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AGRONOMIC BIO-FORTIFICATION OF ZINC IN GRAIN SORGHUM (*SORGHUM BICOLOR* L. MOENCH)

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ABSTRACT

A field experiment was conducted at Agricultural Research Station, Hagari during *kharif*, 2024 to study the effect of agronomic bio-fortification of zinc in grain sorghum (S*orghum bicolor* L.). An experiment was laid in RCBD design with ten treatments and replicated thrice. The results revealed that the treatment receiving soil application of 20 kg $ZnSO_4$ ha^{-1} as basal + Foliar spray of ZnSO4 @ 0.5% each at 30 and 45 DAS recorded significantly higher growth parameters *viz*., plant height, leaf area per plant, leaf area index, yield parameters *viz*., length of earhead, ear head weight, number of grains per ear head, test weight, grain yield (3586 kg ha^{-1}). However, Soil application of 20 kg $ZnSO_4$ ha^{-1} as basal + foliar spray of $ZnSO_4$ @ 0.5% each at 30 and 45 DAS which were found on par with 15 kg $ZnSO_4$ ha^{-1} as basal + foliar spray of $ZnSO_4$ @ 0.5% each at 30 and 45 DAS, 20 kg $ZnSO_4$ ha^{-1} as basal + foliar spray of $ZnSO_4$ @ 0.5% at 45 DAS, 15 kg $ZnSO_4$ ha^{-1} as basal + spray of $ZnSO_4$ @ 0.5% at 45 DAS and 20 kg $ZnSO_4$ ha^{-1} as basal alone with respect to growth, yield and yield parameters. Further, lower growth parameters and yield parameters were noticed in absolute treatment.

***Keywords* :** Sorghum, Agronomic bio-fortification, Zinc, Soil application.

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is an important cereal crop and a staple food crop in semiarid tropics. It is necessary to increase its production and productivity in order to meet the growing demand of sorghum by increasing population. In India the area and production of sorghum during 2024-25 was 4.07 m ha and 4.73 m t, respectively with a productivity of 1162 kg ha^{-1} (Anon, 2025). In Karnataka the area and production of sorghum during 2024-25 was 0.8 m ha and 0.94 m t, respectively with a productivity of 1167 kg ha^{-1} (Anon., 2025a).

The productivity of sorghum is low due to growing on marginal lands and continuous use of macronutrients. Zinc has emerged as the most widespread micronutrient deficiency in soils and crops worldwide, resulting in severe yield losses and deterioration in nutritional quality (Sillanpaa, 1982). Zinc is a vital micronutrient required for the plant growth. Zinc 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 important role in oxidation processes in cell and help in transformation of carbohydrates and regulation of sugar in plants (Swaminathan and Kannan, 2001). Sorghum shows reduced photosynthetic carbon metabolism due to zinc deficiency.

Plant breeding strategy (genetic bio-fortification) appears to be a suitable and cost-effective approach useful in improving Zn concentration in grain. However, it is a long-term process requiring sustainable effort and resources. It is therefore essential for short term approach to improve Zn concentration in cereal grains. Application of Zn fertilizers as Zn enriched N, P, and K fertilizers (e.g. agronomic biofortification) to soil and /or foliage seems to be a practical approach to improve zinc concentration in grains. Zinc Sulphate ($ZnSO_4$) is the widely applied source of Zn because of its high solubility and low cost. Combined application of soil and foliar Zn fertilizers is the most effective way to maximize grain Zn accumulation (Cakmak *et al*., 2010). Agronomic biofortification strategy appears to be essential in keeping sufficient amount of available Zn in soil solution and maintain adequate Zn transport to grain during the reproductive stage.

Agronomic biofortification of food crops might be an effective tool in combating micronutrient malnutrition in human population (Cakmak, 2008).

