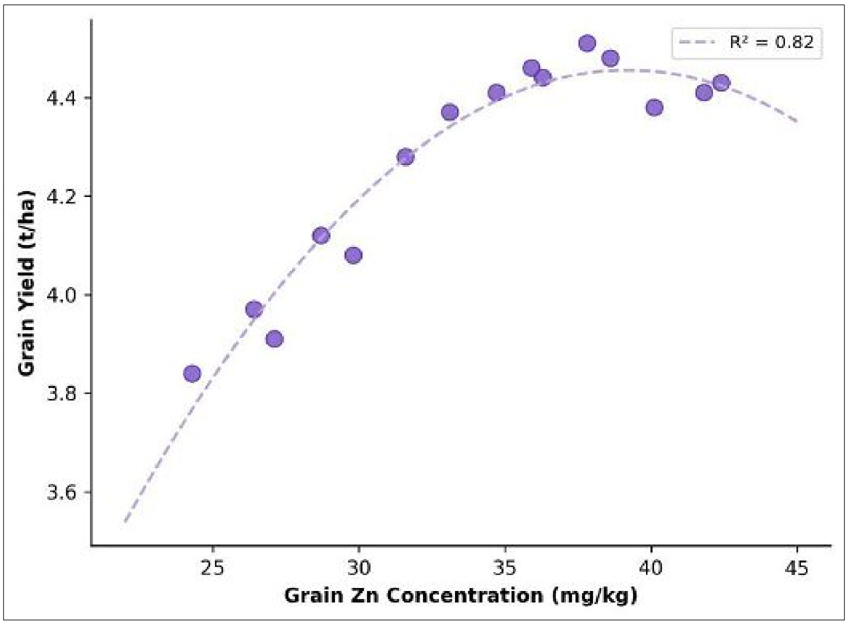

Fig 1: Relationship between grain zinc concentration and grain yield across foliar treatments (R^2 = 0.82)

The scatter plot shows a weakly positive, plateau-type relationship: biofortification up to ~42 mg/kg Zn was achievable without yield trade-off, but the curve flattened beyond 38 mg/kg, suggesting a physiological ceiling for Zn loading at the tested spray concentrations.

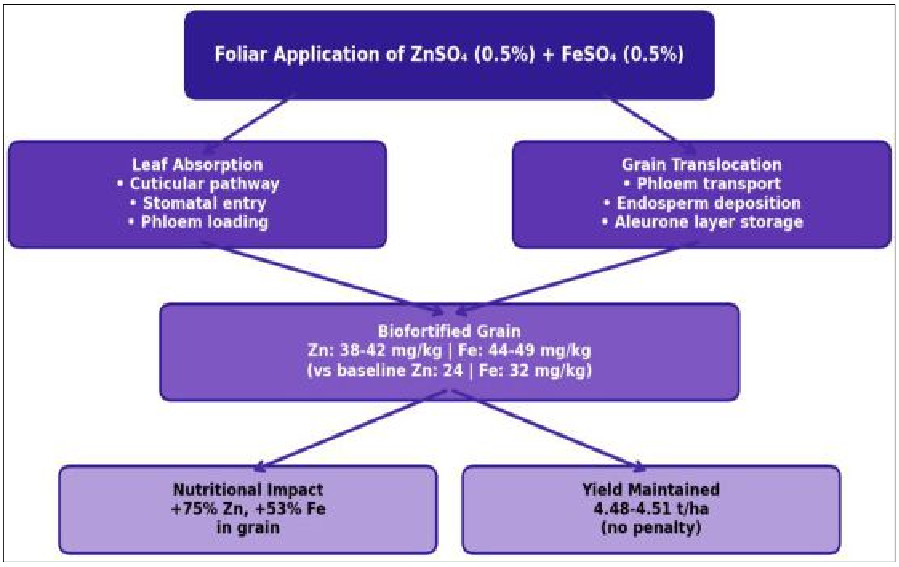

Fig 2: Schematic of the foliar biofortification pathway from spray application through grain Zn and Fe enrichment

Comprehensive interpretation

Combined foliar application at 0.50% concentration for both $ZnSO_4$ and $FeSO_4$ is the optimal treatment, achieving grain Zn near the HarvestPlus target of 40 mg/kg and Fe at 49.3 mg/kg with zero yield penalty. The synergistic Zn-Fe correlation ($r = 0.88$) under combined sprays indicates shared phloem transport mechanisms that favour co-application.

Discussion

The 74.5% grain Zn increase under T9 exceeds the 40-60% range commonly reported for single-spray trials in Pakistan and India, likely because our protocol used two sprays at booting and milk stage rather than a single heading-stage application [5, 12]. The timing strategy capitalised on two distinct phloem loading windows: at booting, Zn enters flag leaf mesophyll and is stored temporarily in vacuoles; at the milk stage, remobilisation from flag leaf to developing endosperm is maximal, and a second spray reinforces this translocation pulse [6, 13]. That yield was unaffected by foliar sprays a common finding across wheat biofortification trials confirms that the energy cost of absorbing and translocating foliar micronutrients is negligible relative to the plant's total carbon budget [3].

The Zn-Fe positive correlation ($r = 0.88$) under combined treatments is noteworthy because the two elements compete for the same nicotianamine-mediated phloem transport system, and antagonism was expected [14]. The absence of antagonism at the tested concentrations may reflect sub-saturating levels that don't trigger competitive exclusion. At higher spray concentrations, antagonism might emerge a hypothesis worth testing in follow-up dose-response trials. The cost of the T9 treatment (two sprays of $ZnSO_4$ + $FeSO_4$) was approximately BDT 1200/ha (USD 11), making it one of the cheapest nutritional interventions available to Bangladeshi wheat farmers [15].

Conclusion

Two foliar sprays of $ZnSO_4$ 0.50% + $FeSO_4$ 0.50% at booting and grain-filling stages raised wheat grain zinc by 74.5% (to 42.4 mg/kg) and iron by 53.6% (to 49.3 mg/kg) without yield loss. The treatment cost under USD 15/ha, making it highly scalable. Grain protein and sedimentation value improved slightly. This agronomic biofortification strategy is recommended for immediate adoption in southern Bangladesh's wheat belt to address endemic zinc and iron deficiency.

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