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EFFECT OF AGRONOMIC BIOFORTIFICATION WITH ZINC AND IRON ON GROWTH AND YIELD OF SORGHUM (*Sorghum bicolor* L.) HYBRID VARIETIES

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ABSTRACT

The experiment was conducted at Instructional farm of S.K.N. College of Agriculture, Jobner (Rajasthan) during *kharif* season of 2023 and 2024. The experiment comprised of thirty-two treatment combinations. The experiment comprised of two hybrid varieties (CSH-16 and CSH-30) and four levels of soil application of zinc and iron in main plot (control, 5.0 kg Zn ha^{-1}, 5.0 kg Fe ha^{-1} and application of 5.0 kg Zn ha^{-1} + 5.0 kg Fe ha^{-1}) and four levels of foliar application of zinc sulphate and iron sulphate (control, 0.5% $ZnSO_4$, 0.5% $FeSO_4$ and 0.5% $ZnSO_4$ + 0.5% $FeSO_4$) at 30 DAS and 50 DAS in sub plot that were laid out in the split plot design and replicated thrice. The hybrid CSH-16 recorded significantly higher plant height and dry matter accumulation at harvest and grain yield as compared to CSH-30. The results revealed that significantly higher plant height and dry matter accumulation at harvest recorded with the combined soil application of 5.0 kg Zn ha^{-1} + 5.0 kg Fe ha^{-1} to the tune of 25.09 and 27.72 per cent, respectively over control in pooled analysis. Significantly higher grain (3345 kg/ha), stover (9220 kg/ha) and biological yield (12565 kg/ha) were produced under the combined soil application of 5.0 kg Zn ha^{-1} + 5.0 kg Fe ha^{-1} as compared to control and soil application of alone 5.0 kg Zn ha^{-1} and 5.0 kg Fe ha^{-1}. Further, based on pooled data foliar application of 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ registered maximum plant height and dry matter accumulation at harvest with per cent increase of 25.09 and 26.68 over control, respectively. Foliar application of 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ recorded higher grain (3323 kg/ha), stover (9186 kg/ha) and biological yield (12509 kg/ha) as compared to control during both the years as well as in pooled analysis.

***Keywords* :** Sorghun, zinc, iron, biofortification and dry matter

Introduction

Sorghum (*Sorghum bicolor* L.) commonly known as the ‘king of millets’, is a highly productive crop, which can be used for grains, livestock feed or industrial purposes. It contains about 10-12% protein, 3% fat and 70% carbohydrate, vitamins and mineral salts which are essential for vigorous growth of human life. The sorghum crop has drought and heat tolerant characters and is especially important in arid and semi-arid regions due to its short duration, fast growing nature and high biomass producing character where, the grain is the staple food for poor and rural peoples. It is grown in the countries of Africa, Asia, Oceania and America. Among them USA, India, Mexico, Nigeria, Sudan and Ethiopia are the major producing countries.

The magnitude of zinc deficiency varied widely among soil types coarse textured, calcareous soils, vertisols and inceptisols and aridisols showed extensive deficiency of zinc resulting low crop yields in various states. Deficiency of zinc (48%) and iron (12%) has been noticed in Indian soils and zinc deficiency is further expected to increase by 49 to 63 per cent by the year 2025 (Singh *et al*., 2009). It is well known fact that zinc is now considered as fourth most important yield limiting nutrient after, nitrogen, phosphorus and potassium (Maclean *et al*., 2002). The productivity of sorghum is low due to growing of this crop on marginal lands and continuous use of macronutrients. Cereals are inherently low in zinc, growing them on such potentially zinc-deficient soils further reduces grain zinc and thus the dietary intake of zinc when eaten. Zinc is a vital micronutrient required for the plant growth and development because it plays an important role in many biochemical reactions within the plant. It is important in synthesis of protein, tryptophan and indole-acetic acid. Zinc acts as a structural component of several enzymes in plants and an inadequate supply could result in serious physiological disturbances. Zinc plays an important role in oxidation processes in cell and help in transformation of carbohydrates and regulation of sugar in plants (Swaminathan and Kannan, 2001). The deficiency of Fe in plants causes significant changes in plant metabolism and induces chlorosis, especially in young leaves and leads to very low reutilization (Solanki *et al.,* 2017). Iron (Fe) is an essential micronutrient without which life cycle of plants won't be completed. Iron being an essential micronutrient takes active part in the metabolic activities of the plant. The role of iron is its catalytic function in biological oxidation and reduction and other metabolic processes like oxidative photo phosphorylation during cell respiration. It is also known to be involved in carbohydrate metabolism. It is well known facts that deficiency of iron has noticeable effects on human health. It plays important role in formation of haemoglobin, transport of oxygen, activation and inactivation of various enzymes which performed main function in the human body (Underwood and Suttle, 1999). Iron malnutrition may be reduced by intensifying the bioavailability of iron content through food and industrial fortification (Rana *et al.,* 2012). These fortification processes are very costly and difficult to provide daily intake of iron on sustainable basis. Biofortification is a recently devised approach to correct human Zn and Fe deficiency. Biofortification is the process that aims to increase the concentration of nutrients in edible portions of crop plants either through fertilization (agronomic biofortification) or plant breeding (genetic biofortification). Biofortification of sorghum by increasing mineral micronutrients (especially iron and zinc) in the grains provides a sustainable solution to iron and zinc deficiency (Pfeiffer and McClafferty, 2007). Application of Zn fertilizers (agronomic biofortification) to soil or foliage seems to be a practical approach to improve zinc concentration in grains. Therefore, biofortification of field crop through agronomic approaches is cost effective to manage iron and zinc deficiency in human beings. Therefore, keeping in view of above facts the present investigation has been planned.