Materials and Methods

A field experiment was conducted during *kharif*, 2024 at Agricultural Research Station, Hagari, on *Vertisol* having pH 7.65 and EC 0.52 dS m^{-1}. The soil was low in available N (252.80 kg ha^{-1}), and medium in organic carbon (5.3 g kg^{-1}) and medium in available P_2O_5 (40.90 kg ha^{-1}) with medium available K_2O content (425.20 kg ha^{-1}). The experimental site was located at a 15^o 13' N latitude and 77^o 05' E longitude with an altitude of 414 meters above the mean sea level and is located in Northern Dry Zone of Karnataka (Zone-III).Total rainfall received during crop growth period was 307.7 mm from July to November 2024. The average maximum and minimum air temperature during crop growth period (July 2024 to November 2024) ranged from 32.2 to 33.7 ^{0}C and 19.0 to 24.8 ^{0}C, respectively. Maximum relative humidity (87.1 %) was observed in July as shown in Figure 1. The research was arranged in Randomized complete block design, there were ten treatment combination with different levels of soil and foliar application of $ZnSO_4$ and those were replicated thrice. The treatment combinations are T_1: Soil application of 10 kg $ZnSO_4$ ha^{-1}, T_2: Soil application of 10 kg $ZnSO_4$ ha^{-1} as basal + Foliar spray of $ZnSO_4$ @ 0.5% at 45 DAS, T_3: Soil application of 10 kg $ZnSO_4$ ha^{-1} as basal + Foliar spray of $ZnSO_4$ @ 0.5% each at 30 and 45 DAS, T_4: Soil application of 15 kg $ZnSO_4$ ha^{-1} as basal, T_5: Soil application of 15 kg $ZnSO_4$ ha^{-1} + Foliar spray of $ZnSO_4$ @ 0.5% at 45 DAS, T_6: Soil application of 15 kg $ZnSO_4$ ha^{-1} as basal + Foliar spray of $ZnSO_4$ @ 0.5% each at 30 and 45 DAS, T_7: Soil application of 20 kg $ZnSO_4$ ha^{-1} as basal T_8: Soil application of 20 kg $ZnSO_4$ ha^{-1} as basal + Foliar spray of $ZnSO_4$ @ 0.5% at 45 DAS, T_9: Soil application of 20 kg $ZnSO_4$ ha^{-1} as basal + Foliar spray of $ZnSO_4$ @ 0.5% each at 30 and 45 DAS and T_{10}: Absolute control. After the previous crop was harvested, the field was ploughed, followed by leveling. The field was prepped to a good seedbed and the fields were set out in preparation for sowing. The variety CSH-16 was used. The basal application of fertilizers in the form of urea, SSP and MOP were applied as per treatments with recommended dose of 100:75:37.5:15 kg N:P_2O_5:K_2O: $ZnSO_4$ ha^{-1}, FYM @ 5.5. t ha^{-1}. 50 % of N, entire P and K were applied as basal and remaining 50 % of N was side dressed at 30 days after sowing. The crop was sowed on 4th July 2024 with a spacing of 45 cm × 15 cm. Growth parameters such as plant height, leaf area and leaf area index were recorded at interval of 30 days. Harvesting was done at physiological maturity of the crop. The earheads were harvested from the standing crop in the net plot area and were sun dried. The sun dried earheads were threshed, cleaned and yield parameters were recorded. The samples were collected harvest and dried at 65 ^{0}C in a hot air oven, powdered using a grinder, fitted with stainless steel bladders and preserved in polythene bags for further analysis of uptake of N, P, K and Zn as suggested by Jackson (1973). During the field experiment, a composite soil sample was collected from experimental plot before sowing. After harvest of the crop, soils from each treated plot were taken separately. The collected soil samples were dried under shade, powdered using pestle and mortar and passed through 2 mm sieve and preserved for analysis which were analyzed for available nitrogen, phosphorus, potassium and zinc. The analysis and interpretation of data were done using the Fisher's method of analysis and variance technique as given by Panse and Sukhatme (1967). The level of significance used in "F" and "t" test was at 5 % probability level and wherever "F" test was found significant, the "t" test was performed to estimate critical differences among various treatments.

