



Evaluating the Efficacy Levels of Zinc Fertilizers on Growth, Yield and Quality of Maize (*Zea mays* L.)

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ABSTRACT

Background: Zinc deficiency constitutes a significant global issue affecting agricultural productivity and human health, particularly in developing regions where maize is a staple food. Maize is a widely propagated cereal crop on a global scale, playing a pivotal role in agricultural systems across diverse regions as a primary source of calories and nutrients for millions of people. However, maize often lacks essential micronutrients, including zinc, which is crucial for various physiological functions in both plants and humans.

Methods: A field experiment was conducted on sandy clayey loam soil during the *rabi* seasons of 2022 and 2023 in Coimbatore, Tamil Nadu to study the effect of zinc fertilization through integrated nutrient management for enhancement of maize productivity and quality under western ghat condition. Maize was planted at a spacing of 60 × 25 cm using a split plot design (SPD) with two integrated nutrient treatments as the main plot and six nutrient level treatments in sub-plots with three replications.

Result: The results revealed that zinc fertilization treatments containing 0.5% Zn as ZnSO₄ (H₂), led to higher growth and yield attributes, grain yield (8906 kg ha⁻¹) and stover yield (12652 kg ha⁻¹) and also resulted in maximum crude protein content (15.12%), starch content (63.85 mg g⁻¹), Fe (38.25 mg kg⁻¹) and Zn (36.06 mg kg⁻¹) in maize grain. It was observed that zinc fertilization through 100% integrated nutrient management enhanced the vegetative growth, yield components and grain quality of maize crop.

Key words: Maize, Micronutrient, Nutrient, Yield, Zinc.

INTRODUCTION

Maize ranks as third cereal crop globally after rice and wheat. It performs optimally across both tropical and temperate zone throughout the world. Maize, known as the “Queen of Cereals” and “King of Fodder Crops”, is renowned for its exceptional yield potential across various grains (Behera *et al.*, 2019). It serves as the primary feed grain for livestock and is a crucial food staple for millions in Asia, Africa and Latin America.

Maize is grown round the year in India, spanning *kharif*, *rabi* and summer cropping seasons. It is grown on 9.4 million hectares, producing 2.3 million tonnes with an average yield of 2.55 tonnes per hectare. On an average, maize grains contain 60% carbohydrates, 10% protein, 4.5% oil, 3.5% fibre and 2% minerals. Each 100 grams of maize grain also contains 348 mg of phosphorus, 286 mg of potassium, 114 mg of sulfur, 10 mg of calcium, 2.3 mg of iron and 90 micrograms of carotene. In India, approximately 45 per cent of maize crop is utilized as a fundamental food source in multiple forms (Prasanna *et al.*, 2001).

Maize serves for various purposes, mainly for food, livestock feed and industrial raw material. However, in the past decade, maize has experienced the highest growth in production and productivity among all food grains, expanding at an annual growth rate of 4.2 per cent (Erenstein *et al.*, 2022). Its high adaptability allows it to be grown twice a year, during both the early and late seasons.

Zinc is a crucial micronutrient, playing a key role in enzymatic processes related to photosynthesis (Zafar *et al.*, 2023). Although the foliar application of zinc fertilizers generally enhances the zinc concentration in crop grains,

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its efficacy is influenced by factors like fertilizer formulation, source and particle size (Palacio-Marquez *et al.*, 2021). Zinc serves as a cofactor and structural element in numerous enzymes that participate in various metabolic processes. Treatment with zinc can enhance plant growth, development and productivity. It aids in managing pests and diseases, reduces the absorption of pollutants and increases tolerance to environmental stressors (Rehman *et al.*, 2018).

