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Nutri-fortification of grain Amaranth (*Amaranthus hypochondriacus* L.) through soil and foliar application of micronutrients

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Abstract
A field experiment entitled "Nutri-fortification of grain amaranth (*Amaranthus hypochondriacus* L.) through soil and foliar application of micronutrients" was conducted at K block, UAS, GKVK, Bengaluru during *kharif* season of 2022. It was carried out in a RCBD with ten treatments, which was replicated three times and the cultivar used was KBGA-15. The results revealed that, a significant increase in growth parameters was recorded in RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1} followed by foliar application of $ZnSO_4$ @ 0.5% and $FeSO_4$ @ 0.5% at 30 and 60 DAS *i.e.*, plant height (180.5 cm), number of leaves $plant^{-1}$ (23.33), leaf area $plant^{-1}$ (3280 cm^2), total dry matter production $plant^{-1}$ (104.8 g). Similarly yield attributes such aspanicle length (56.9 cm), number of fingers $panicle^{-1}$ (60.0), length of finger (21.4 cm), grain yield $plant^{-1}$ (21.45 g), grain and stover yield (2154 and 6964 kg ha^{-1}, respectively). Further, the same treatment led to higher net returns (Rs. 1, 37,905 ha^{-1}) and B: C ratio (4.01). Significantly higher protein and oil content (13.88% and 8.56%, respectively) was recorded with combined application of micronutrients (Fe and Zn) *i.e.*, RDF + soil application of $FeSO_4$ @ 10 kg ha-1 + $ZnSO_4$ @ 15 kg ha^{-1} followed by foliar application of $ZnSO_4$ @ 0.5% and $FeSO_4$ @ 0.5% at 30 and 60 DAS (T9) and it was found to be on par with RDF + soil application of $FeSO_4$ @ 10 kg ha-1 + $ZnSO_4$ @ 15 kg ha-1 (13.68% and 8.23%, respectively) and RDF + foliar application of $FeSO_4$ @ 0.5% & $ZnSO_4$ @ 0.5% at 30 and 60 DAS (13.54% and 7.85%).

Keywords: Grain amaranth, nutri-fortification, Soil and foliar, micronutrients, growth, yield

Introduction

Grain amaranth (*Amaranthus hypochondriacus* L.) is a South American native belonging to the Amaranthaceae family. This annual herb can grow up to 2 meters in height, featuring broad green leaves and colorful flower heads that produce small edible seeds. These seeds often called amaranth grain which is part of a group known as pseudocereals, resembling true cereals but with distinct nutritional advantages, notably in protein and amino acid content. Amaranth seeds are nutritionally dense, offering all essential amino acids, fiber, vitamins, and minerals. They are particularly noteworthy for their high protein content (14-16%), with superior levels of lysine and other essential amino acids, enhancing their overall protein quality. Additionally, the seeds contain around 7-8% oil, primarily composed of unsaturated fatty acids (76%). Amaranth oil has.7 percent squalene which is costly and it is used in cosmetics and pharmaceutical industries (He *et al*., 2002 and He and Corke, 2003) [10, 9]. In India it is estimated that grain amaranth is being grown in about 40-50 thousand hectares, especially in Banaskantha and Kheda districts of Gujarat state. Gujarat alone covers more than 50 percent area of our country (Raiger *et al*., 2023) [23]. In Karnataka, grain amaranth is being grown by tribal communities in Biligiri Rangana Hills (BR-Hills) of Chamarajnagara and other rainfed areas as leafy vegetables and seed purpose (Anand *et al*., 2020) [2].
Micronutrients play a crucial role in promoting balanced growth in both plants and humans. Insufficient intake of these micronutrients can lead to malnutrition and hinder growth, particularly in children.

Children and lactating women are particularly susceptible to micronutrient deficiencies. According to a UNICEF report, more than 80% of teenagers in India suffer from hidden hunger and nearly one-third of the global population is at risk of this condition. Hidden hunger refers to the lack of essential vitamins and micronutrients in the human body. Addressing these deficiencies can be accomplished by number of methods including mineral supplementation, the consumption of fortified commercial food products, and bio-fortification. Nevertheless, incorporating external supplements into the diet is considered an effective and swift approach to combat deficiencies (Sethi *et al*., 2019) [25]. Hence, usage of grain amaranth based diet plans would help in alleviating the nutritional insecurity as it appears to be cheap sources of vitamins and minerals.