Results and Discussion

Growth parameters

Plant height (cm)

Significantly higher plant height were noticed in the treatment receiving soil application of 20 kg $ZnSO_4$ ha^{-1} as basal + Foliar spray of $ZnSO_4$ @ 0.5% each at 30 and 45 DAS (T_9) (30.1, 122.1, 150.0 and 153.3 at 30, 60, 90 DAS and at harvest, respectively) (Table 1). Which was statistically on par with 15 kg $ZnSO_4$ ha^{-1} as basal + foliar spray of $ZnSO_4$ @ 0.5% each at 30 and 45 DAS (29.6, 121.5, 149.5 and 152.3 at 30, 60, 90 DAS and at harvest, respectively), 20 kg $ZnSO_4$ ha^{-1} as basal + foliar spray of $ZnSO_4$ @ 0.5% at 45 DAS (29.1, 121.1, 149.1 and 152.1 at 30, 60, 90 DAS and at harvest, respectively), 15 kg $ZnSO_4$ ha^{-1} as basal + spray of $ZnSO_4$ @ 0.5% at 45 DAS (28.8, 120.5, 148.3 and 150.8 at 30, 60, 90 DAS and at harvest, respectively) and 20 kg $ZnSO_4$ ha^{-1} as basal alone (28.1, 119.9, 147.9 and 150.1 at 30, 60, 90 DAS and at harvest, respectively) presented in Table 1. Similar results were reported by Zayed *et al.*, 2011. The enhancement in plant height due to $ZnSO_4$ application could be attributed to its role in promoting meristematic activity, auxin synthesis and elongation of internodes which together improve overall vegetative growth and plant stature. As a consequence of increased plant height, the number of nodes and internodes increased which resulted in higher number of leaves.

Leaf area and Leaf area index

Higher leaf area and leaf area index of sorghum were recorded by application of 20 kg $ZnSO_4$ ha^{-1} as basal + foliar spray of $ZnSO_4$ @ 0.5% each at 30 and 45 DAS (T_9) (14.4, 30.2, 35.2 and 30.0 dm^2 $plant^{-1}$ and 0.21, 0.45, 0.52 and 0.44, at 30, 60, 90 DAS and at harvest, respectively) as given in Table 1. Which was statistically on par with 15 kg $ZnSO_4$ ha^{-1} as basal + foliar spray of $ZnSO_4$ @ 0.5% each at 30 and 45 DAS, 20 kg $ZnSO_4$ ha^{-1} as basal + foliar spray of $ZnSO_4$ @ 0.5% at 45 DAS, 15 kg $ZnSO_4$ ha^{-1} as basal + spray of $ZnSO_4$ @ 0.5% at 45 DAS and 20 kg $ZnSO_4$ ha^{-1} as basal alone 30, 60, 90 DAS and at harvest presented in Table 1.

As a result of foliar spray and soil application of $ZnSO_4$ along with basal dose of conventional fertilizers, the availability of nitrogen and phosphorous increased. The increased availability resulted in increased plant height, leaf area and finally leaf area index. These findings were in accordance with Mohsin *et al.* (2014).

Table 1 : Plant height, leaf area, leaf area index of *kharif* grain sorghum cultivation as influenced agronomic bio-fortification of zinc at different levels

Treatment	Plant height (cm)				Leaf area (dm^2 $plant^{-1}$)				Leaf area index			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
T_1	21.1	108.6	128.9	136.2	10.1	21.7	24.2	22.0	0.15	0.32	0.36	0.33
T_2	25.1	110.3	132.6	141.2	11.1	22.5	27.1	22.3	0.16	0.33	0.40	0.33
T_3	27.1	112.5	140.3	144.0	12.5	25.2	30.2	25.6	0.19	0.37	0.45	0.38
T_4	26.4	111.2	138.5	143.4	12.1	24.3	29.2	24.1	0.18	0.36	0.43	0.36
T_5	28.8	120.5	148.3	150.8	13.9	28.1	32.9	28.1	0.21	0.42	0.49	0.42
T_6	29.6	121.5	149.5	152.3	14.2	29.1	34.1	29.5	0.21	0.43	0.51	0.44
T_7	28.1	119.9	147.9	150.1	13.7	27.2	32.1	27.5	0.20	0.40	0.48	0.41
T_8	29.1	121.1	149.1	152.1	14.1	28.5	33.5	28.9	0.21	0.42	0.50	0.43
T_9	30.1	122.1	150.0	153.3	14.4	30.2	35.2	30.0	0.21	0.45	0.52	0.44
T_{10}	19.9	98.5	123.1	128.5	8.8	19.4	22.1	21.8	0.13	0.29	0.33	0.32
S.Em.±	**0.9**	**2.9**	**3.0**	**3.0**	**0.43**	**1.24**	**1.18**	**1.16**	**0.01**	**0.02**	**0.02**	**0.02**
C. D (P=0.05)	**2.6**	**8.7**	**8.8**	**8.9**	**1.29**	**3.69**	**3.52**	**3.45**	**0.02**	**0.05**	**0.05**	**0.05**