Biofortification in cereals can be accomplished by the innovation of crop varieties that have elevated zinc levels in their grains or by applying sufficient zinc fertilizers to crops cultivated in zinc-deficient soils. Enhancing the concentration of zinc and its bioavailability in maize grain through agronomic practices holds significant promise for addressing zinc deficiency. This study was carried out to assess the impact of various sources and application methods in zinc on maize productivity as well as the

concentrations and uptake of nitrogen and zinc in high-quality protein. To study the effectiveness of zinc fertilizers in generating high-quality maize seed crops different combinations of nitrogen fertilizer rates were analyzed. Considering the importance of zinc fortification, this field research was done to investigate the combined effects of N doses and foliar spray of zinc on the growth metrics, yield components and quality of maize.

MATERIALS AND METHODS

A field experiment was conducted on sandy clayey loam during *rabi* seasons of 2022 and 2023 at South farm, KITS campus, Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu, India (10°59'N latitude and 76°64'E longitude at an altitude of 474 meters above mean sea level) (Fig 1). The field is situated in the western region of Tamil Nadu, characterized as a semi-arid tropical zone, featuring hot, dry summers and mild winters. The average precipitation during the crop growing period was 875.50 mm in 2022 and 925 mm in 2023 for the *rabi* seasons, which span from October to January. The peak and lowest temperatures during the crop-growing season reached 37.2°C and 22.8°C, respectively. The sandy clayey loam soil in the experimental field had an alkaline pH of 8.2, moderate electrical conductivity of 0.33 dS/m, low available nitrogen (210.45 kg ha⁻¹), medium available phosphorus (11.50 kg ha⁻¹) and medium levels of available potassium (140.35 kg ha⁻¹). Sufficient in available iron (4.25 ppm), copper (1.10 ppm), manganese (15.00 ppm) and deficient in available zinc (0.39 ppm).

Split-plot design was implemented for the experiment, encompassing of twelve treatments comprising of M₁-100% RDF + FYM, M₂- 75% RDF + FYM as main plot and six zinc fertilization levels (three replications each) comprising of H₁ - 0.5% Zn as ZnO, H₂ - 0.5% Zn as ZnSO₄, H₃ - 1% Zn as ZnO, H₄ - 1% Zn as ZnSO₄, H₅ - 1.5% Zn as ZnO, H₆ - 1.5% Zn as ZnSO₄ as sub-plots. Maize variety Mahyco (MRM 4065) with a duration of 100-110 days was selected for this

experiment. Planting was done at a spacing of 60 × 25 cm. The prescribed fertilizer rate for maize hybrids was 250:75:75 (N: P: K) kg ha⁻¹. A 0.5% Zinc Sulphate (ZnSO₄) was applied as a foliar spray twice during the active vegetative phase (on 40th and 60th days) using a knapsack sprayer. All other standard agronomic practices were followed as per the schedule.

The growth and yield attribute parameters were collected at harvest from randomly selected five plants. Grain yield were recorded in kg ha⁻¹ as: The shelled grains from the net plot were cleaned, sundried and weighed at 14 per cent moisture content and the grain yield was calculated, computed and expressed in kg ha⁻¹. The stover yield were recorded in kg ha⁻¹ as: After the harvest of cobs, the stover in the net plot area were cut close to the ground level and left in the field for three days for sun drying. The dry weight of stover from each plot was recorded and expressed in kg ha⁻¹.

The quality attributes like crude protein (%) is calculated as: The total nitrogen is estimated by micro-Kjeldahl method as per procedure suggested by AOAC (1995) and the crude protein is calculated by the following formula:

Crude protein content (%) =

Micro-kjeldahl nitrogen content (%) × 6.25 (based on the assumptions that nitrogen constitutes 16% of protein)

Starch (mg g⁻¹) were done as per the procedure by Hedge and Hofreiter (1962). For available Fe and Zn concentration, the samples were dried in an oven at 70°C for 24 h and ground using a sample rotating mill. A ground sample of 0.5 g was weighed on a balance sensitive to the nearest 0.00001 g and put into a digestion tube. The samples were prepared by a standard HNO₃-H₂O₂ digestion method using wet digestion with nitric acid (Thavarajah *et al.*, 2009). The Zn and Fe concentration was measured using flame AAS (AJ ANOVA 300, Lab Synergy) in maize grain and were recorded in mg kg⁻¹.

