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Impact of Zinc Fertilization on Yield, Yield Attributes and Quality Parameters of Finger Millet Varieties under Rainfed *alfisols* of Southern Zone, Andhra Pradesh

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To study the effect of zinc fertilization through soil and foliar at different stages of finger millet on yield, yield attributes and quality in two major finger millet varieties under rainfed *alfisols* of southern zone, Andhra Pradesh
Study Design: Split-plot design
Place and Duration of Study: Wetland farm, S.V Agricultural College, Tirupati and during *kharif* season of 2019 and 2020 (Two seasons)
Methodology: Zinc fertilization to two major finger millet varieties *viz.,* Vakula and Tirumala through soil and foliar application at different crop stages with following treatments *viz.,* Control (No fertilizers and manures); RDF (60 -30-20 kg N-P-K + FYM @ 4 t ha^{-1}); RDF + soil application of

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$ZnSO_4$ @ 25 kg ha^{-1} as basal; RDF+Soil application of chelated-$ZnSO_4$ @ 5 kg ha^{-1}; RDF+foliar application of 0.2% $ZnSO_4$ at ear head emergence stage; RDF+foliar application of 0.2% $ZnSO_4$ at grain filling stage; and RDF+foliar application of 0.2% $ZnSO_4$ at ear head emergence and grain filling stage. The yield, yield attributes and quality parameters *viz.,* protein, zinc and iron content in grains were determined by adopting standard protocols.

Results: The application of zinc significantly ($p \leq 0.05$) improved the yield and quality parameters over control. The foliar application of 0.2% $ZnSO_4$ at ear head emergence and grain filling stage was significantly ($p \leq 0.05$) improved the yield and yield attributes of finger millet over RDF. The grain yield, straw yield, no. of productive tillers per plant, no. of fingers per plant were increased to 57.0%, 83.2%, 44.6% and 51.7%, respectively over RDF *i.e.,* 60-30-20 kg N-P-K + FYM @ 4 t ha^{-1}. The quality parameters namely protein, grain zinc and iron also increased up to 40.7%, 69.5% and 43.2%, respectively over RDF.

Conclusion: Application of zinc sulphate at ear head emergence and grain filling stages enhanced the yield, yield parameters and quality parameters compared to other treatments of tirumala variety under rainfed alfisols of southern zone of Andhra Pradesh

Keywords: Zn fertilization; fortification; grain yield; protein, recommended fertilizer dose.

1. INTRODUCTION

Finger millet (*Eleusine coracana*) is commonly known as “Nutritious millet” owing to its nutritional superiority over many cereal crops (rice, maize and sorghum) in terms of proteins, minerals, iron, calcium and vitamins. The grains contains about 5 to 8 per cent protein, 65 to 75 per cent carbohydrates, 15 to 20 per cent dietary fiber and 2.5 to 3.5 per cent minerals and it has 30 times more calcium than rice (344 mg/100 g). Finger millet well recognized with their health beneficial effects *viz.,* anti-diabetic, anti-tumerogenic, atherosclerogenic, antioxidant and antimicrobial properties [1].

Finger millet extensively cultivated in the tropical and sub-tropical regions, which accounts for about 85% of total millet production in India. It is an important small millet crop ranked third in cultivated area, production and productivity of 1.19 mha, 1.98 mt and 1661 kg ha^{-1}, respectively [2] and it has the pride of place in having the highest productivity among the millets after sorghum and pearl millet [3]. In Andhra Pradesh it covers an area of 31.63 thousand ha with a production and productivity of 35,000 tonnes and 1087 kg ha^{-1}, respectively. The grains have long storability even under ambient conditions and have made them “famine reserves”. This aspect is at most important as Indian agriculture suffers from vagaries of monsoon [4]. Under increased probability of occurrence of drought and soil fertility degradation, many farmers opted to raise this crop, hence the cultivated area was allocated for this crop has significantly ($p \leq 0.05$) increased over the last decade [5].