Bio-fortification involves improving the nutritive value of food crops through various methods such as agronomic practices, conventional plant breeding, or modern biotechnology. The selection of germplasm with improved nutrient content through plant breeding is a time-consuming and labour-intensive process. An alternative approach, known as ferti-fortification or nutri-fortification, is considered a quicker and straighter forward method to combat micronutrient deficiencies (Elemike *et al*., 2019) [7]. Ferti-fortification entails externally applying nutrients to plants to boost their nutrient content, providing individuals with sufficient nutrition upon consumption. However, the success of agronomic fortification is hindered by the limited availability of micronutrients in the soil. Despite the presence of adequate micronutrient levels, soil biochemical properties like pH and their interaction with soil components may render them in forms that are inaccessible to plants. Farmers and crop growers, unaware of this relationship, sometimes excessively apply nutrients to the soil, leading to uncontrolled nutrient accumulation. Consequently, there is a pressing need to develop strategies for enhancing crop nutrition without disrupting the natural soil balance, promoting the sustainable use of chemicals.

Materials and Methods

A field experiment was carried out at 'K' block, UAS, GKVK, Bengaluru during *kharif* season of 2022-23. It is situated in Eastern Dry Zone of Karnataka at a latitude of 13º 05′ North, longitude of 77º 34′ East and altitude of 949 m above mean sea level. The experimental site had red sandy loam soil classified as *Alfisols*. Composite soil samples from 0-15 cm depth were collected before treatment imposition and analyzed for physical and chemical properties. The soil was neutral (pH 6.42), with low available nitrogen (248 kg ha^{-1}), medium in available phosphorous (43 kg ha^{-1}) and available potassium (234 kg ha^{-1}), high in available iron (11.06 ppm), low in available zinc (0.55 ppm), and low organic carbon content (0.40%). The experiment was conducted in a complete randomized block design with ten treatments replicated three times. The treatments are RDF (60:40:40 kg ha^{-1} N: P_2O_5: K_2O) (T_1), RDF + foliar application of $ZnSO_4$ @ 0.5% at 30 and 60 DAS (T_2), RDF + foliar application of $FeSO_4$ @ 0.5% at 30 and 60 DAS (T_3), RDF + foliar application of $ZnSO_4$ @ 0.5% at 30 DAS followed by $FeSO_4$ @ 0.5% at 60 DAS (T_4), RDF + foliar application of $FeSO_4$ @ 0.5% & $ZnSO_4$ @ 0.5% at 30 and 60 DAS (T_5), RDF + soil application of $ZnSO_4$ @ 15 kg ha^{-1} (T_6), RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1} (T_7), RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1} (T_8), RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1} followed by foliar application of $ZnSO_4$ @ 0.5% and $FeSO_4$ @ 0.5% at 30 and 60 DAS (T_9) and Absolute control (No fertilizer) (T_{10}). Nutrients are applied through fertilizer *viz*., nitrogen, phosphorus, potassium were applied to all the plots. Zinc and iron being the experimental material, $ZnSO_4$ and $FeSO_4$ was applied through soil and foliar mode as per the treatments. Recommended full dose of phosphorus, potassium, zinc sulphate and iron sulphate (60:40:40 N:P_2O_5:K_2O) along with 50 percent of nitrogen for each treatment was applied as basal dose and remaining 50 percent nitrogen dose was given at 30 days after sowing. Soil application of $FeSO_4$ @ 10 kg $ha^{-1}$and $ZnSO_4$ @ 15 kg ha^{-1} were applied at the time of sowing. Foliar spray of $FeSO_4$ and $ZnSO_4$ each @ 0.5% was done at 30 and 60 days after sowing as per the treatments. The experimental raw data collected were subjected to the appropriate statistical procedure Fisher's method of "Analysis of Variance" (ANOVA) as outlined by Panse and Sukhatme (1967) [21].