The data collected on various characters studied during the course of investigation were statistically analyzed

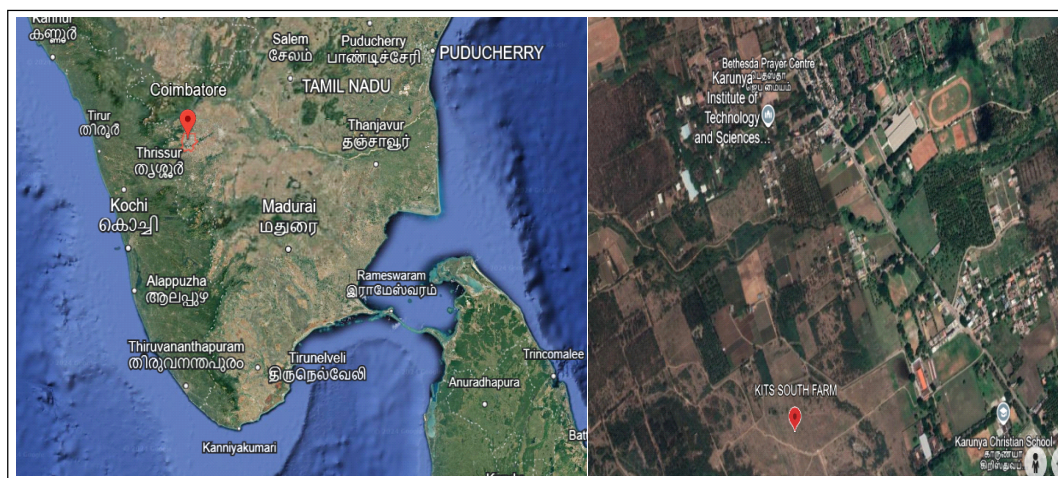


Fig 1: Field location of research work.

following the analysis of variance for Split Plot Design as suggested by Gomez and Gomez (1984). Wherever the results were found significant ("F" test) the critical differences were worked out at 5 per cent probability level and the values were furnished and the non-significant comparison was indicated as "NS".

RESULTS AND DISCUSSION

Growth parameters

The data analyzed on two-year pooled basis of growth parameters are presented in Table 1. It showed that the maximum plant height (206.96 cm) at harvest was observed under treatment H₂ in 0.5% Zn as ZnSO₄, when compared to the other nutrient levels. The lowest plant height was recorded under the treatment H₅ (192.39 cm). The foliar spray application combined with integrated nutrient management demonstrated remarkable effect in terms of growth parameters in both growing seasons. This was likely due to the crop's efficient nutrient uptake and the ability to address soil nutrient deficiencies. Similar findings was reported by Auwal and Amit (2017).

The research outcome proved that fertilizer use significantly affected the leaf area index and dry matter yield of maize throughout its growth phases. Among all treatments, maximum LAI was observed with H₂ was significantly higher than all other treatments during both the years. Similarly, the H₅ treatment with 1.5% Zn as ZnO have shown a reduced leaf area index and lower dry matter production in the crop. Elnaz *et al.* (2016) observed that improved nitrogen uptake through the application of zinc foliar sprays in maize resulted in an enhanced leaf area index (LAI) and Dry matter production (DMP). Better utilization of zinc through integrated nutrient management allowed the plants to enhance their photosynthetic activity, culminating in enhanced biomass

yield. The results revealed a significant impact of the treatment on cob length across different growth stages of the crop as noted (Table 1). The treatment H₂ (0.5% Zn as ZnSO₄), recorded the longest cob length of (22.16 cm). This suggests that zinc fertilization has a major effect on boosting cob growth, potentially leading to improved yield in maize cultivation. Results were agreed with the study of Augustine and Imayavaramban, (2022).

Yield attributes and yield

The data on yield attributes was presented in Table 2.

Both the yields of grain and stover exhibited significant variations based on nutrient levels. across both growing seasons (Table 2) (Fig 2). It showed that among all the zinc fertilization treatments, the maximum cob weight (102.24 g), test weight (273.15 g) and shelling percentage (77.32%) was recorded with H₂ (0.5% Zn as ZnSO₄) which was statistically higher than all other zinc level treatments.