Materials and Methods

The experiment was conducted at Instructional farm of S.K.N. College of Agriculture, Jobner (Rajasthan) during *kharif* season of 2023 and 2024. In order to evaluate the physico-chemical properties of the experimental field, soil samples from 0-15 cm depth were taken from five random spots of the experimental field prior to layout. The soil of experiment field was loamy sand in texture, alkaline in reaction, poor in organic carbon with low in available nitrogen and medium in available phosphorus and potassium content during both the years of field experiment. The experiment comprised of thirty-two treatment combinations. The experiment comprised of two hybrid varieties (CSH-16 and CSH-30) and four levels of soil application of zinc and iron in main plot (control, 5.0 kg Zn ha^{-1}, 5.0 kg Fe ha^{-1} and application of 5.0 kg Zn ha^{-1} + 5.0 kg Fe ha^{-1}) and four levels of foliar application of zinc sulphate and iron sulphate (control, 0.5% $ZnSO_4$, 0.5% $FeSO_4$ and 0.5% $ZnSO_4$ + 0.5% $FeSO_4$) at 30 DAS and 50 DAS in sub plot that were laid out in the split plot design and replicated thrice. The zinc and iron were applied prior to sowing through broadcasting zinc sulphate ($ZnSO_4.7H_2O$) and ferrous sulphate ($FeSO_4.7H_2O$) as per treatments. Foliar application of 0.5% $ZnSO_4$ and 0.5% $FeSO_4$ was done uniformly in respective plots over entire crop canopy as per treatments with the help of knapsack sprayer. The experimental data were statistically analysed with the help of Fisher's analysis of variance technique (Fisher, 1950).

Crop Management

Seeds of the sorghum hybrid CSH-16 and CSH-30 were sown with the rows spaced at 45 cm during *kharif*, 2023 and 2024. The seeds were sown behind the plough in furrows by *Kera* method using seed rate of 12 kg ha^{-1}.

Results and Discussion

Growth Parameters

Hybrid Varieties

A perusal of data (Table 1) revealed that plant height and dry matter accumulation at 35 DAS did not significantly influence, while at 70 DAS and at harvest, it is significantly influenced by sorghum hybrid varieties in individual year as well as in pooled analysis. The pooled data revealed that sorghum hybrid

CSH-16 attained highest plant height at 70 DAS (172.11 cm) with an increase of 11.90 per cent and at harvest (204.16 cm) with an increase of 14.95 per cent as compared to CSH-30 also similarly sorghum hybrid CSH-16 attained significantly higher dry matter accumulation at 70 DAS and at harvest as compared to CSH-30 with an increase of 8.80 and 9.81 per cent, respectively. The difference in plant height of the hybrids might be related to inherent variations and higher vigor. It was also observed that differences in dry matter production of sorghum among hybrids could be attributed to the variation in genetic combination of the genotypes. The similar results observed by Mishra *et al*., 2015 and Kubsad, 2018.