Zinc (Zn) is considered the major limiting micronutrient in most of the areas limiting the crop yields. Zinc has role in diverse physiological functions in biological systems. Zinc is typically the second most abundant transition metal in organisms after iron and the only metal represented in all six enzyme classes *viz.,* oxidoreductase, transferases, hydrolases, lyases, isomerases and ligases [6]. Further around 200 enzymes responsible for growth, development, immune function and resistance to infections are regulated by zinc in plant system [7]. Hence, Zinc insufficiency in soils may cause lower yield or sometimes crop failure and leads to poor accumulation of zinc into grains causing zinc malnutrition in humans [8,9]. Zinc deficiency is 5th leading cause of deaths in the developing world and about 0.8 million people die annually of which 0.45 million are children under the age of five as per WHO reports. The extent of zinc deficiency was 49% in Indian soils [10]. The soils of Andhra Pradesh are also deficient in Zn, hence there is a dietary need to increase grain Zn content of finger millet, improving the remobilization of absorbed and accumulated Zn to grain is a research priority. Zn application also reported to increase the grain iron (Fe) concentration in pearl millet [11].

The agronomic bio-fortification is a easier and faster approach to increase grain Zn concentration in finger millet. Several studies revealed that Zn fertilization increased Zn concentration in rice grain from 35 to 141 percent [12], increased from 24 to 48 percent in wheat [13] and up to 72 percent in maize [14]. But limited research has done on impact of zinc fertilization on yield, quality and bio-fortification in finger millet. Hence present study was initiated to study the effect of Zn fertilization on yield, yield attributes and grain fortification in finger millet under rainfed condition.

2. MATERIAL AND METHODS

2.1 Description of Experimental Site

2.1.1 Climate

Field experiment was carried out at wetland farm, S.V.Agricultural College, Tirupati Andhra Pradesh, India during *kharif* season in the year 2019 and 2020. Geographically located between 13.5^0 N and 79.5^0 E with an altitude of 182.9 m above MSL. The region has a semi-arid type climate. During *kharif* 2019, crop received 769.0 mm of rainfall in 43 rainy days with standard week wise mean maximum and minimum temperature ranged from 28.2 to 36.1^0C and 21.3 to 27.6^0C, respectively. The mean sunshine hours and mean evaporation (USWB Class-A Open Pan evaporimeter) ranged from 2.0 to 8.8 hours day^{-1} and 1.9 to 6.0 mm per day with an average of 4.7 hr day^{-1} and 4.2 mm per day, respectively. During *kharif* 2020, crop received 723.8.0 mm of rainfall in 31 rainy days with standard week wise mean maximum and minimum temperature ranged from 28.4 to 36.0^0C and 20.8 to 24.7^0C, respectively. The mean sunshine hours and mean evaporation (USWB Class-A Open Pan evaporimeter) ranged from 0.2 to 8.2 hours day^{-1} and 2.1 to 5.0 mm per day with an average of 3.8 hr day^{-1} and 3.4 mm per day, respectively.

2.1.2 Initial soil characteristics

Composite soil sample at 0-15 cm depth was collected, processed and analyzed for different physical, chemical properties by following the standard procedures and The soil was sandy clay loam in texture (18.3% clay, 5.5% silt and 76.2% sand), slightly alkaline (7.87) in reaction, non-saline (0.423 dS m^{-1}) in nature. The oxidizable organic carbon was medium (6.5 g kg^{-1}). The available nitrogen was low (213 kg ha^{-1}) and available phosphorus and potassium was in high category (189 and 564 kg ha^{-1} respectively) whereas, DTPA extractable zinc was sufficient (1.33 g kg^{-1}).

2.2 Treatments and Experimental Design

The experiment was laid out in split plot design with two finger millet varieties as main treatments *viz.,* Vakula and Tirumala released by Agricultural Research Station, Perumallapalli and zinc fertilization at different methods and crop stages as sub treatments *viz.,* T_1: Control (No fertilizers and manures), T_2: 60 -30-20 kg N-P-K + FYM @ 4 t ha^{-1}, T_3: T_2 + Soil application of $ZnSO_4$ @ 25 kg ha^{-1} as basal, T_4: T_2 + Soil application of chelated zinc sulphate @ 5 kg ha^{-1}, T_5:T_2+Foliar application of 0.2% $ZnSO_4$ at ear head emergence stage, T_6: T_2 + Foliar application of 0.2% $ZnSO_4$ at grain filling stage and $T_{7:}$$T_2$+Foliar application of 0.2% $ZnSO_4$ at ear head emergence and grain filling stage. The treatments randomized in split plot design with three replications. The recommended dose of 60 kg N, 30 kg P_2O_5 and 20 kg K_2O ha^{-1} applied through urea, SSP and MOP, respectively. Fertilizer nitrogen was applied in two equal splits *as* first half dose at the time of transplanting and second half at 30 DAT and the full dose of FYM @ 4 t ha^{-1}, phosphorus and potassium applied at the time of transplanting.

