



Zn and Fe bio-fortification and its effect on fodder maize and sorghum for sustainable livestock production in Himalayan foothills of India

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Abstract

A field experiment was conducted at G B Pant University of Agriculture & Technology, Pantnagar, India) in kharif (crop-growing season from June to October) 2019 and 2020 to study the effect of Zn and Fe biofortification on fodder quality of maize and sorghum in Himalayan foothills of India. The experimental site was clay loam with organic matter 0.74% and available N, P and K was 280.2, 25.2, 215 kg ha⁻¹, respectively. The initial soil Fe and Zn content was 3.582 and 0.461 ppm, respectively. The growth, yield, quality and economics of fodder crops differed significantly with higher plant height, number of plants m⁻¹ row length, flowering, fodder yield, crude protein yield and economics in sorghum. Fodder sorghum produced 27.2, 18.8 and 82.5% % higher green fodder yield, dry fodder yield and net return, respectively, than maize. The green and dry fodder yields, crude protein yield and economics were significantly higher at Zn_{10b}Fe_{10b}Zn_{1f}Fe_{1f}, while Zn and Fe contents in soil and plants were significantly greater at Zn_{20b}Fe_{20b}Zn_{1f}Fe_{1f}. Therefore, it may be concluded that both maize and sorghum, preferably sorghum, could be biofortified with application of 10 kg ZnSO₄ ha⁻¹+10 kg FeSO₄ ha⁻¹ (basal)+1% ZnSO₄+1% FeSO₄ (foliar 45 DAS) for higher biofortified fodder yield and net profit for sustainable livestock production in Himalayan foothills of India and these results may be replicated in similar ecologies.

Introduction

Presently India is short of 36% green fodder, 21.9% dry fodder and 44% concentrates. Fodder maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* L.) are the major crops cultivated globally for green fodder, silage and hay but cereal-based diets are deficient in essential amino acids, i.e. lysine and tryptophan, vitamin A, zinc (Zn) and iron (Fe). Recently wide range deficiency of Fe and Zn in soil, food and feed has drawn attention due to nutritional health problems. Fe is the third most limiting nutrient for plant growth and its deficiency causes chlorosis, low yield and a loss in nutritional quality in many agricultural plants. Zn is also an essential micronutrient and acts as co-factor of many enzymes and regulates auxin synthesis and antioxidant production, but its deficiency decreases photosynthetic rate and induces chlorosis, sterility and fungal infection. Normally sorghum is deficient in Ca, Zn and Fe causes health problems in livestock. Most sorghum varieties contain 30 ppm Fe and 20 ppm Zn, while balanced nutrition requires 60 and 32 ppm, respectively. Agronomic manipulation is an effective tool of biofortification of micronutrients like Fe and Zn in forage crops. Mousavi et al. (2012) reported positive effect of Zn and Fe on biomass components and composition of plants. Zinc improves kernel number and weight in maize (Liu et al., 2020). Deficiency of Fe and Zn in sorghum can be altered through biofortification, which is a sustainable solution to their deficiencies (Kumar et al. 2015). Recent studies showed that foliar application of a minute

concentration of nutrients, especially Ca, Zn and Fe significantly increased nutrient contents and yield in both sorghum and maize. However, research work on biofortification of Fe and Zn in forage maize and sorghum is very limited. Therefore, the present study was planned to study the effects of bio-fortification of Zn and Fe on yield and quality of maize and sorghum fodder for sustainable livestock production in Himalayan foothills of India.

Methods

Field experiment was conducted at Fodder Block, G B Pant University of Agriculture & Technology, Pantnagar, India, during *kharif* (crop season from June to October) 2019 and 2020 to study the effect of Zn and Fe biofortification on fodder maize and sorghum for sustainable livestock production in Himalayan foothills of India. The soil at the site was clay loam with pH 7.2, 0.74% organic carbon, available nitrogen 280.2, phosphorus 25.16 and potassium 215.0 kg/ha, 0.461 ppm Zn and 3.582 ppm Fe. The experiment consisted of two crops, i.e. maize and sorghum, in main plot and 07 treatments in subplot was planted in split plot design and replicated thrice. The maize var. African Tall and sorghum var. PC-6 were planted at 30 cm x 10 cm plant geometry on 21st June in 2019 and 28th June 2020. The recommended dose of fertilizers for both crops was 100 kg N ha⁻¹, 60 kg P₂O₅ ha⁻¹ and 40 kg K₂O ha⁻¹. Pendimethalin 30EC @ 1.0 kg ai ha⁻¹ was sprayed as a pre-emergent herbicide to control weeds. The crop did not require irrigation due to sufficient rainfall during the crop growth period. The crop was harvested manually at 50% flowering. Crude protein content was estimated by multiplying the nitrogen content by factor 6.25, while the crude protein yield was the result of crude protein content x dry fodder yield. The Fe and Zn were determined using Atomic Absorption Spectroscopy (AAS). The economics including gross return (green fodder yield (qha⁻¹) x Sale rate ((Rs q⁻¹)) and net return (Gross return (₹ ha⁻¹) – cost of cultivation (₹ ha⁻¹)) were worked out on the basis of prevailing sale rate of the green fodder. The benefit:cost ratio (B:C ratio) was estimated on per hectare basis. The data were analyzed with standard procedures using OPSTAT-Online Statistical Analyzing Tools developed by Sheoran (2021). The treatments are abbreviated as given in Table 1.;