Results and Discussion

Effect of nutri-fortification of grain amaranth through soil and foliar application of micronutrients on growth parameters

The growth parameters were observed to be significant among different soil and foliar application of micronutrients (Table 1). Significantly higher plant height, number of leaves per plant, leaf area per plant and dry matter per plant were (180.5 cm, 23.33, 3214 cm^2 and 104.80 g $plant^{-1}$, respectively) recorded with application of RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1}+ $ZnSO_4$@ 15 kg ha^{-1} followed by foliar application of $ZnSO_4$@ 0.5% and $FeSO_4$@ 0.5% at 30 and 60 DAS (T_9) which was found to be on par with RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1}+ $ZnSO_4$ @ 15 kg ha^{-1} (175.9 cm, 21.32, 3214 cm^2 and 100.10 g $plant^{-1}$, respectively) and RDF + foliar application of $FeSO_4$@ 0.5% & $ZnSO_4$@ 0.5% at 30 and 60 DAS (169.8 cm, 20.10, 2984 cm^2 and 96.84 g $plant^{-1}$, respectively).

The enhancement in growth attributes can likely be ascribed to the positive influence of zinc and iron application on various growth parameters. This might be ascribed to sufficient supply of nutrients to the plant leading to an increase in number of functional leaves and the leaf area per plant. This effect can be credited to the catalytic or stimulating role that zinc and iron play in the majority of the plant's photosynthetic, physiological, and metabolic processes. Furthermore, it's noteworthy that zinc plays a crucial role in regulating the concentration of auxin in plants. The higher dry matter could be due to enhanced plant height and photosynthetic accumulation. The prerequisite for obtaining higher yields in any crop is higher total dry matter accumulation (Naik and Das, 2007) [20]. These findings are consistent with those reported by Mali and Dashora (2003) [16].

Effect of nutri-fortification of grain amaranth through soil and foliar application of micronutrients on yield parameters of grain amaranth

Panicle or inflorescence length was significantly influenced by soil and foliar application of micronutrients (Table 2). Significantly higher panicle length, number of fingers per panicle, length of fingers, and 10 ml seed volume weight (56.9 cm, 60.0, 21.4 cm and 8.72 g, respectively) were recorded with RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1}+ $ZnSO_4$ @ 15 kg ha^{-1} followed by foliar application of $ZnSO_4$ @ 0.5% and $FeSO_4$ @ 0.5% at 30 and 60 DAS (T_9), while it was on par with RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1}+ $ZnSO_4$ @ 15 kg ha^{-1} (53.3 cm, 56.7, 19.9 cm and 8.64 g, respectively) and RDF + foliar application of $FeSO_4$ @ 0.5% & $ZnSO_4$ @ 0.5% at 30 and 60 DAS (51.4 cm, 55.0, 19.6 cm and 8.45 g, respectively).This could be ascribed to several factors, including increased dry matter production and distribution, enhanced synthesis and transport of photosynthates from source to sink, improved availability and absorption of both macro and micronutrients and their effective translocation to the reproductive parts of the plant. These findings align with the results of Mukhtar *et al.* (2009) [19] and Zayed (2011) [29] who observed that combination of zinc with other elements enhanced the photosynthetic activity which had a positive impact on reproductive parts resulting in increased grain and straw yield in rice crop. This could also be due to supply of Zinc and iron to plants as they play important role in energy formation and translocation from source towards sink. Combined application of zinc, copper, iron, manganese and boron resulted in higher grain weight in rice (Jat *et al.*, 2011) [12]. Similar results were also obtained by Adsul *et al*. (2011) [1], Bandiwaddar and Patil (2015) [3].

Effect of nutri-fortification of grain amaranth through soil and foliar application of micronutrients on grain yield and economics of grain amaranth

It was observed that soil and foliar application of micronutrients had a significant impact on the grain yield of grain amaranth (Table 3). Among the different treatments, combination of soil application of $FeSO_4$ @ 10 kg ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1} followed by foliar application of $ZnSO_4$ @ 0.5% and $FeSO_4$ @ 0.5% at 30 and 60 DAS (T_9) recorded significantly higher grain and stover yield (2154 and 6964 kg ha^{-1}, respectively) which was found on par with RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1}+ $ZnSO_4$ @ 15 kg ha^{-1} (1973 and 6693 kg ha^{-1}, respectively) and RDF + foliar application of $FeSO_4$ @ 0.5% & $ZnSO_4$ @ 0.5% at 30 and 60 DAS (1950 and 6661 kg ha^{-1}, respectively) as compared to RDF. The yield increased in the tune of 32 percent, 21.7 percent and 20 percent (T_9, T_8 and T_5) as compared to RDF. Combined application of $ZnSO_4$ and $FeSO_4$ recorded significantly higher grain yield due to improved performance of growth and yield parameters. This can be attributed to the sufficient availability of essential nutrients in the soil. This leads to positive impact on physiological processes and the accumulation of photosynthates. This was attributed to enhanced vegetative growth and growth parameters including total dry matter accumulation in various plant parts such as leaves and stem. Similar results were also reported by Tabassum *et al.* (2013) [26], Yadav *et al.* (2011) [27], Hamaad *et al.* (2012) [8] and Choudhary *et al.* (2016) [6].