2.3 Soil and Plant Analysis

Post harvest soil samples were collected from each treatment before after harvesting of both the seasons during 2019 and 2020 at 0 to 15 cm. The samples were air-dried at room temperature, pulverized, sieved through a 2-mm sieve. The available zinc DTPA method [15]. Weighed 10 g of soil into a 150 ml conical flask, added 20 ml of DTPA extractant (0.005 M DTPA, 0.01 M $CaCl_2$ and 0.1 M Triethanol amine (TEA) with pH 7.3) and shake the contents on a horizontal shaker for 2 hrs and Filtered the suspension through whatman No.42 filter paper and zinc content was determined in the extractant using Atomic absorption spectrophotometer (model No: Spectra A varian 220).

2.4 Yield and Yield Attributes

The grain obtained from the net plot area including the grain of the sampled plants was thoroughly sundried to a safe moisture level of 14 per cent, weighed and expressed in kg ha^{-1}. Similarly straw was sun dried to a constant weight and expressed in kg ha^{-1}.

2.5 Estimation of Quality Parameters

2.5.1 Grain zinc and iron content (mg kg^{-1})

Di-acid digestion was carried out using a mixture of HNO_3:$HClO_4$ (9:4) by taking one gram of powdered grain sample in 150 ml conical flask and added 10 ml of di-acid mixture and mixed by swirling. The contents were placed on hot plate in a digestion chamber. The contents were further evaporated until the volume was reduced to 3 to 5 ml but not to dryness. The completion of digestion was confirmed by white fumes and kept for cooling. Added double distilled water and filter the contents into a 100 ml volumetric flask by using whatman No. 42 filter paper and made upto 100 ml. The filtrate was used for estimating zinc by AAS. Grain zinc (ppm) = [AAS reading x volume made (100 ml)]/ wt of the plant sample (g).

2.5.2 Grain protein content (%)

Estimation of total protein content in seeds of finger millet was done as per the method developed by [16]. Weighed 0.5 g grain, grounded with pestle and mortar by adding 10 ml of phosphate buffer. The contents were centrifuged at 3500 rpm for 15 min. The supernatant was used for protein estimation. Aliquot of 0.2 ml of sample extract was pipette out in test tube and made up to 1.0 ml volume. A test tube with 1 ml volume of water was used as a blank. 5 ml of reagent-C was added to all the test tubes including the blank. The contents were mixed well and allowed to stand for 10 min. added 0.5 ml of reagent-D and mixed well, incubated for 30 min at room temperature in dark. The colour intensity was read at 660 nm using spectrophotometer (Model: Genesys 10S UV-VIS). From the standard curve, concentration of protein in different samples was determined and expressed in percentage.

2.6 Statistical Analysis

The experimental data were analyzed statistically by following standard procedure outlined by [17]. Significance was tested by comparing 'F' value at 5 per cent level of probability. Treatmental differences that were non-significant were denoted as NS and the data analysed by OPSTAT.

3. RESULTS AND DISCUSSION

3.1 Effect of Zinc on Yield Attributes

The yield attributes among the two varieties (main plots) and the interaction effect were found non-significant. Among the zinc application treatments (sub plots) there is a significant difference. Two years (2019 & 2020) data was presented. The response was almost similar among main, sub plots and interactions in two years of experiments and hence only pooled date are used to highlight the results.