Table 1. Treatment details

Treatment	Details of treatment (Trt)	Abbreviated treatment
T ₁	Control (no Zn or Fe application)	Zn ₀ Fe ₀
T ₂	10 kg ZnSO ₄ ha ⁻¹ (basal soil application)+1% ZnSO ₄ foliar spray at 45 DAS (days after sowing)	Zn _{10b} Zn _{1f}
T ₃	10 kg FeSO ₄ ha ⁻¹ (basal soil application) +1% FeSO ₄ foliar spray at 45 DAS	Fe _{10b} Fe _{1f}
T ₄	10 kg ZnSO ₄ ha ⁻¹ +10 kg FeSO ₄ ha ⁻¹ (basal soil application) +% ZnSO ₄ +1% FeSO ₄ foliar spray at 45 DAS	Zn _{10b} Fe _{10b} Zn _{1f} Fe _{1f}
T ₅	20 kg ZnSO ₄ ha ⁻¹ (basal soil application) +1% ZnSO ₄ foliar spray at 45 DAS,	Zn _{20b} Zn _{1f}
T ₆	20 kg Zn SO ₄ (basal soil application) + 1% FeSO ₄ foliar spray at 45 DAS	Zn _{20b} Fe _{1f}
T ₇	20 kg ZnSO ₄ ha ⁻¹ +20 kg FeSO ₄ ha ⁻¹ (basal soil application) +1% ZnSO ₄ +1% FeSO ₄ foliar spray at 45 DAS	Zn _{20b} Fe _{20b} Zn _{1f} Fe _{1f}

Results and Discussion

a. Effect of Zn and Fe on fodder crops

Sorghum had significantly taller plants and more plants per unit area than maize (Table 2) mainly due to better field emergence and greater tolerance to higher soil moisture in crop seasons, similar to Adesh et al. (2021). Maize had significantly more leaves than sorghum mainly due to higher plant density in sorghum with increased internodes length. Sorghum took more days than maize to 50% flowering. The L:S ratio was significantly greater in maize than sorghum because of broader leaves in maize (Table 3). Vinita et al. (2021) also reported higher number of leaves/plant and greater L:S ratio in maize than in sorghum. Sorghum had significantly higher green

fodder yield (GFY) and dry fodder yield (DFY) than maize (Table 3), ascribed to taller plants and more plants per unit area.

Table 2. Effect of Zn and Fe on growth of fodder maize and sorghum (pooled of 2019 & 2020)

Trt	Height (cm)			Plants m ⁻²			Leaves plant ⁻¹			50% flowering (Days)		
	Maize	Sorgh.	Mean	Maize	Sorghum	Mean	Maize	Sorghum	Mean	Maize	Sorghum	Mean
T1	220	259	240	26.0	63.0	44.5	11.7	10.1	10.9	59.5	71.5	65.5
T2	235	265	250	26.0	59.0	42.5	13.0	9.5	11.2	58.2	69.3	63.8
T3	231	270	251	27.5	49.0	38.3	12.2	9.9	11.1	60.7	70.3	65.5
T4	244	262	253	26.5	56.5	41.5	12.3	9.8	11.1	57.5	70.7	64.1
T5	236	272	254	28.0	60.0	44.0	12.5	10.0	11.2	58.2	69.5	63.8
T6	233	278	256	26.0	59.0	42.5	12.9	10.1	11.5	59.5	70.5	65.0
T7	237	257	247	26.5	56.5	41.5	11.0	9.7	10.3	58.0	68.7	63.3
Mean	234	266	-	26.6	57.6	-	12.2	9.9	-	58.8	70.1	-
		SEm±	CD (5%)		SEm±	CD (5%)		SEm±	CD (5%)		SEm±	CD (5%)
Maize Factor(A)		02	05		0.8	2.4		0.1	0.4		0.2	0.5
Sub Factor (B)		03	10		1.5	NS		0.2	NS		0.3	0.8
Interaction (AXB)		05	NS		2.1	6.2		0.3	1.0		0.4	1.2