The increased yield in grain amaranth resulting from the application of zinc and iron can be ascribed to their roles in various physiological processes and the enhancement of growth components which includes improved partitioning of carbohydrates from leaves to reproductive parts, ultimately leading to increased yield. Furthermore, this effect could be attributed to the enhancement of regulatory functions in metallo enzyme systems and the production of growth-promoting auxins. Nevertheless, iron is a structural component of porphyrin molecules, cytochromes, hems, hematin and ferrochrome. These substances are involved in oxidation-reduction reactions in respiration and photosynthesis. The increase in yield ascribed to the fact that because of favourable nutritional environment in rhizosphere and higher uptake of nutrients by plant leading to the increased photosynthetic efficiency and production of assimilates. Similar results were also reported by Khan *et al.* (2010) [14], Piri (2012) [22] and Bhunwal *et al.* (2015) [4].

The maximum net returns of Rs. 1,37,905 $ha^{-1}$was obtained with RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1}+ $ZnSO_4$ @ 15 kg ha^{-1} followed by foliar application of $ZnSO_4$ @ 0.5% and $FeSO_4$ @ 0.5% at 30 and 60 DAS (Table 3) it was on par with RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1}+ $ZnSO_4$ @ 15 kg ha^{-1} (Rs. 1,26,205 ha^{-1}) and RDF + foliar application of $FeSO_4$ @ 0.5% & $ZnSO_4$ @ 0.5% at 30 and 60 DAS (Rs. 1,23,570 ha^{-1}). Lower net returns of Rs. 37,720 $ha^{-1}$was obtained with absolute control (T_{10}). Similarly, higher B: C ratio of 4.01 was recorded with RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1}+ $ZnSO_4$ @ 15 kg ha^{-1} followed by foliar application of $ZnSO_4$ @ 0.5% and $FeSO_4$ @ 0.5% at 30 and 60 DAS (T_9). Whereas, the lowest B: C ratio (1.87) was obtained with absolute control (T_{10}). Maximum net returns could be attributed to higher grain yield and market price of grain amaranth. Similar results were earlier reported by Reddy *et al*. (2021) [30], who reported similar trend of results in grain amaranth.

Effect of nutri-fortification of grain amaranth through soil and foliar application of micronutrients on nutrient content in seeds of grain amaranth

The results on crude protein and oil content as influenced by soil and foliar application of micronutrients (Fig 1). Significantly higher protein and oil content (13.88% and 8.56%, respectively) was recorded with combined application of micronutrients (Fe and Zn) *i.e*., RDF + soil application of $FeSO_4$ @ 10 kg ha-1 + $ZnSO_4$ @ 15 kg ha-1 followed by foliar application of $ZnSO_4$ @ 0.5% and $FeSO_4$ @ 0.5% at 30 and 60 DAS (T9) and it was found to be on par with RDF + soil application of $FeSO_4$ @ 10 kg ha-1 + $ZnSO_4$ @ 15 kg ha-1 (13.68% and 8.23%, respectively) and RDF + foliar application of $FeSO_4$ @ 0.5% & $ZnSO_4$ @ 0.5% at 30 and 60 DAS (13.54% and 7.85%). The significant increase in protein and oil content may be ascribed to role of zinc in nitrate conversion to ammonia in plants (Boorboori *et al.,* 2012) [5] and zinc sulphate leads to activate Indole acetic acid which makes amino acids into protein (Moussavi-Nik and Kiani, 2012). The increase in essential oil content of the crop with application zinc and iron might be due to higher assimilate supply in such condition (Khan *et al.*, 2009) [13]. The result of the present study re-establishes the opinion of Mirzapour and Khoshgoftar (2006) [17] and Khurana and Chatterjee (2001) [15].