3.1.2 Productive tillers per plant

Number of productive tillers per plant has been tabulated in Table 1. From the pooled data, it was noticed that the productive tiller number per plant was significantly influenced by the application of zinc. The treatment RDF + FYM +foliar application of 0.2% $ZnSO_4$ at ear head emergence and grain filling stages (T_7) recorded significantly more number of productive tillers per plant (1.88) which was on par with the treatments RDF + FYM + foliar application of 0.2% $ZnSO_4$ at grain filling stage (T_6) (1.68), RDF + FYM +foliar application of 0.2% $ZnSO_4$ at ear head emergence stage (T_5) (1.62) and RDF + FYM +soil application $ZnSO_4$ @ 25 kg ha^{-1} (T_3) (1.53) regardless of main plot treatments. The lowest was expressed in (T_1) control (1.17). The main plot treatment ranged from 1.43 to 1.61 and there was no significant difference between the varieties. The interaction effect was noticed as non-significant and ranged from 1.07 to 1.80. The results are in coincidence with [18] and [19]. Increased number of productive tillers per plant due to optimum supply of zinc which increases the availability of other nutrients (macro & micro) results in the enhancement of metabolic activities of plant and finally increased the yield.

3.1.2 No. of finger number per plant

The data pertaining to finger number per plant was presented in Table 1. From the pooled data, The treatment RDF + FYM +foliar application of 0.2% $ZnSO_4$ at ear head emergence and grain filling stages (T_7) recorded significantly more number of finger number per plant (21.58) which was on par with the treatments RDF + FYM + foliar application of 0.2% $ZnSO_4$ at grain filling stage (T_6) (19.40) and RDF + FYM +foliar application of 0.2% $ZnSO_4$ at ear head emergence stage (T_5) (18.17) and the lowest was noticed in (T_1) control (12.82) regardless of main plot treatments. There was no significant difference among main plot treatments and interaction effect. The values ranged between 15.82 to 18.35 and 22.17 to 11.00 respectively. Matching results were expressed in the year 2019 and 2020 experiments conducted by [20] and [21] respectively.

3.1.3 Test weight (1000 grains)

The data pertaining to finger number per plant was presented in Table 1. From the pooled data, The treatment RDF + FYM +foliar application of

0.2% $ZnSO_4$ at ear head emergence and grain filling stages (T_7) recorded significantly highest test weight (3.05 g) which was on par with RDF + FYM +foliar application of 0.2% $ZnSO_4$ at grain filling stage (T_6) (2.98 g) and RDF + FYM + foliar application of 0.2% $ZnSO_4$ at ear head emergence stage (T_5) (2.95 g). Lowest test weight was registered by absolute control (T_1) (2.72 g). Among the main plot and interaction, the effect was non-significant. The values ranged from 2.86 g to 2.94 g and 2.66 g to 3.06 g respectively. The highest test weight (g) in T_7 treatment was due to foliar spray which helps to rapid absorption of zinc through leaf resulted in better grain filling ability of the crop. The supremacy of yield components is due to combined application of RDF + FYM + $ZnSO_4$ which enhanced the photosynthesis and better translocation of photosynthates from source to sink. The above results of yield components are in coincidence with the experimental results conducted by [22] and [23].

3.1.4 Grain yield (kg ha^{-1})

The data pertaining to grain yield (kg ha^{-1}) was presented in Table 2. Grain yield is the combination of yield attributing characters viz., number of productive tillers per plant, no. of fingers per plant and test weight (g). From the pooled data, it was revealed that significantly ($p \leq 0.05$) grain yield (2298.27 kg ha^{-1}) was observed in (V2) tirumala variety when compared to vakula variety of finger millet. Among sub plots, the highest grain yield was received by the treatment applied with RDF + FYM + Foliar application of 0.2% $ZnSO_4$ at both ear head emergence and grain filling stages (T_7) (3150.55 kg ha^{-1}). The lowest grain yield of 1452.9 kg ha^{-1} was registered in absolute control (T_1) compared to other treatments. Regardless of application of Zinc sulphate, incorporation of FYM + RDF recorded 38% higher when compared to absolute control. The increase in grain yield in T_7 was 57% compared to T_2 (RDF + FYM). The interaction effect also shows significant ($p \leq 0.05$) difference and highest was noticed by Tirumala variety (V_2) (3048 kg ha^{-1}) by the foliar spray of 0.2% $ZnSO_4$ at both ear head emergence and grain filling stages (T_7) *ie.,* (V_2T_7) and the lowest (1434 kg ha^{-1}) was noticed by Vakula variety (V_1) with absolute control (T_1) *ie.,* V_1T_1. Similar results were reported by [24] and [25]