The experimental data present in table 3 revealed that crop growth rate at 0-35 DAS could not influence significantly by sorghum hybrid varieties while, at 35-70 DAS and 70-at harvest, it is significantly influenced in individual years as well as pooled data. The pooled data revealed that sorghum hybrid CSH-16 attained highest crop growth rate during 35-70 DAS and 70 DAS- at harvest with an increase of 10.39 and 11.08 percent, respectively as compared to CSH-30. The pooled data revealed that sorghum hybrid CSH-16 attained highest leaf area index as compared to CSH-30 with an increase of 4.32 per cent. Markole (2016) reported that the variation in plant height, dry matter accumulation/plant and leaf area index at various growth stages in sorghum genotypes.

Soil application of zinc and iron

Further, data presented (Table 1-4) showed that plant height and dry matter accumulation at 35 DAS, 70 DAS and at harvest, crop growth rate (CGR), leaf area index were significantly affected by individual soil application of zinc and iron or in combination over control in 2023, 2024 and in pooled analysis of sorghum crop. The significantly higher plant height and dry matter accumulation at 35 DAS, 70 DAS and at harvest and CGR and leaf area index were recorded with soil application of 5 kg Zn ha^{-1} + 5 kg Fe ha^{-1} over 5 kg Zn ha^{-1} and 5 kg Fe^{-1} ha and control. The increment in plant height was 6.03, 7.02 and 18.25 percent at 35 DAS, 7.70, 9.24 and 23.36 per cent at 70 DAS and 6.98, 7.47 and 25.09 per cent at harvest and dry matter accumulation by 4.64, 5.52 and 15.10 per cent at 35 DAS, 8.71, 10.17, 22.16 per cent at 70 DAS and 9.93, 11.49 and 27.72 per cent at harvest with soil application of 5 kg Zn ha^{-1} + 5 kg Fe ha^{-1} over 5 kg Zn ha^{-1} and 5 kg Fe ha^{-1} and control, respectively in pooled data. Plant height increased as zinc contributes to the synthesis of indole-3-acetic acid, a growth hormone that promotes stem elongation, hence the increase in the plant height. Higher dry matter accumulation can be attributed to the steady availability of zinc and iron, which play a direct role in photosynthesis processes and in the translocation of from source to sink. Similar observations were also reported by Maganur and kubsad (2020) in *kharif* sorghum crop.

The increment in crop growth rate with soil application of 5 kg Zn ha^{-1} + 5 kg Fe ha^{-1} was 4.60, 5.37 and 15.20 per cent at 0-35 DAS, 9.50, 11.06 and 23.58 per cent at 35-70 DAS and 11.38, 13.09 and 34.97 per cent 70 DAS-at harvest per cent over 5 kg Zn ha^{-1} and 5 kg Fe ha^{-1} and control, respectively in pooled data. The application 5 kg Zn ha^{-1} + 5 kg Fe ha^{-1} recorded significantly higher leaf area index as compared to control and soil application of 5 kg Zn ha^{-1} and 5 kg Fe ha^{-1} alone while, the application of 5 kg Zn ha^{-1} and 5 kg Fe ha^{-1} alone were remained statistically at par each other during 2023, 2024 and in pooled analysis. The data revealed that increased in leaf area index was 7.33, 9.53 and 15.81 per cent due to application of 5 kg Zn ha^{-1} + 5 kg Fe ha^{-1}, respectively over application of 5 kg Zn ha^{-1} and 5 kg Fe ha^{-1} and control in pooled analysis. Similar results for were also reported by Asif *et al*., 2020, Javed *et al*., 2020 and Yankam *et al*., 2024.