Sorghum had significantly higher crude protein content (CPC) and crude protein yield (CPY) than maize (Table 4), similar to Adesh et al. (2021). The crude fibre (CF) was significantly higher in maize than sorghum as maize has more crude protein and soluble sugar. Iron content in both soil and plant as well as Zn in plant was significantly higher in maize, but Zn content in soil was significantly higher in sorghum (Table 5). The gross and net returns as well as B:C ratio was also significantly higher in sorghum (Table 6). Sorghum gave 27.0 and 82.5% higher gross and net returns, respectively than maize, attributed to higher green and dry fodder yield. Asif et al. (2020) concluded that combined foliar application of Ca@3%, Zn@2% and Fe@ 1% improved yield and quality of forage sorghum.

Table 3. Effect of Zn and Fe on L:S ratio and yield of fodder maize and sorghum (pooled 2019 & 2020)

Treatment	L:S ratio			GFY (t ha ⁻¹)			DFY (t ha ⁻¹)		
	Maize	Sorghum	Mean	Maize	Sorghum	Mean	Maize	Sorghum	Mean
T ₁	0.25	0.22	0.23	32.93	51.22	42.07	6.54	9.63	8.09
T ₂	0.24	0.22	0.23	39.46	51.63	45.54	7.91	8.98	8.45
T ₃	0.25	0.22	0.23	41.25	53.33	47.29	7.91	10.08	9.00
T ₄	0.26	0.22	0.24	48.55	55.56	52.05	10.07	10.25	10.16
T ₅	0.26	0.23	0.24	46.78	56.54	51.66	8.76	10.81	9.78
T ₆	0.30	0.20	0.25	45.45	58.60	52.02	8.49	10.70	9.59
T ₇	0.26	0.21	0.23	43.83	52.37	48.10	8.66	8.83	8.74
Mean	0.26	0.22	-	42.61	54.18	-	8.33	9.90	-
		SEm±	CD(5%)		SEm±	CD (5%)		SEm±	CD(5%)
Maize Factor (A)		0.005	0.013		0.59	1.74		0.17	0.50
Sub Factor (B)		0.009	NS		1.11	3.26		0.32	0.94
Interaction (A X B)		0.012	NS		1.58	4.61		0.45	1.32

b. Effect of Zn and Fe

The tallest plants of maize were measured at Zn_{10b}Fe_{10b}Zn_{1f}Fe_{1f}, while sorghum was found tallest under that was non-significant with Zn_{20b}Fe_{1f} that was significantly equal to Fe_{10b}Fe_{1f} and Zn_{20b}Zn_{1f} (Table 2). The plants m⁻² and leaves plant⁻¹ did not differ significantly among treatments; however, the highest values were noted at Zn_{20b}Zn_{1f}.

Sorghum took significantly more days to flowering than maize with highest days at Fe_{10b}Fe_{1f} and Zn₀Fe₀. The L:S ratio of maize was highest under Zn_{20b}Fe_{1f}, while L:S ratio of sorghum did not vary statistically among treatments (Table 2). The GFY and DFY was influenced significantly by fortification of Zn and Fe with significantly higher values under sorghum (Table 2). The highest GFY of maize was recorded at Zn_{10b}Fe_{10b}Zn_{1f}Fe_{1f} that was statistically similar to Zn_{20b}Zn_{1f} and Zn_{20b}Fe_{1f} but the sorghum gave the highest values at Zn_{20b}Fe_{1f} that was non-significant with Zn_{20b}Zn_{1f} and Zn_{10b}Fe_{10b}Zn_{1f}Fe_{1f}. The higher GFY and DFY was described with better growth attributes because both Fe and Zn improved enzymatic reactions, photosynthesis and finally biomass production (Cabot et al., 2019).

The Zn content in soil both fodder crops was estimated significantly higher in Zn_{20b}Fe_{20b}Zn_{1f}Fe_{1f} that was non-significant with Fe_{10b}Fe_{1f} (Table 4). In case of Fe content in soil, maize had significantly higher values than sorghum. The highest Fe content in both soils of maize and sorghum was recorded significantly highest in Zn_{20b}Fe_{20b}Zn_{1f}Fe_{1f}. The Fe content in maize was measured significantly higher at Zn_{20b}Fe_{1f} which was statistically at par with Zn_{20b}Fe_{20b}Zn_{1f}Fe_{1f}. Similarly, the Fe content in sorghum was higher at Zn_{20b}Fe_{20b}Zn_{1f}Fe_{1f} that was significantly equal to at Zn_{20b}Fe_{1f}. The higher dose of Zn and Fe resulted into more nutrient contents in plant and soil after crop harvest.