The treatment with 0.5% Zn as ZnSO₄ (H₂) achieved the higher grain yield 8906 kg ha⁻¹ and stover yield of 12,652 kg ha⁻¹ followed by H₄ (1% Zn as ZnSO₄) which recorded grain yield of 8789 kg ha⁻¹ and stover yield of 12096 kg ha⁻¹ respectively during both the seasons. The increase in grain yield due to zinc application could be linked to the rise in chlorophyll levels and the increased activity of antioxidant enzymes during the maize growth stages. It shows that combined use of zinc with nitrogen, phosphorus and potassium encouraged strong root growth. This stimulates overall plant growth, leading to better photosynthetic efficiency, improved yield attributes and ultimately a higher grain yield. The results were also in agreement with the findings of Chen *et al.* (2023). The higher grain yield and straw yield is due to better photosynthate mobilization as well as increase of the number of sink space. The increment of yield due to the stand-alone application of

Table 1: Effect of zinc fertilization on growth attributes of maize (Pooled data of *rabi* seasons, 2022 and 2023).

Treatments		PH (cm)	LAI	DMP (kg ha ⁻¹)	CL (cm)
M ₁ - 100% RDF + FYM		201.41	5.00	1580.31	18.87
M ₂ - 75% RDF + FYM		197.36	4.83	1512.95	16.74
SE(d)		0.08	0.01	8.92	0.22
CD (P=0.05)		0.38	0.06	41.32	1.02
H ₁ - 0.5% Zn as ZnO		196.48	4.79	1474.31	17.16
H ₂ - 0.5% Zn as ZnSO ₄		206.96	5.34	1849.38	22.16
H ₃ - 1% Zn as ZnO		194.76	4.61	1392.86	15.16
H ₄ - 1% Zn as ZnSO ₄		204.57	5.20	1670.40	19.98
H ₅ - 1.5% Zn as ZnO		192.39	4.49	1307.44	13.84
H ₆ - 1.5% Zn as ZnSO ₄		201.15	5.06	1585.39	18.54
SE(d)		0.29	0.02	11.31	0.49
CD (P=0.05)		0.62	0.05	23.76	1.04
M at S	SE(d)	0.39	0.03	17.11	0.68
	CD (P=0.05)	0.86	0.08	47.72	1.61
S at M	SE(d)	0.42	0.03	16.00	0.70
	CD (P=0.05)	0.93	0.08	44.62	1.66

RDF - Recommended dose of fertilizer; FYM - Farm yard manure; PH - Plant height; LAI - Leaf area index; DMP - Dry matter production; CL - Cob length (cm); ZnO - Zinc oxide; ZnSO₄ - Zinc sulphate; Significant at P 0.05; NS- Non-significant at P>0.05.

zinc on maize was also earlier reported by Karthika *et al.*, (2023).

Quality attributes

Protein

The data on quality attributes are given in Table 3.

It showed that among all zinc fertilization level treatments, maximum crude protein content was obtained from H₂. Results showed that H₂ was statistically higher than all other treatments.

Zinc functions as an enzyme activator in plants and is directly engaged in the biosynthesis of metabolites, there may be a correlation between the larger impact of zinc levels and the growth in crude protein content. Similar observations were documented by Zeidan *et al.* (2010). The maximum

crude protein percent was significantly increased with combined treatments due to the favourable environment and extended benefits of biochemical relations (*i.e.*, respiration, photosynthesis and chlorophyll content) in plants (Krishnasree *et al.*, 2020).

Starch

The data revealed that among all zinc fertilization levels, maximum starch content in maize grain was obtained from H₂. Results noted that H₂ (68.85 mg g⁻¹) was statistically higher than all other zinc treatments. The escalating ZnSO₄ doses resulted in higher starch concentrations in maize grain. The same factors that contributed to grain yield also enhanced the starch content. Similar observations was reported by Stephen Mason *et al.* (2010).