Similarly, significantly higher iron and zinc content (16.88 mg and 4.72 mg, respectively) recorded in RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1} followed by foliar application of $ZnSO_4$ @ 0.5% and $FeSO_4$ @ 0.5% at 30 and 60 DAS (T9) and it was on par with RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1} (16.74 mg and 4.64 mg, respectively) and RDF + foliar application of $FeSO_4$ @ 0.5% & $ZnSO_4$ @ 0.5% at 30 and 60 DAS (16.33 mg and), while lower concentration of iron recorded in absolute control (12.30 mg and 4.39 mg, respectively). This is because the soil and foliar application of these nutrients allows the plant to absorb them continuously for a longer period of time which eventually leads to their accumulation in the grain and straw. The most effective method for increasing Zn in grain was the soil + foliar application that resulted in about 3.5-fold increase in the grain Zn concentration (Yilmaz *et al.*, 1997) [28]. Saharawat *et al*. (1998) [24] reported that application of Zn and Fe along with NPK significantly increased the uptake of iron in grain and straw of sorghum. Similarly, Jadhao and Konde (2007) [11] also reported that uptake of iron is more at harvest stage than that of panicle initiation and ear head emergence.

Table 1: Plant height, number of leaves plant^{-1}, leaf area and total dry matter production of grain amaranth as influenced by soil and foliar application of micronutrients

	Treatment	Plant height (cm)	Number of leaves	Leaf area (cm^2)	Total dry matter (g plant^{-1})
T_1	RDF (60:40:40 kg ha^{-1} N: P_2O_5: K_2O)	150.5	15.91	2081	75.85
T_2	RDF + foliar application of $ZnSO_4$@ 0.5% at 30 and 60 DAS	154.1	16.11	2335	78.29
T_3	RDF + foliar application of $FeSO_4$ @ 0.5% at 30 and 60 DAS	156.4	16.35	2366	81.71
T_4	RDF +foliar application of $ZnSO_4$ @ 0.5% at 30 DAS followed by $FeSO_4$ @ 0.5% at 60 DAS	163.7	18.22	2693	94.08
T_5	RDF + foliar application of $FeSO_4$ @ 0.5%&$ZnSO_4$ @ 0.5% at 30 and 60 DAS	169.8	20.10	2984	96.84
T_6	RDF + soil application of $ZnSO_4$ @ 15 kg ha^{-1}	161.6	16.98	2461	91.15
T_7	RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1}	158.1	16.65	2410	86.09
T_8	RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1}	175.8	21.32	3214	100.10
T_9	RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1} followed by foliar application of $ZnSO_4$ @ 0.5% and $FeSO_4$ @ 0.5% at 30 and 60 DAS	180.5	23.33	3280	104.80
T_{10}	Absolute control (No fertilizer)	121.7	13.14	1743	54.88
	F-test	*	*	*	*
	S.Em ±	4.99	0.91	84.45	2.88
	CD @ 5%	14.83	2.70	251	8.56

Note: DAS- Days after sowing, RDF- Recommended dose of fertilizers, $ZnSO_4$ – Zinc Sulphate, $FeSO_4$ – Iron sulphate

Table 2: Panicle length, number of finger panicle^{-1} and length of finger of grain amaranth as influenced by soil and foliar application of micronutrients

	Treatment	Panicle length (cm)	Number of fingers panicle^{-1}	Length of finger (cm)	10 ml seed volume weight (g)
T_1	RDF (60:40:40 kg ha^{-1} N: P_2O_5: K_2O)	40.9	41.5	16.0	8.02
T_2	RDF + foliar application of $ZnSO_4$@ 0.5% at 30 and 60 DAS	43.5	44.8	17.3	8.10
T_3	RDF + foliar application of $FeSO_4$ @ 0.5% at 30 and 60 DAS	44.8	45.6	17.5	8.17
T_4	RDF +foliar application of $ZnSO_4$ @ 0.5% at 30 DAS followed by $FeSO_4$ @ 0.5% at 60 DAS	49.7	47.4	18.1	8.27
T_5	RDF + foliar application of $FeSO_4$ @ 0.5% &$ZnSO_4$ @ 0.5% at 30 and 60 DAS	51.4	54.8	19.6	8.45
T_6	RDF + soil application of $ZnSO_4$ @ 15 kg ha^{-1}	46.4	47.2	17.8	8.22
T_7	RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1}	45.1	46.6	17.5	8.18
T_8	RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1}	53.3	56.7	19.9	8.64
T_9	RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1} followed by foliar application of $ZnSO_4$ @ 0.5% and $FeSO_4$ @ 0.5% at 30 and 60 DAS	56.9	60.0	21.4	8.72
T_{10}	Absolute control (No fertilizer)	30.9	26.3	14.6	7.78
	F-test	*	*	*	*
	S.Em ±	2.26	1.83	0.89	0.14
	CD @ 5%	6.72	5.45	2.65	0.43