Table 4. Effect of Zn and Fe on Zn and Fe content in soil and plant of fodder crops (pooled 2019 & 2020)

Trt	Zn content (ppm)						Fe content (ppm)					
	Soil			Plant			Soil			Plant		
	Maize	Sorg.	Mean	Maize	Sorgh.	Mean	Maize	Sorg.	Mean	Maize	Sorg.	Mean
T ₁	0.42	0.55	0.49	30.05	32.15	31.10	3.35	3.00	3.18	88.53	76.90	82.72
T ₂	0.58	2.00	1.29	67.79	54.18	60.99	3.33	2.93	3.13	88.53	76.67	82.60
T ₃	0.49	0.65	0.57	35.54	28.00	31.77	5.65	5.59	5.62	131.70	114.70	123.20
T ₄	0.68	1.89	1.29	72.97	52.70	62.84	5.93	5.21	5.57	137.77	117.17	127.47
T ₅	1.46	3.59	2.53	92.47	89.53	91.00	3.35	3.13	3.24	90.07	80.73	85.40
T ₆	0.64	0.65	0.65	35.17	29.63	32.40	5.96	5.52	5.74	192.83	152.07	172.45
T ₇	1.64	3.79	2.72	94.00	91.34	92.67	6.30	6.02	6.16	191.83	158.03	174.93
Mean	0.85	1.88	-	61.14	53.93	-	4.84	4.49	-	131.61	110.90	-
		SEm±	CD (5%)		SEm±	CD (5%)		SEm±	CD (5%)		SEm±	CD (5%)
Main Factor (A)	0.04	0.11		0.55	1.59		0.05	0.15		1.18	3.44	
Sub Factor (B)	0.07	0.20		1.02	2.98		0.10	0.29		2.20	6.43	
Interaction (A X B)	0.10	0.29		1.44	4.22		0.14	NS		3.11	9.09	

Table 5. Effect of Zn and Fe on quality of fodder maize and sorghum (pooled of 2019 & 2020).

Trt	Crude protein content (%)			Crude protein yield (t ha ⁻¹)			Crude fiber (%)		
	Maize	Sorghum	Mean	Maize	Sorghum	Mean	Maize	Sorghum	Mean
T ₁	7.40	9.14	8.27	3.64	4.65	4.14	30.33	31.33	30.83
T ₂	7.72	10.53	9.13	3.84	5.39	4.61	32.62	31.03	31.83
T ₃	7.63	11.52	9.58	3.89	5.74	4.82	32.67	32.05	32.36
T ₄	7.87	11.98	9.93	3.97	5.97	4.97	33.40	30.67	32.03
T ₅	7.78	11.71	9.75	3.92	5.91	4.92	32.27	31.23	31.75
T ₆	7.88	11.58	9.73	3.97	5.79	4.88	31.90	32.72	32.31
T ₇	8.07	11.58	9.83	4.07	5.88	4.98	33.87	32.68	33.28
Mean	7.76	11.15	-	3.90	5.62	-	32.44	31.67	-
		SEm±	CD (5%)		SEm±	CD (5%)		SEm±	CD (5%)
Main Factor (A)		0.10	0.30		0.06	0.18		0.15	0.43
Sub Factor (B)		0.19	0.56		0.12	0.34		0.28	0.81
Interaction (AX B)		0.27	0.79		0.16	NS		0.39	1.14

The biofortification of Zn and Fe had significant effect on crude protein content and crude protein yield (Table 4). The highest crude protein content in maize fodder was recorded at Zn_{20b}Fe_{20b}Zn_{1f}Fe_{1f} that was significant with only

control treatment, while sorghum had significantly higher CPC at Zn_{10b}Fe_{10b}Zn_{1f}Fe_{1f} that was significant with Zn₀Fe₀ and Zn_{20b}Fe_{20b}Zn_{1f}Fe_{1f}. The CPY of both maize and sorghum followed almost similar pattern as CPC with highest values at Zn_{20b}Fe_{20b}Zn_{1f}Fe_{1f} and Zn_{10b}Fe_{10b}Zn_{1f}Fe_{1f}, respectively. The mean CPC and CPY was significantly higher at Zn_{20b}Fe_{20b}Zn_{1f}Fe_{1f} that was significantly similar to Zn_{10b}Fe_{10b}Zn_{1f}Fe_{1f}. Chand *et al.* (2017) claimed that soil application of ZnSO₄ at 25kg/ha+2% its foliar spray gave maximum CPC because Zn and Fe enhanced CH₂O and protein production. The fibre content in maize and sorghum was found significantly highest at Zn_{20b}Fe_{1f} and Fe_{10b}Fe_{1f}, respectively. The mean CF was estimated the highest at Zn_{20b}Fe_{20b}Zn_{1f}Fe_{1f}. The results revealed that combined application of Zn and Fe increased the CF because Zn and Fe are essential components of various enzymes involved in plant metabolism. Qadir *et al.* (2017) noted that Zn and Fe content were greatly improved by foliar fertilization of Zn and Fe in sorghum. So, there is the direct and positive correlation between Zn and Fe. Xia *et al.* (2019) also described that Zn fertilization had positive impact on Fe contents of plant.