3.1.5 Straw yield (kg ha^{-1})

The data pertaining to straw yield (kg ha^{-1}) was presented in Table 2. Application of RDF + FYM + foliar application of 0.2% $ZnSO_4$ at ear head emergence and grain filling stages (T_7) improved the straw yield (7364.58 kg ha^{-1}) of finger millet by 83.2 per cent compared to absolute control (T_1) and 51.5 % compared to T_2. The main plot and interactions were non-significant and the values are in the range of 5531 to 5423 and 7404 to 3866. kg ha^{-1} respectively. These findings are in matching with [24] and [19]. The highest straw yield (kg ha^{-1}) in T_7 treatment was due to increase in cell division and cell elongation. The lowest straw yield of 3566 kg ha^{-1} was expressed by T_1 (absolute control). The grain yield was the ultimate end product of many yield contributing attributes, physiological and morphological processes that took place in plants during its life cycle. The Integrated application of organic and inorganic sources showed beneficial effect on physiological process of plant metabolism and growth, thereby resulting in higher grain and straw yield.

3.2 Quality Parameters

3.2.1 Protein content in grain (%)

The data pertaining to protein content (%) in grain was presented in Table 3.There was significant difference among the zinc application treatments (sub-plots) and the highest protein content (9.63%) in grain was recorded in the treatment receiving RDF + FYM + foliar application of 0.2% $ZnSO_4$ at ear head emergence and grain filling stages (T_7). Lowest grain yield was registered with absolute control (4.49%). Table. 3. The protein content of two varieties (main plots) showed non-significant and the values ranged between 7.90 to 7.56%. The interaction between varieties and zinc application treatments was non-significant (Table. 3) on protein content of grain. The values ranged between 9.93% (V_2T_7) to 4.54% (V_1T_1). The results were coincided with the results obtained by [22] and [26]. The increase in protein content with zinc application is in agreement with the hypothesis that zinc plays an important role in protein synthesis.

3.3.2 Zinc content in grain (mg kg^{-1})

The data pertaining to zinc content in grain was presented in Table 3. Among the two varieties, Tirumala (V_2) recorded significantly ($p \leq 0.05$) highest zinc content (28.68 mg kg^{-1}) in grain. Among the treatments (zinc application) of sub-plot, (T_7) RDF + FYM + foliar application of 0.2% $ZnSO_4$ at ear head emergence and grain filling

Table 1. Yield and yield attributes as influenced by zinc application of finger millet varieties