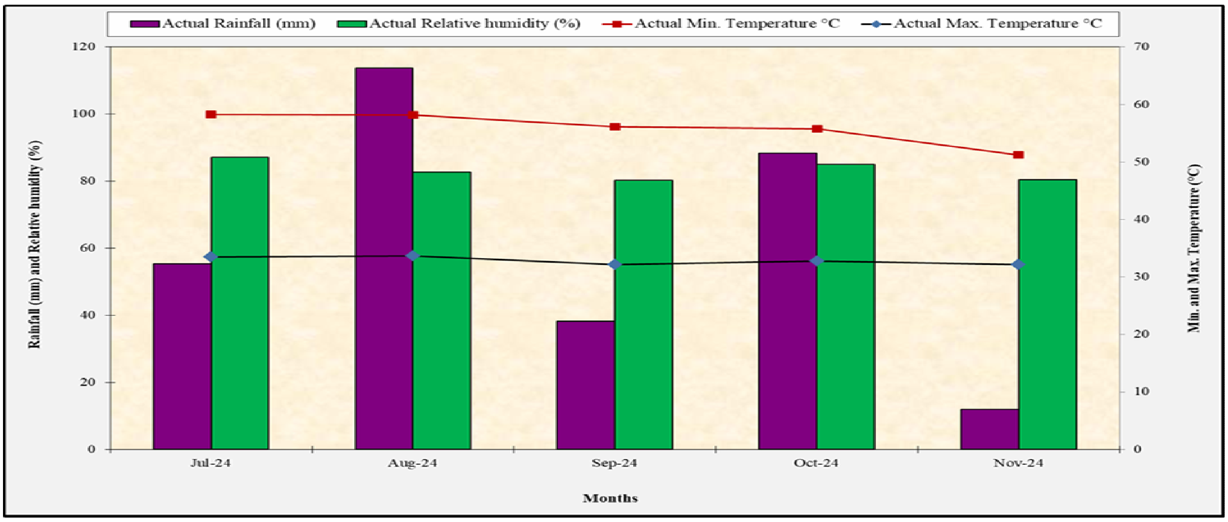

Fig. 1: Meteorological data of experimental site from July 2024 to November 2024) at ARS, Hagari (Karnataka)