Table 2: Effect of zinc fertilization on yield and yield attributes of maize (Pooled data of *rabi* seasons, 2022 and 2023).

Treatments	Cob weight (g)	Test weight (g)	Shelling (%)	Grain yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)
M ₁ - 100% RDF + FYM	100.06	273.78	74.07	8835	11771
M ₂ - 75% RDF + FYM	87.15	257.22	72.20	8317	11149
SE(d)	0.42	0.20	0.07	7.9	38.6
CD (P=0.05)	1.94	0.95	0.33	36.4	178.9
H ₁ - 0.5% Zn as ZnO	91.97	263.10	72.24	8453	11213
H ₂ - 0.5% Zn as ZnSO ₄	102.24	273.15	77.32	8906	12652
H ₃ - 1% Zn as ZnO	88.89	260.73	71.20	8374	10863
H ₄ - 1% Zn as ZnSO ₄	98.42	269.89	75.28	8789	12096
H ₅ - 1.5% Zn as ZnO	85.78	258.48	69.59	8294	10529
H ₆ - 1.5% Zn as ZnSO ₄	94.35	267.65	73.20	8642	11409
SE(d)	0.50	0.66	0.10	17.6	125.3
CD (P=0.05)	1.05	1.40	0.23	37.0	263.1
M at S	SE(d)	0.77	0.88	24.0	166.3
	CD (P=0.05)	2.20	NS	57.0	372.0
S at M	SE(d)	0.71	0.94	24.9	177.2
	CD (P=0.05)	2.02	NS	59.0	396.3

RDF - Recommended dose of fertilizer; FYM - Farm yard manure; ZnO - Zinc oxide; ZnSO₄ - Zinc sulphate; Significant at P 0.05; NS- Non-significant at P>0.05.

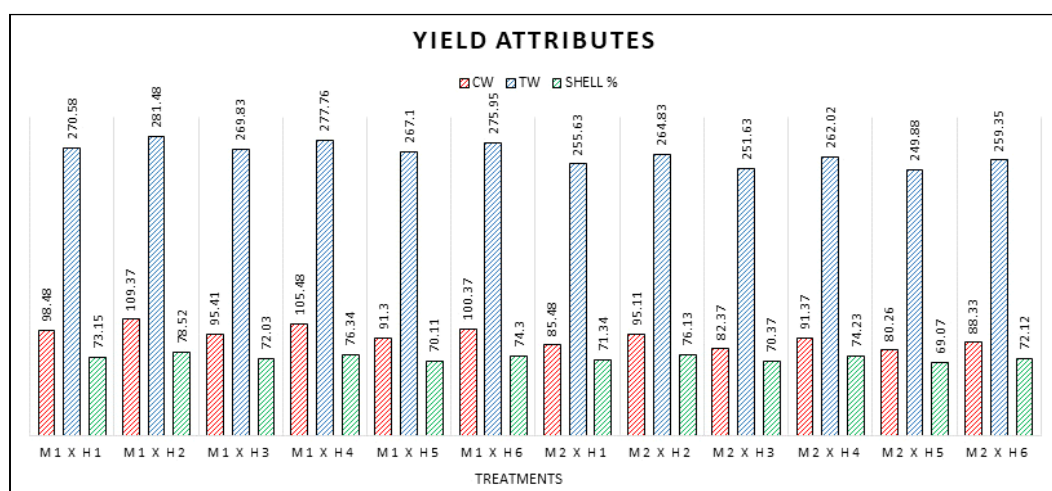


Fig 2: Effect of zinc fertilization on yield attributes of maize.

Iron

The data revealed that among all the zinc fertilization level treatments, maximum iron content was obtained from H₂. Results showed that H₂ (38.25 mg kg⁻¹) was statistically higher than other zinc treatments (Table 3). Foliar spray in zinc enhanced the movement of endogenous iron while simultaneously enhancing zinc and iron levels and their concentration in maize grains. These outcomes agree with the study of Saleem *et al.* (2016).