Note: DAS- Days after sowing, RDF- Recommended dose of fertilizers, $ZnSO_4$ – Zinc Sulphate, $FeSO_4$ – Iron sulphate

Table 3: Grain yield, stover yield, net returns and B: C ratio of grain amaranth as influenced by soil and foliar application of micronutrients

	Treatment	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Net returns (₹ha^{-1})	B:C ratio
T_1	RDF (60:40:40 kg ha^{-1} N: P_2O_5: K_2O)	1621	5647	100030	3.37
T_2	RDF + foliar application of $ZnSO_4$@ 0.5% at 30 and 60 DAS	1769	6152	109445	3.41
T_3	RDF + foliar application of $FeSO_4$ @ 0.5% at 30 and 60 DAS	1784	6184	110715	3.46
T_4	RDF +foliar application of $ZnSO_4$ @ 0.5% at 30 DAS followed by $FeSO_4$ @ 0.5% at 60 DAS	1917	6611	121320	3.79
T_5	RDF + foliar application of $FeSO_4$ @ 0.5% &$ZnSO_4$ @ 0.5% at 30 and 60 DAS	1950	6661	123570	3.81
T_6	RDF + soil application of $ZnSO_4$ @ 15 kg ha^{-1}	1846	6368	116755	3.78
T_7	RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1}	1811	6241	114520	3.77
T_8	RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1}	1973	6693	126205	3.99
T_9	RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1} followed by foliar application of $ZnSO_4$ @ 0.5% and $FeSO_4$ @ 0.5% at 30 and 60 DAS	2154	6964	137905	4.01
T_{10}	Absolute control (No fertilizer)	724	2681	37720	1.87
	F-test	*	*	-	-
	S.Em ±	76.4	116	-	-
	CD @ 5%	227	346	-	-

Note: DAS- Days after sowing, RDF- Recommended dose of fertilizers, $ZnSO_4$ – Zinc Sulphate, $FeSO_4$ – Iron sulphate