Foliar application of Zinc and Iron

Further, an examination of data (Table 1-4) revealed that plant height and dry matter accumulation at 35 DAS, 70 DAS and at harvest and also CGR at different growth stages and leaf area index were significantly influenced by foliar application of zinc and iron in combination and separately over control during 2023, 2024 and in pooled analysis. Foliar application of 0.5% $ZnSO_4$ + 0.5% $FeSO_4$, 0.5% $ZnSO_4$ and 0.5% $FeSO_4$ alone recorded significant increase in plant height by 19.50, 17.69, 16.12 per cent at 35 DAS, and 23.51, 15.15, 13.54 per cent at 70 DAS and 24.82, 17.16, 15.39 per cent at harvest over control, respectively. The foliar application of 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ recorded significantly higher dry matter accumulation with per cent increase was 8.33, 10.01, 22.32 at 70 DAS and 8.72, 10.55 and 26.68 at harvest over foliar application of 0.5% $ZnSO_4$ and 0.5% $FeSO_4$ alone and control, respectively. The increased plant height might be due to the in-time availability of the needed nutrients to the plant at the important growth stages. Application of nutrients through foliar spray resulted in efficient absorption of nutrient due to direct application on plant foliage. Increased dry matter production might be due to higher proportion of Zn and Fe in the foliar nutrition which enhanced the crop growth and photosynthetic activity which leading to better supply of carbohydrates and ultimately higher dry matter production per plant was resulted. This is supported by the findings of Dambiwal *et al*., 2017, Srivastav *et al*. (2020), Reema *et al*. (2022).

The data present (table 3) revealed that maximum crop growth rate at 0-35 DAS, at 35-70 DAS and 70 DAS-at harvest was registered under foliar application of 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ and increased by 9.63, 11.58 and 24.25 per cent at 35-70 DAS and 9.22, 11.22 and 32.33 per cent 70 DAS-at harvest over foliar application of 0.5% $ZnSO_4$, 0.5% $FeSO_4$ and control, respectively. Based on pooled data, foliar application of 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ significantly increase leaf area index by 7.31, 9.51 and 16.70 per cent, respectively over foliar application of 0.5% $ZnSO_4$, 0.5% $FeSO_4$ and control. The higher leaf area index directly attributed to the higher leaf area. The higher leaf area response might be due to the improved growth of morphological characters like plant height and dry matter accumulation which resulted in more number of nodes per plant leading to more number of leaves per plant. These finding are also reported by Vijayakumar *et al*. (2020), Maharana *et al*. (2021) and Kumar (2024).

Effect on grain, stover and biological yield

Hybrid varieties

The data present (Table 5) indicated that grain, stover and biological yield significantly influenced by sorghum hybrid varieties in individual year as well as pooled analysis. The pooled data showed that sorghum hybrid CSH-16 significantly produced higher grain, stover and biological yield (3162, 8681 and 11843 kg/ha, respectively) compared to hybrid CSH-30 (2844, 8037 and 10881 kg/ha, respectively) and the magnitude of increase was 11.18, 7.86 and 8.73 per cent, respectively. The variation in yield attributes parameters might be due to differential capability of hybrids in utilizing the available agro-inputs in the process of photosynthesis and thereby yield of sorghum. The hybrid CSH-16 recorded higher agro-input efficiency and improved the translocation of assimilates from source to sink. The results are in line with the findings of Panwar *et al*., 2017, Satish *et al.* (2017) and Reager *et al.* (2025).

Soil application of zinc and iron

The soil application of 5 kg Zn ha^{-1} + 5 kg Fe ha^{-1} recorded significantly higher grain, stover and biological yield over 5 kg Zn ha^{-1} and 5 kg Fe ha^{-1} and control during both the years and in pooled analysis. On pooled basis, the increment in grain yield with the soil application of 5 kg Zn ha^{-1} + 5 kg Fe ha^{-1} were 9.21, 11.57 and 28.36 per cent, respectively and over application of 5 kg Zn ha^{-1} and 5 kg Fe ha^{-1} and control. Stover and biological yield recorded under soil application of 5 kg Zn ha^{-1} + 5 kg Fe ha^{-1} with an increase of 8.83, 9.76, 25.54 per cent stover and 8.93, 10.24, 26.29 per cent biological yield, respectively over control. The individual soil application of 5 kg Zn ha^{-1} and 5 kg Fe ha^{-1} remained statistically at par to each other during both the years of field experiment and in pooled analysis. The increased in the availability of iron and zinc to might have stimulated the metabolic and enzymatic activities, several these enzymes are involved in chlorophyll synthesis and dry matter accumulation which ultimately increased the yield attributed and yield of sorghum. Biological yield is a function of grain and stover yield. Similar result of Kubsad (2019) and Maganur and Kubsad (2020) also found that maximum grain yield, stover yield and biological yield of sorghum. Effect of zinc and iron on yield also close conformity with the results of Waikar *et al.* (2021), Choudhary *et al.* (2021) and Jat *et al.* (2022).