The highest gross and net return of maize was calculated at Zn_{10b}Fe_{10b}Zn_{1f}Fe_{1f} that was non-significant with Zn_{20b}Zn_{1f} and Zn_{20b}Fe_{1f}, while sorghum gross and net return was significantly higher under Zn_{20b}Fe_{1f} that was significantly similar to Zn_{10b}Fe_{10b}Zn_{1f}Fe_{1f} and Zn_{20b}Zn_{1f}(Table 5). The mean gross and net returns were highest at Zn_{10b}Fe_{10b}Zn_{1f}Fe_{1f} which was non-significant with Zn_{20b}Zn_{1f} and Zn_{20b}Fe_{1f}. The B:C ratio had similar pattern where maize and sorghum had the highest values at Zn_{10b}Fe_{10b}Zn_{1f}Fe_{1f} and Zn_{20b}Fe_{1f}, respectively. The mean values of B:C ratio was significantly higher at Zn_{20b}Fe_{1f} that was significantly higher than Zn_{10b}Fe_{10b}Zn_{1f}Fe_{1f} and Zn_{20b}Zn_{1f}. These results enumerate that biofortification of Fe and Zn improved the fodder yield resulting in greater gross and net returns.

Table 6. Effect of Zn and Fe on economics of fodder maize and sorghum (pooled 2019 & 2020)

Treatment	Gross return (₹ ha ⁻¹)			Net return (₹ ha ⁻¹)			B:C ratio		
	Maize	Sorghum	Mean	Maize	Sorghum	Mean	Maize	Sorghum	Mean
T ₁	65846	102432	84139	18935	61922	40429	1.41	2.53	1.97
T ₂	78923	103251	91087	30217	60941	45579	1.62	2.44	2.03
T ₃	82496	106655	94576	33791	64345	49068	1.70	2.52	2.11
T ₄	97103	111111	104107	47243	68001	57622	1.95	2.58	2.26
T ₅	93561	113087	103324	43701	69977	56839	1.88	2.63	2.25
T ₆	90895	117202	104049	41035	74092	57564	1.82	2.72	2.27
T ₇	87655	104735	96195	37120	60826	48972	1.73	2.39	2.06
Mean	85211	108353	-	36006	65729	-	1.73	2.54	-
	SEm±	CD (5%)		SEm±	CD (5%)		SEm±	CD(5%)	
Main Factor (A)	1191	3481		1191	3481		0.03	0.08	
Sub Factor (B)	2228	6513		2228	6513		0.05	0.14	
Interaction (A X B)	3151	9210		3151	9210		0.07	0.20	

Interaction effect

Maize green and dry fodder yield were highest at Zn_{10b}Fe_{10b}Zn_{1f}Fe_{1f}, which was statically at par with Zn_{20b}Zn_{1f} and Zn_{20b}Fe_{1f}. The sorghum fodder yields were highest at Zn_{20b}Fe_{1f}, which were significantly equal to Zn_{10b}Fe_{10b}Zn_{1f}Fe_{1f} and Zn_{20b}Zn_{1f}. Similar trends were found for gross and net returns of both maize and sorghum. It indicates that maize and sorghum do best with 10kg and 20 kg Zn ha⁻¹ while both crops performed better at 1% spray of FeSO₄. However, the higher Zn and Fe contents in fodder crops were observed at Zn_{20b}Fe_{20b}Zn_{1f}Fe_{1f} which had higher cost of cultivation and lower B:C ratio.

Conclusion & Implications

Both maize and sorghum, preferably sorghum, could be biofortified with application of 10 kg ZnSO₄ ha⁻¹+10 kg FeSO₄ ha⁻¹(basal)+1% ZnSO₄+1% FeSO₄ (foliar 45 DAS) for higher fodder yield and net profit for sustainable livestock production in Himalayan foothills of India and may be replicated in similar ecologies.

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