Yield attributes and yield

With respect to test weight, there was no significant difference between the treatments presented in Table 2. Whereas, among different treatments, T_9 *i.e.,* Soil application of 20 kg $ZnSO_4$ ha^{-1} as basal + Foliar spray of $ZnSO_4$ @ 0.5% each at 30 and 45 DAS recorded numerically higher test weight (31.3 g). Significantly higher length of ear head, ear head weight, number of grains $earhead^{-1}$, and grain yield were recorded in Soil application of 20 kg $ZnSO_4$ ha^{-1} as basal + Foliar spray of $ZnSO_4$ @ 0.5% each at 30 and 45 DAS (T_9) (35.6 cm, 89.7 g, 2305 and 3586 kg ha^{-1}, respectively). Which was statistically on par with 15 kg $ZnSO_4$ ha^{-1} as basal + foliar spray of $ZnSO_4$ @ 0.5% each at 30 and 45 DAS (T_6) (35.1 cm, 88.4 g, 2278 and 3484 kg ha^{-1}, respectively), 20 kg $ZnSO_4$ ha^{-1} as basal + foliar spray of $ZnSO_4$ @ 0.5% at 45 DAS (T_8) (34.9 cm, 86.4 g, 2240 and 3405 kg ha^{-1}, respectively), 15 kg $ZnSO_4$ ha^{-1} as basal + spray of $ZnSO_4$ @ 0.5% at 45 DAS (T_5) (34.4 cm, 84.2 g, 2180 and 3353 kg ha^{-1}, respectively) and 20 kg $ZnSO_4$ ha^{-1} as basal alone (T_7) (33.9 cm, 84.3 g, 2120 and 3267 kg ha^{-1}, respectively). Similar results were reported by Kubsad *et al.* (2019). combined basal and foliar zinc application could be attributed to enhanced zinc availability during critical reproductive stages, which supports panicle development by promoting pollen viability and spikelet fertility. Zinc-mediated activation of enzymatic systems such as carbonic anhydrase and dehydrogenases may have supported increased photosynthate production and efficient nutrient partitioning towards the developing panicles. The improvement in grain number was likely due to zinc's role in promoting reproductive organ development, pollen viability and grain setting. Zinc also supports auxin synthesis and enzyme activation, which together enhance assimilate translocation and floret retention.

Table 2: Yield attributes and grain yield of *kharif* sorghum as influenced by agronomic bio-fortification of zinc at different level

Treatment	Length of ear head (cm)	Ear head weight (g)	Number of grains $earhead^{-1}$	Test weight (g)	Grain yield (kg ha^{-1})
T_1	28.2	67.1	1870	29.7	2925
T_2	28.6	69.3	1890	29.8	3029
T_3	30.1	73.6	1960	30.2	3051
T_4	29.5	71.1	1910	30.1	3075
T_5	34.4	84.2	2180	30.9	3353
T_6	35.1	88.4	2278	31.1	3484
T_7	33.9	84.3	2120	30.8	3267
T_8	34.9	86.4	2240	31.0	3405
T_9	35.6	89.7	2305	31.3	3586
T_{10}	21.5	60.1	1805	29.6	2025
S.Em.±	**0.9**	**1.9**	**82**	**1.7**	**117**
C.D. (P=0.05)	**2.8**	**5.7**	**245**	**NS**	**348**

Nutrient content and uptake by plants

The data on nutrient content and uptake of sorghum as influenced by the application of different levels of soil applied zinc and foliar spray of $ZnSO_4$ are presented in Table 3 and Figure 2. Among all the treatments, significantly higher concentration of nitrogen, phosphorus, potassium and zinc in grain of sorghum were recorded in treatment T_9 *i.e.,* Soil application of 20 kg $ZnSO_4$ ha^{-1} as basal + Foliar spray of $ZnSO_4$ @ 0.5% each at 30 and 45 DAS (1.16, 0.43, 0.69 % and 24.7 mg kg^{-1}, respectively). Whereas significantly lower concentration of nitrogen, phosphorus, potassium and zinc in sorghum grain were noticed in T_{10}: Control (1.11, 0.40, 0.66 % and 19.4 mg kg^{-1}, respectively). The uptake of major nutrients *viz.,* nitrogen, phosphorus, potassium and zinc were recorded significantly higher in T_9: Soil application of 20 kg $ZnSO_4$ ha^{-1} as basal + Foliar spray of $ZnSO_4$ @ 0.5% each at 30 and 45 DAS (116.1, 42.3, 123.9 kg ha^{-1} and 291.2 mg kg^{-1}, respectively). The increase in nutrient uptake was due to the foliar application of nano fertilizers which have higher This could be attributed to application of FYM @ 5.5 t ha^{-1} with in organic fertilizers might have improved the nutritional environment in the root zone as well as in the plant system leading increased uptake and translocation of nutrients especially nitrogen and phosphorous in the reproductive structure leading to higher content and uptake. Since uptake of nutrients is the function of grain and stover yield and their nutrient content, the significant improvement in content of these nutrients coupled with increased grain and stover yield and total uptake of nitrogen, phosphorous and potassium substantially was recorded. Increase in uptake of N was also due to increase in dry matter production and content. The results obtained in the present study are in accordance with Sharma *et al.* (2007).