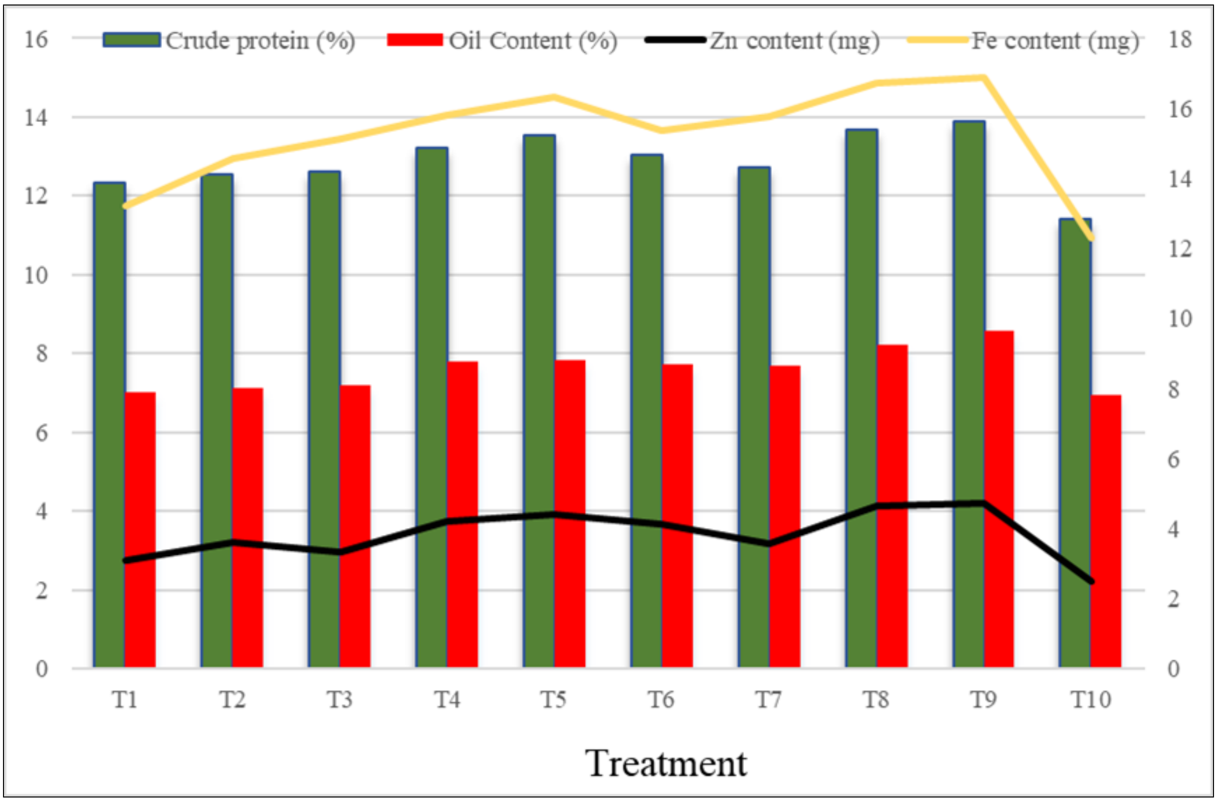

Fig 1: Crude protein, Zn content, oil content and Fe content of grain amaranth as influenced by soil and foliar application of micronutrients

Conclusion

The nutri-fortification of grain amaranth through soil and foliar application of micronutrients has proven to be a promising approach for enhancing its growth, yield, and economic viability. The results of this study have shown that the judicious use of micronutrients, when applied both through the soil and as foliar sprays, can significantly improve the overall performance of grain amaranth crop. Further, this can be concluded that either soil or foliar application of micronutrients (RDF + soil application of $FeSO_4$ @ 10 kg ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1} followed by foliar application of $ZnSO_4$ @ 0.5% and $FeSO_4$ @ 0.5% at 30 and 60 DAS) is found to be better for higher grain yield and net returns to the farming community.

Reference

1. Adsul PB, Anuradha P, Ganesh G, Ajeet P, Shiekh SS. Uptake of N, P, K and yield of Kharif sorghum as influenced by soil and foliar application of micronutrients. Bioinfolet. 2011;11(2):578-582.
2. Anand SR, Murthy N, Prithviraj SK. Response of grain amaranth (*Amaranthus cruentus* L.) genotypes to different levels of fertilizers (NPK) under eastern dry zone of Karnataka. Mysore J Agric Sci. 2020;54(1):60-64.
3. Bandiwaddar TT, Patil BN. Response of bread wheat to varied levels of iron and zinc fortified micronutrients with organics in maize-wheat cropping sequence. Karnataka J Agric Sci. 2015;28(4):467-473.
4. Bhunwal V, Patel VR, Bajrang B, Anwala. Effect of FYM, iron and zinc on growth, yield attributes and yield of fodder sorghum (*Sorghum bicolor* L. Moench). Progress Res J. 10(4):423-424.
5. Boorboori MR, Asli DR, Tehrani M. The effect of dose and different methods of iron, zinc, manganese and copper application on yield components, morphological traits and grain protein percentage of barley (*Hordeum vulgare* L.) in greenhouse conditions. Adv Environ Biol. 2012;6:740-746.
6. Choudhary GL, Rana KS, Rana DS, Bana RS, Prajapat K, Mukesh C. Moisture management and zinc fortification impacts on economics, quality and nutrient uptake of pearl millet under rainfed conditions. Indian J Agric Sci. 2016;86(1):71-77.
7. Elemike EE, Uzoh IM, Onwudiwe DC, Babalola OO. The role of nanotechnology in the fortification of plant nutrients and improvement of crop production. Appl Sci. 2019;9(3):499.
8. Hamaad RA, Tariq A, Shahid H, Muhammad A, Muhammad S, Saif UK, Mohamed HM. Zinc-enriched farm yard manure improves grain yield and grain zinc concentration in rice grown on a saline-sodic soil. Int J Agric Bio. 2012;5(3):32-35.
9. He H, Corke H. Oil and squalene in amaranthus grain and leaf. J Agric Food Chem. 2003;51(27):7913-7920.
10. He HPY, Cai M, Sun, Corke H. Extraction and purification of squalene from Amaranthus grain. J Agric Food Chem. 2002;50(2):368-372.
11. Jadhao SM, Konde NM. Influence of organic and inorganic sources on yield, uptake and availability of nutrient in sorghum. Asian J Soil Sci. 2007;2(2):79-85.
12. Jat SL, Shivay YS, Parihar CM. Dual purpose summer legumes and zinc fertilization for improving productivity and zinc utilization in aromatic hybrid rice (*Oryza sativa*). Indian J Agron. 2011;56(4):328-333.
13. Khan MA, Din J, Nasreen S, Khan MY, Khan SU, Gurmani AR. Response of sunflower to different levels of zinc and iron under irrigated conditions. Sarhad J Agric. 2009;25(2):159-163.
14. Khan MB, Farooq M, Hussain M, Ghulam S. Foliar application of micronutrients improves the wheat yield and net economic return. Int J Agric Biol. 2010;12(6):953–956.
15. Khurana N, Chatterjee C. Influence of variable zinc on yield, seed oil content, and physiology of sunflower. Commun Soil Sci Plant Anal. 2001;32(19-20):3023-3030.