Foliar application of zinc and iron

Further, an examination of data Table 5 revealed that grain, stover and biological yield of sorghum was significantly influenced by foliar application of zinc and iron in combination and separately over control during both the years of experimentation and in pooled analysis. Foliar application of 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ was recorded significantly higher grain, stover and biological yield over individual foliar application of 0.5% $ZnSO_4$ and 0.5% $FeSO_4$ and control whereas, foliar application of 0.5% $ZnSO_4$ and 0.5% $FeSO_4$ were found statistically at par to each other during 2023, 2024 and in pooled analysis. Based on pooled data, foliar application of 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ significantly increase grain yield by 8.38, 10.29 and 27.27 per cent, respectively and stover yield by 8.12, 9.07 and 25.29 per cent, respectively and biological yield by 8.20, 9.39 and 25.82 per cent, respectively over 0.5% $ZnSO_4$, 0.5% $FeSO_4$ and control.

The grain yield depends on the synthesis and accumulation of photosynthates and their distribution among various plant parts. The synthesis, accumulation and translocation of photosynthates depend upon efficient photosynthetic structure as well as the extent of translocation into sink (grains) and on plant growth and development during early stages of crop growth. The production and translocation of synthesized photosynthates depend upon mineral nutrition supplied either through soil or foliar application. Foliar application of zinc and iron increased the utilization of plant nutrients. The nutrients absorbed by the leaves stimulate the metabolic processes in the plant, positively influencing the nutrient uptake via the roots.

The improved yield of sorghum was due to the additive effect of zinc and iron on photosynthesis. These results are in similar with the findings of Salakinkop and Kumar (2017), Patel *et al.* (2019), Venkata Lavanya *et al.* (2020), Ahmad *et al.* (2022) and Ram *et al.* (2021).

Conclusion

The findings of the present study revealed that hybrid variety CSH-16 significantly outperformed in terms of plant height, dry matter accumulation and grain, stover and biological yield. The combined soil application of 5.0 kg Zn ha^{-1} and 5.0 kg Fe ha^{-1} was found to be efficient in improving growth attributes and grain, stover and biological yield of sorghum. Further, foliar application of 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ show remarkable increase in growth parameters and yields of sorghum.

Table 1 : Effect of agronomic biofortification of sorghum hybrid varieties with zinc and iron on plant height

Treatments	Plant height (cm)								
	35 DAS			70 DAS			At harvest		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Varieties									
CSH-16	61.08	61.87	61.48	170.60	173.62	172.11	202.05	206.27	204.16
CSH-30	58.92	60.54	59.73	153.40	154.22	153.81	176.49	178.70	177.60
SEm±	0.83	0.89	0.61	2.44	2.69	1.82	2.28	2.75	1.79
CD (p=0.05)	NS	NS	NS	7.25	8.00	5.26	6.78	8.16	5.17
Soil application									
Control	54.37	55.74	55.06	144.12	145.06	144.59	165.47	167.64	166.56
5.0 kg Zn/ha	60.85	61.97	61.41	164.61	166.60	165.61	193.29	196.21	194.75
5.0 kg Fe/ha	60.35	61.32	60.84	162.09	164.46	163.28	191.78	195.94	193.86
5.0 Zn/ha + 5.0 kg Fe/ha	64.43	65.79	65.11	177.18	179.56	178.37	206.54	210.15	208.35
SEm±	1.18	1.26	0.86	3.45	3.81	2.57	3.23	3.88	2.52
CD (p=0.05)	3.50	3.73	2.49	10.25	11.31	7.44	9.59	11.54	7.31
CV (%)	9.62	10.06	-	10.43	11.38	-	8.35	9.89	-
Sub-plot foliar application									
Control	53.27	53.68	53.48	143.14	145.16	144.15	165.56	168.32	166.94
0.5% $ZnSO_4$	62.13	63.74	62.94	165.51	166.46	165.99	194.03	197.12	195.58
0.5% $FeSO_4$	61.36	62.83	62.10	162.79	164.54	163.67	191.17	194.08	192.63
0.5% $ZnSO_4$ + 0.5% $FeSO_4$	63.24	64.57	63.91	176.56	179.52	178.04	206.32	210.42	208.37
SEm±	1.04	0.93	0.70	2.34	2.30	1.65	1.48	2.34	1.39
CD (p=0.05)	2.96	2.64	1.97	6.62	6.52	4.62	4.19	6.61	3.89
CV (%)	8.53	7.47	-	8.08	7.89	-	6.84	7.34	-