Table 3: Total nutrient content and uptake by *kharif* grain sorghum as influenced by agronomic

Treatment	Grain nutrient content (%)			Zinc (mg kg^{-1})	Total nutrient uptake (kg ha^{-1})			Zinc (g ha^{-1})
	Nitrogen	Phosphorus	Potassium		Nitrogen	Phosphorus	Potassium	
T_1	1.14	0.41	0.67	22.2	96.9	34.3	105.0	218.0
T_2	1.14	0.41	0.67	22.3	98.8	35.3	106.2	224.5
T_3	1.15	0.42	0.68	22.9	99.5	35.8	106.8	229.2
T_4	1.16	0.42	0.68	23.3	100.5	36.2	107.5	236.4
T_5	1.16	0.42	0.69	24.4	108.7	39.2	115.7	270.6
T_6	1.16	0.42	0.69	24.5	115.1	41.5	123.6	288.2
T_7	1.16	0.43	0.69	24.7	108.1	38.7	115.2	269.7
T_8	1.16	0.43	0.69	24.7	111.5	40.0	119.1	279.3
T_9	1.16	0.43	0.69	24.7	116.1	42.3	123.9	291.2
T_{10}	1.11	0.40	0.66	19.4	67.4	23.5	69.1	130.7
S.Em.±	**0.006**	**0.41**	**0.67**	**22.2**	**3.1**	**1.1**	**3.4**	**7.0**
C.D. (P=0.05)	**0.017**	**0.41**	**0.67**	**22.3**	**9.3**	**3.2**	**10.1**	**20.7**

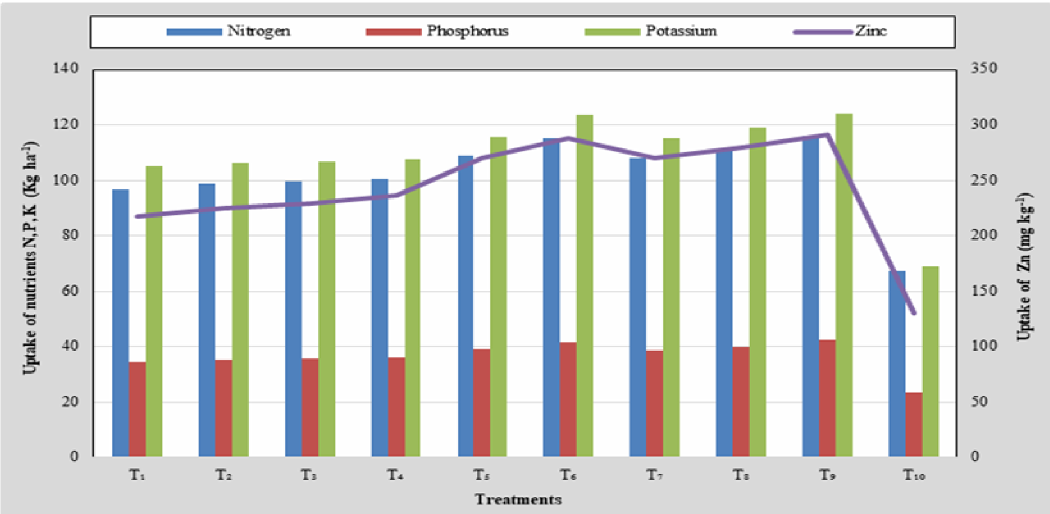

Fig. 2: Uptake of nutrients by *kharif* grain sorghum as influenced by agronomic bio-fortification of zinc at different levels

Conclusion

Soil applied zinc and foliar application of $ZnSO_4$ *i.e.,* Soil application of 20 kg $ZnSO_4$ ha^{-1} as basal + Foliar spray of $ZnSO_4$ @ 0.5% each at 30 and 45 DAS is best to increase growth attributes, yield parameters and nutrient uptake by the plants found to be superior in higher zinc accumulation in grain compared to absolute control.

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