16. Mali AL, Dashora LN. Response of sorghum to iron and zinc. Ann Agric Res. 2003;24(2):421-422.
17. Mirzapour MH, Khoshgoftar AH. Zinc application effects yield and seed oil contents of sunflower grown on saline calcareous. Soil. J Plant Nut. 2006;29(10):1719-1727.
18. Moussavi-Nik MS, Kiani Z. Considering interaction effects of micronutrition elements (Fe, Zn, Mn) on qualitative yield of wheat varieties. Ann Biol Res. 2012;3(3):1467-1472.
19. Mukhtar AK, Din J, Nasreen S, Khan MY, Khan SU, Gurmani AR. Response of sunflower to different levels of zinc and iron under irrigated conditions. Sarhad J Agric. 2009;25(2):159-163.
20. Naik SK, Das DK. Effect of split application of zinc on yield of rice (*Oryza sativa* L.) in an inceptisol. Arch Agron Soil Sci. 2007;53(3):305-313.
21. Panse VG, Sukhatme PV. Statistical Methods for Agricultural Workers. New Delhi: ICAR Pub; 1967. p. 381.
22. Piri I. Effect of fertilizer and micronutrient foliar application on sorghum yield. Ann Biol Res. 2012;3:3998-4001.
23. Raiger HL, Mishra D, Jajoria NK, Deewan P, Dhaliwal YS. Grain amaranth: nutrient enriched grain of future. Intensive Agric. 2023;57(1):4-13.
24. Saharawat KL, Rego, Rahman MH, Rao JK. Phosphorus response effect on macro and micronutrients removal by sorghum under rainfed cropping on a vertisol. J Indian Soc Sci. 1998;46(1):58-60.
25. Sethi V, Lahiri A, Bhanot A, Kumar A, Chopra M, Mishra R. Adolescents, diets and nutrition: Growing well in a changing world. The Comprehensive National Nutrition Survey, Thematic Reports. 2019;(1):1-4.
26. Tabassum S, Khamparia RS, Singh S. Effect of zinc and organic manures on yield attributes and yield of rice. Bioinfolet. 2013;10(3A):879-881.
27. Yadav RS, Patel AM, Dodia IN, Aglodiya AVG, Patel A, Augustine N. Agronomic bio-fortification of wheat (*Triticum aestivum* L.) through iron and zinc enriched organics. J Wheat Res. 2011;3(1):46-51.
28. Yilmaz A, Ekiz H, Torun B, Gultekin, I, Karanlik, S, Bagci, SA. Cakmak I. Effect of different zinc application methods on grain yield and zinc concentration in wheat cultivars grown on zinc-deficient calcareous soils. J Plant Nut.1997;20(4-5):461-471.
29. Zayed BA, Salem AKM, Sharkawy HME. Effect of different micronutrient treatments on rice (*Oryza sativa* L.) growth and yield under saline soil conditions. World J. Agric. Sci. 2011;7(2):179-184.
30. Reddy MS, Ponnamma D, Choudhary R, Sadasivuni KK. A comparative review of natural and synthetic biopolymer composite scaffolds. Polymers. 2021 Mar 30;13(7):1105.