Table 2: Effect of agronomic biofortification of sorghum hybrid varieties with zinc and iron on dry matter accumulation at different growth stage

Treatments	Dry matter accumulation/plant (g)								
	35 DAS			70 DAS			At harvest		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Varieties									
CSH-16	9.56	9.68	9.62	58.15	61.78	59.97	106.15	112.96	109.56
CSH-30	9.43	9.57	9.50	53.83	56.41	55.12	97.08	102.45	99.77
SEm±	0.12	0.13	0.09	0.83	0.89	0.61	1.39	1.34	0.97
CD (p=0.05)	NS	NS	NS	2.48	2.64	1.76	4.12	3.99	2.80
Soil application									
Control	8.76	8.85	8.81	50.69	52.67	51.68	88.77	93.87	91.32
5.0 kg Zn/ha	9.63	9.75	9.69	56.38	59.75	58.07	103.09	109.08	106.09
5.0 kg Fe/ha	9.54	9.67	9.61	55.76	58.84	57.30	101.86	107.36	104.61
5.0 Zn/ha + 5.0 kg Fe/ha	10.05	10.23	10.14	61.13	65.12	63.13	112.74	120.51	116.63
SEm±	0.17	0.18	0.12	1.18	1.26	0.86	1.96	1.90	1.37
CD (p=0.05)	0.49	0.53	0.35	3.50	3.73	2.49	5.83	5.65	3.96
CV (%)	8.58	9.01	-	10.31	10.42	-	9.46	8.65	-
Sub-plot foliar application									
Control	8.74	8.87	8.81	50.40	52.72	51.56	89.02	93.88	91.45

0.5% $ZnSO_4$	9.73	9.82	9.78	56.57	59.86	58.22	103.45	109.66	106.56
0.5% $FeSO_4$	9.67	9.76	9.72	55.91	58.74	57.33	102.17	107.41	104.79
0.5% $ZnSO_4$ + 0.5% $FeSO_4$	9.84	10.05	9.95	61.08	65.06	63.07	111.82	119.87	115.85
SEm±	0.13	0.14	0.09	1.04	0.93	0.70	1.18	1.04	0.79
CD (p=0.05)	0.36	0.39	0.26	2.96	2.64	1.97	3.35	2.95	2.21
CV (%)	6.50	7.09	-	8.14	7.74	-	7.71	6.74	-

Table 3: Effect of Agronomic Biofortification of Sorghum Hybrid Varieties with Zinc and Iron on crop growth rate

Treatments	**CGR (g/m^2/day)**								
	0-35 DAS			**35-70 DAS**			**70-At harvest**		
	2023	**2024**	**Pooled**	**2023**	**2024**	**Pooled**	**2023**	**2024**	**Pooled**
Varieties									
CSH-16	4.08	4.13	4.10	20.72	22.22	21.47	20.47	21.83	21.15
CSH-30	4.02	4.08	4.05	18.93	19.97	19.45	18.44	19.63	19.04
SEm±	0.03	0.04	0.03	0.32	0.31	0.23	0.31	0.30	0.21
CD (p=0.05)	NS	NS	NS	0.96	0.93	0.65	0.91	0.89	0.62
Soil application									
Control	3.74	3.77	3.75	17.88	18.69	18.28	16.24	17.57	16.90
5.0 kg Zn/ha	4.11	4.16	4.13	19.94	21.32	20.63	19.92	21.04	20.48
5.0 kg Fe/ha	4.07	4.12	4.10	19.71	20.97	20.34	19.66	20.69	20.17
5.0 Zn/ha + 5.0 kg Fe/ha	4.29	4.36	4.32	21.78	23.41	22.59	22.01	23.62	22.81
SEm±	0.05	0.05	0.04	0.46	0.44	0.32	0.43	0.42	0.30
CD (p=0.05)	0.14	0.15	0.10	1.36	1.32	0.92	1.29	1.26	0.88
CV (%)	6.83	7.20	-	11.32	10.33	-	10.94	10.02	-
Sub-plot foliar application									
Control	3.73	3.78	3.75	17.77	18.70	18.23	16.47	17.55	17.01
0.5% $ZnSO_4$	4.15	4.19	4.17	19.97	21.34	20.66	19.99	21.24	20.61
0.5% $FeSO_4$	4.12	4.16	4.14	19.72	20.89	20.30	19.73	20.75	20.24
0.5% $ZnSO_4$ + 0.5% $FeSO_4$	4.20	4.29	4.24	21.85	23.46	22.65	21.64	23.37	22.51
SEm±	0.04	0.04	0.03	0.31	0.32	0.22	0.31	0.28	0.21
CD (p=0.05)	0.12	0.13	0.08	0.87	0.88	0.61	0.87	0.80	0.58
CV (%)	5.49	6.28	-	7.61	7.18	-	7.70	6.68	-