Zinc

The data regarding zinc content (mg kg⁻¹) in maize grain showed that the maximum zinc content was obtained from H₂. Results showed that H₂ (36.06 mg kg⁻¹) was statistically higher than all other treatments. The study indicates that an increase in zinc concentration in maize grain is positively linked to increased grain yield, test weight, cob diameter

and cob length. These results corroborated with the findings of Sadiq Naveed *et al.* (2018). Thus, increased zinc concentration was due to combined application with organic nutrient resources and mineral fertilizers that increased maize grain Zn uptake. This was in conformity with the findings of Manzeke *et al.* (2014).

Interaction effect of INM and zinc

The interaction effect of INM and zinc levels at two pooled seasons were observed on grain quality indicated that higher crude protein (17.23%), starch (70.49 mg kg⁻¹), Fe (39.18 mg kg⁻¹), Zn (37.97 mg kg⁻¹) was recorded at 75% RDF + FYM (M₂) with 0.5% Zn as ZnSO₄ (H₂) than 100% RDF + FYM (M₁) with the same treatment (Fig 3). The lower quality were recorded under the 100% RDF + FYM (M₁) with 1.5% Zn as ZnO (H₆) in both the *rabi* seasons, respectively. Significant changes in the quality do occur might be due to

Table 3: Effect of Zinc fertilization on quality parameters of maize (Pooled data of *rabi* seasons, 2022 and 2023).

Treatments	Protein (%)	Starch (mg g ⁻¹)	Iron (mg kg ⁻¹)	Zn (mg kg ⁻¹)
M ₁ - 100% RDF + FYM	10.13	62.32	32.25	27.79
M ₂ - 75% RDF + FYM	12.79	64.55	34.75	30.12
SE(d)	0.25	0.14	0.10	0.35
CD (P=0.05)	1.16	0.66	0.49	1.63
H ₁ - 0.5% Zn as ZnO	10.71	62.20	32.70	27.61
H ₂ - 0.5% Zn as ZnSO ₄	15.12	68.85	38.25	36.06
H ₃ - 1% Zn as ZnO	9.31	60.06	30.81	24.86
H ₄ - 1% Zn as ZnSO ₄	13.69	66.86	36.20	32.70
H ₅ - 1.5% Zn as ZnO	8.30	58.23	28.55	22.57
H ₆ - 1.5% Zn as ZnSO ₄	11.64	64.39	34.51	29.93
SE(d)	0.22	0.22	0.22	0.40
CD (P=0.05)	0.46	0.48	0.46	0.85
M at S	SE(d)	0.32	0.30	0.63
	CD (P=0.05)	1.22	0.73	1.82
S at M	SE(d)	0.32	0.31	0.57
	CD (P=0.05)	1.00	0.75	1.65

RDF - Recommended dose of fertilizer; FYM - Farm yard manure; ZnO - Zinc oxide; ZnSO₄ - Zinc sulphate; Significant at P 0.05; NS- Non-Significant at P>0.05.



Fig 3: Interaction effect of INM and Zinc levels on quality parameters.

nature and availability of organic sources, its nutrient content, agronomic and environmental changes.

CONCLUSION

The findings of the study highlight that applying zinc fertilizers significantly boosts the growth, productivity and nutritional quality of maize. The treatment with 0.5% Zn as ZnSO₄ (H₂) consistently resulted in superior outcomes, including the greatest plant height, the longest cob length and the highest grain and stover yields. Additionally, this treatment notably improved quality parameters viz., protein, starch, zinc and iron concentration in the maize grain, reinforcing the critical role of zinc in optimizing nutritional quality. In contrast, the treatment with 1.5% Zn as ZnO (H₅) exhibited lower growth and yield parameters, highlighting the importance of selecting appropriate zinc sources for effective maize fortification. Overall, this evidence substantiates the incorporation of integrating zinc fertilization into maize cultivation practices to enhance agronomic performance and nutritional value in maize grain.

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Conflict of interest

All authors declare that they have no conflict of interest.

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