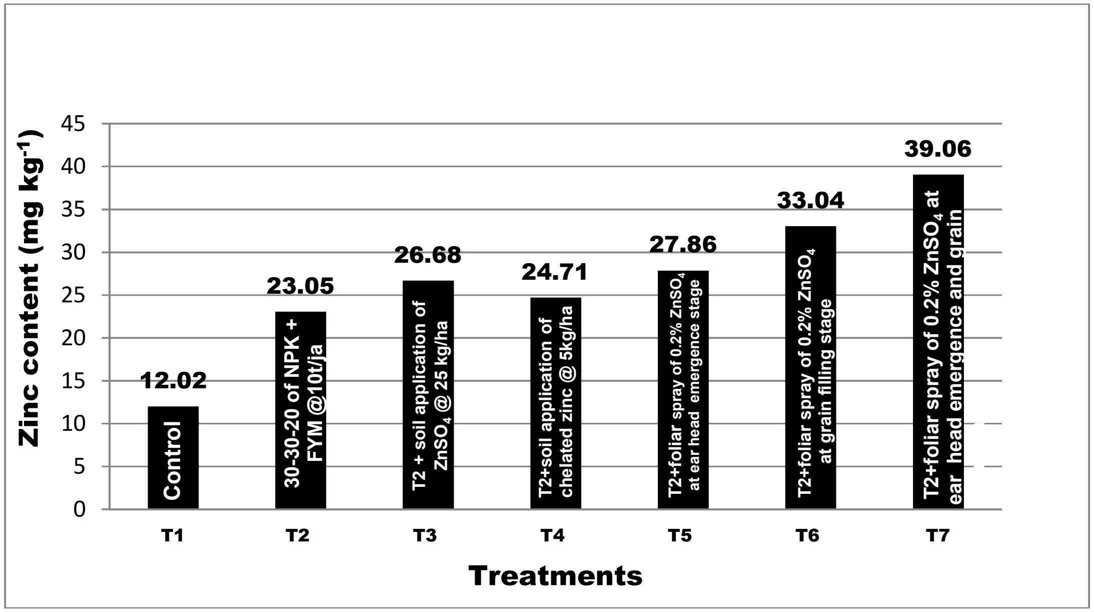
Treatments	No. of productive tillers per plant			Finger number per plant			Test weight (1000 grain weight)		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
Varieties (V)									
(V_1) : Vakula	1.97	0.86	1.43	16.81	15.17	15.98	2.95	2.76	2.86
(V_2) : Tirumala	2.26	0.95	1.61	18.80	17.89	18.35	2.98	2.90	2.94
S.E (m)	0.125	0.044	0.062	1.061	1.015	1.048	0.040	0.014	0.025
C.D (p=0.05)	NS	NS	NS	NS	NS	NS	NS	0.095	NS
Method and stage of Zn application									
Control (no fertilizers and manures)	1.66	0.68	1.17	13.08	12.55	12.82	2.76	2.68	2.72
RDF (60 -30-20 kg N-P-K & FYM @ 4 t/ha)	1.85	0.75	1.30	14.98	13.45	14.22	2.93	2.77	2.86
RDF+ Soil application of $ZnSO_4$ @ 25 kg/ha as basal	2.18	0.87	1.53	17.93	16.73	17.33	2.93	2.85	2.89
RDF+ Soil application of chelated Zinc @ 5 kg/ha	2.07	0.83	1.47	17.33	15.95	16.63	2.90	2.80	2.85
RDF+ foliar application of 0.2% $ZnSO_4$ at ear head emergence stage	2.22	0.97	1.62	18.90	17.45	18.17	3.02	2.87	2.95
RDF+ foliar application of 0.2% $ZnSO_4$ at grain filling stage	2.33	0.98	1.68	19.98	18.78	19.40	3.06	2.89	2.98
RDF+ foliar application of 0.2% $ZnSO_4$ at ear head emergence & grain filling stage	2.51	1.25	1.88	22.40	22.78	21.58	3.17	2.95	3.05
S.E (m)	0.200	0.137	0.125	0.876	0.980	0.915	0.050	0.061	0.037
C.D (p=0.05)	NS	NS	0.366	2.571	2.879	2.686	0.148	NS	0.109
Interaction (main x sub)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2. Grain yield and straw yield as influenced by zinc application in finger millet varieties

Treatments	Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})		
	2019	**2020**	**Pooled**	**2019**	**2020**	**Pooled**
Varieties (V)						
(V_1) : Vakula	2481	1980	2230	5922	4923	5423
(V_2) : Tirumala	2585	2010	2298	6195	4867	5531
S.E (m)	6.1	6.7	6.03	142.7	188.2	146.4
C.D (p=0.05)	40.0	NS	40.2	NS	NS	NS
Method and stage of Zn application						
Control (no fertilizers and manures)	1666	1239	1452	4641	3395	4018
RDF (60 -30-20 kg N-P-K & FYM @ 4 t/ha)	2183	1823	2003	5262	4454	4858
RDF+ Soil application of $ZnSO_4$ @ 25 kg/ha as basal	2413	1990	2201	5516	4662	5089
RDF+ Soil application of chelated Zinc sulphate @ 5 kg/ha	2353	1933	2143	5366	4591	4979
RDF+ foliar application of 0.2% $ZnSO_4$ at ear head emergence stage	2521	2073	2297	6691	4866	5779
RDF+ foliar application of 0.2% $ZnSO_4$ at grain filling stage	3036	2169	2603	6908	5595	6252
RDF+ foliar application of 0.2% $ZnSO_4$ at ear head emergence & grain filling stage	3560	2740	3150	8025	6704	7364
S.E (m)	76.8	25.7	40.5	335.7	236.8	190.8
C.D (p=0.05)	22.5	75.4	119.0	985.8	695.4	560.2
Interaction (main x sub)	NS	111.8	171.1	NS	NS	NS

Table 3. Grain quality parameters of finger millet varieties as influenced by zinc application