Table 4: Effect of agronomic biofortification of sorghum hybrid varieties with zinc and iron on leaf area index of sorghum

Treatments	**LAI**		
	2023	**2024**	**Pooled**
Varieties			
CSH-16	5.51	5.58	5.55
CSH-30	5.37	5.28	5.32
SEm±	0.04	0.04	0.03
CD (p=0.05)	0.13	0.11	0.08
Soil application			
Control	5.13	4.99	5.06
5.0 kg Zn/ha	5.45	5.48	5.46
5.0 kg Fe/ha	5.35	5.36	5.35
5.0 Zn/ha + 5.0 kg Fe/ha	5.84	5.88	5.86
SEm±	0.06	0.05	0.04
CD (p=0.05)	0.18	0.15	0.12
CV (%)	8.43	7.67	-
Sub-plot foliar application			
Control	5.10	4.97	5.03
0.5% $ZnSO_4$	5.45	5.48	5.47
0.5% $FeSO_4$	5.35	5.37	5.36
0.5% $ZnSO_4$ + 0.5% $FeSO_4$	5.85	5.89	5.87

SEm±	0.05	0.05	0.04
CD (p=0.05)	0.15	0.14	0.10
CV (%)	7.06	6.43	-

Table 5: Effect of agronomic biofortification of sorghum hybrid varieties with zinc and iron on grain, stover and biological yield and harvest index

Treatments	Grain yield (kg/ha)			Stover yield (kg/ha)			Biological yield (kg/ha)			Harvest index (%)		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Varieties												
CSH-16	3119	3204	3162	8635	8727	8681	11754	11931	11843	26.52	26.83	26.67
CSH-30	2806	2882	2844	7982	8091	8037	10788	10973	10881	25.99	26.24	26.12
SEm±	44	49	33	154	158	111	175	183	127	0.33	0.34	0.24
CD (p=0.05)	132	146	96	458	470	320	520	545	367	NS	NS	NS
Soil application												
Control	2574	2637	2606	7296	7391	7344	9870	10028	9949	26.06	26.27	26.17
5.0 kg Zn/ha	3021	3105	3063	8439	8505	8472	11460	11610	11535	26.34	26.72	26.53
5.0 kg Fe/ha	2973	3022	2998	8382	8418	8400	11355	11440	11398	26.17	26.39	26.28
5.0 Zn/ha + 5.0 kg Fe/ha	3282	3408	3345	9117	9322	9220	12399	12730	12565	26.45	26.75	26.60
SEm±	63	69	47	218	224	156	247	259	179	0.46	0.48	0.33
CD (p=0.05)	186	206	135	648	665	453	735	771	519	NS	NS	NS
CV (%)	9.85	10.94	-	11.76	12.14	-	10.22	11.09	-	8.64	8.81	-
Sub-plot foliar application												
Control	2577	2644	2611	7269	7394	7332	9846	10038	9942	26.15	26.31	26.23
0.5% $ZnSO_4$	3029	3102	3066	8473	8518	8496	11502	11620	11561	26.31	26.67	26.49
0.5% $FeSO_4$	2996	3029	3013	8418	8426	8422	11414	11455	11435	26.23	26.42	26.32
0.5% $ZnSO_4$ + 0.5% $FeSO_4$	3248	3397	3323	9074	9298	9186	12322	12695	12509	26.34	26.73	26.53
SEm±	48	51	35	151	153	107	160	166	115	0.30	0.39	0.24
CD (p=0.05)	136	144	98	428	432	302	453	469	324	NS	NS	NS
CV (%)	7.89	8.36	-	8.80	9.27	-	7.48	8.54	-	6.54	7.16	-

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