Treatments	Protein (%)			Zinc (mg kg^{-1})			Iron (mg kg^{-1})			Calcium (%)		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
Varieties (V)												
(V_1) : Vakula	7.70	7.41	7.56	25.10	24.06	24.58	149.38	147.5	148.4	0.27	0.68	0.48
(V_2) : Tirumala	8.10	7.69	7.90	29.39	27.97	28.68	152.93	150.6	151.8	0.29	0.74	0.51
S.E (m)	0.09	0.053	0.07	0.96	0.72	0.25	2.81	4.6	1.92	0.007	0.17	0.09
C.D (p=0.05)	NS	NS	NS	NS	NS	1.682	NS	NS	NS	NS	NS	NS
Method and stage of Zn application												
Control (no fertilizers and manures)	4.61	4.36	4.49	12.69	11.36	12.02	116.2	114.2	115.2	0.30	0.52	0.41
RDF (60 -30-20 kg N-P-K & FYM @ 4 t/ha)	6.89	6.78	6.84	23.66	22.44	23.05	123.0	126.7	124.8	0.27	0.57	0.42
RDF+ Soil application of $ZnSO_4$ @ 25 kg/ha as basal	8.62	8.35	8.48	27.47	25.88	26.68	156.3	154.2	155.3	0.28	0.97	0.63
RDF+ Soil application of chelated Zinc sulphate @ 5 kg/ha	8.34	8.07	8.21	25.13	24.29	24.71	149.1	144.2	146.6	0.30	0.87	0.59
RDF+ foliar application of 0.2% $ZnSO_4$ at ear head emergence stage	8.16	7.64	7.90	28.36	27.36	27.86	162.7	159.3	161.0	0.27	0.40	0.33
RDF+ foliar application of 0.2% $ZnSO_4$ at grain filling stage	8.69	8.37	8.53	33.54	32.55	33.04	169.9	167.9	168.9	0.26	0.78	0.52



Graph 1. Influence of zinc application on grain zinc content in finger millet

stages recorded significantly ($p \leq 0.05$) highest zinc content (39.06 mg kg^{-1}) in grain. The lowest was registered by absolute control (T_1) (12.02 mg kg^{-1}). The interaction effect shows non-significant results and values ranged between 11.17 to 40.82 mg kg^{-1}. The results are in coincidence with the experiments conducted during the year 2019 and 2020 by [27] and [28] respectively. Enhancement of zinc content in grain of finger millet by 69.5% compared to RDF + FYM (T_2) was due to foliar application of 0.2% $ZnSO_4$ at both ear head emergence and grain filling stages. Whereas, the increase of protein content of T_7 by (69.5%) compared to T_2.

3.3.3 Iron content in grain (mg kg^{-1})

The data pertaining to iron content in grain was presented in Table 3. The iron content (mg kg^{-1}) in grain was significantly influenced by sub plots (zinc application) and main plot (varieties) and interaction between varieties and zinc application showed non-significant. Highest iron content (151.81 mg kg^{-1}) was registered significantly with Tirumala variety (V_2). Significantly highest iron content (178.92 mg kg^{-1}) in grain was recorded by T_7 (RDF + FYM + foliar application of 0.2% $ZnSO_4$ at ear head emergence and grain filling stages) which was on par with T_6 (168.91 mg kg^{-1}) (RDF + FYM + foliar application of 0.2% $ZnSO_4$ at grain filling stage). Both the treatments were significantly superior over other treatments which were tried in this experiment. The results are similar with the field experiments conducted by [29] and [30]. The Lowest iron content (114.28 mg kg^{-1}) in grain of finger millet was recorded with absolute control (T_1). The interaction effect ranged from 182.07 to 113.80 mg kg^{-1} in grains of finger millet. The iron content was increased by (43.2%) compared to RDF + FYM (T_2) whereas the increase in iron content by 55.2% compared to absolute control (T_1).

The foliar application of ZnSO4 at both ear head emergence and grain filling stages enhanced all grain quality parameters.

4. CONCLUSION

The results of the present experiment confess that significantly yield attributes, yield and quality parameters of finger millet were recorded highest with the application of RDF+ foliar spray of 0.2% $ZnSO_4$ at both ear head emergence and grain filling stages. It might be acknowledged that combination of inorganic and organic nutrient sources and addition of external application of zinc through foliar spray proved to be superior over other treatments. So, we can informed that the application of zinc sulphate at both stages enhanced the yield, yield parameters and quality parameters compared to other treatments of tirumala variety under rainfed alfisols of southern zone of Andhra Pradesh.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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