

International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(6): 437-444
www.biochemjournal.com
Received: 07-03-2026
Accepted: 10-04-2026

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Effect of nano zinc oxide on morpho physiological yield parameters and quality of finger millet [*Eleusine coracana* (L.) Garten.]

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DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i6Sf.8630>

Abstract

Attempts to apply nanotechnology in agriculture began with the growing realization that global population is rapidly increasing and is predicted to reach 9.6 billion by 2050 and the limited resources tend to push the sector forward demanding the development of a highly efficient agriculture. Nanotechnology has emerged as a transformative tool in offering novel solutions to enhance crop productivity, nutrient utilization and sustainability. Among the various nanomaterials, nano zinc (nZn) has garnered significant attention for its potential to revolutionize agricultural practices. Hence in view of this an investigation was initiated to examine the effect of nano zinc oxide on morpho physiological yield Parameters and Quality of Finger Millet [*Eleusine coracana* (L.) Garten.] was conducted during rabi, 2022-23 Dry land farm, S.V. Agricultural College, ANGRAU, with Ten treatments and three replications.

Keywords: Finger millet, nano technology, nano zinc oxide, zinc sulphate

Introduction

Millets are popularly known as nutri-cereals as they provide most of the nutrients required for human body. These are highly nutritious, non-gluten, acid free having many nutraceutical and health promoting properties. These are the imperative food and fodder crops in semi-arid regions with higher efficiency of water that are gaining more relevance in the world. Millets are an often over looked staple food for millions living in the harshest, food-insecure regions of the developing world. Millets represent a diverse group of small-seeded grasses grown for food, feed or forage. Millets are extraordinarily tolerant to drought and other abiotic stresses viz., high temperatures and poor fertile soils. This makes them "climate smart" and often a good source for genetic characters that can strengthen the resilience of other crops in the scenario of climate change.

Millets are known to provide many vitamins such as vit E and vit B which are essential and micronutrients that can support nutrition for those living in dryland areas particularly women and children. Millets are also rich source of phytochemicals which act as antioxidants and detoxifying agents. According to the data from the US Department of Agriculture's Foreign Agricultural Service, as of February 2023, India produced 39% of the millets worldwide of the year 2022. India produced about 120 Lakh tonnes produced globally in 2022.

Among the micronutrients, zinc (Zn) is considered as the major limiting micronutrient which limits 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 (Auld, 2001) [5]. Further around 200 enzymes responsible for growth, development, immune function and resistance to infections are regulated by zinc in plant system. Hence, zinc deficiency in soils may cause lower yield or sometimes crop failure and poor accumulation of zinc into grains and thus may lead to zinc malnutrition in human. Zinc deficiency in soils strongly correlates to zinc deficiency in humans.

Finger millet crop is frequently referred as a "Pandora box of nutrients" for better health because the grains are enhanced with various significant nutritional benefits with 65-75 percent carbs, 15-20 percent dietary fibre, 5-8 percent protein, and 2.5-3.5 percent minerals,

finger millet grains are incredibly nutrient-dense. Finger millet, an orphan crop, possesses immense potential in mitigating climate change and could offer threefold security in terms of food, fodder and nutrition.

Government of India had proposed to United Nations for declaring 2023 as International Year of Millets (IYoM). The proposal of India was supported by 72 countries and United Nation's General Assembly (UNGA) declared 2023 as International Year of Millets on 5th March, 2021.

Nanotechnology is considered the potential solution for solving various agricultural problems and increases agricultural productivity through various delivery agents like nanopesticides, nanofertilizers. Nano particles afford 'magic bullets', which comprise chemicals, and herbicides or genes that target specific crop components for the proclamation of their content (Periakaruppan *et al.*, 2023) [27].

The use of Zinc oxide nano particles (ZnO-NPs) in agriculture also possess some potential adverse effects, including toxicity to non-target organisms, accumulation in the food chain and environmental pollution. These effects are influenced by various factors such as particle size, concentration and exposure time. The application of ZnO-NPs can significantly enhance plant growth, physiological and metabolic activity and yield as well as crop quality. (Seleiman *et al.*, 2023) [34].

Materials and Methods

A field experiment entitled "Effect of nano zinc oxide on morpho physiological yield Parameters and quality of Finger Millet [*Eleusine coracana* (L.) Garten.] was conducted during rabi, 2022 at Dryland S.V. Agricultural College, Tirupati campus of Acharya N.G. Ranga Agricultural University, which is geographically situated at 13.5° N latitude and 79.5° E longitude with an altitude of 182.9 m above the mean sea level, in the Southern Agro-Climatic Zone of Andhra Pradesh. According to Trolls classification, it comes under the Semi-Arid Tropics (SAT). The experimental soil was Sandy loam in texture.

Zinc was applied in the form of ZnSO₄.7H₂O to treatments T₃ and T₅ for soil and foliar for T₄ and T₅ application, respectively. Whereas, foliar application of nano zinc oxide was done in T₆ to T₁₀ applied at time (30 DAT and 60 DAT) as per treatment details T₁: Absolute control (Water spray), T₂: RDF (Reccomended NPK + FYM), T₃: T₂ + Soil application ZnSO₄.7H₂O @ 50 kg/ha (at sowing), T₄: T₂ + Foliar ZnSO₄.7H₂O @ 0.2% at 30 and 60 DAT, T₅: (T₂ + T₃ + T₄), T₆: T₂ + Foliar Nano ZnO @ 50 ppm ha⁻¹ at 30 and 60 DAT, T₇: T₂ + Foliar Nano ZnO @ 100 ppm ha⁻¹ at 30 and 60 DAT, T₈: T₂ + Foliar Nano ZnO @ 150 ppm ha⁻¹ at 30 and 60 DAT, T₉: T₂ + Foliar Nano ZnO @ 200 ppm ha⁻¹ at 30 and 60 DAT, T₁₀: T₂ + Foliar Nano ZnO @ 250 ppm ha⁻¹ at 30 and 60 DAT.

Results and Discussion

Growth parameters

Plant height

It was observed from the data presented in Table 1 that significantly a higher plant height (97.10 cm) was recorded with foliar application of T₈: T₂ + Foliar Nano ZnO @ 150 ppm ha⁻¹ at 30 and 60 DAT and next highest plant height was recorded by the treatment which received T₇: T₂ + Foliar Nano ZnO @ 100 ppm ha⁻¹ at 30 and 60 DAT.

Significantly the lowest plant height (93.36 cm) was with T₁: Absolute control (water spray). With the change in Zn application method from soil to foliar, plant height increased which might be attributed to greater photosynthetic activity and chlorophyll synthesis due to Zn fertilization that resulted in better vegetative growth. Similarly significant increase in plant height was recorded by Kumar *et al.* (2021) [19].

Number of Tillers per Plant

The data pertaining to number of tillers per plant is furnished in Table 1. Among different combination of conventional and foliar fertilization of nano fertilizers, the treatment that received T₈: T₂ + Foliar Nano ZnO @ 150 ppm ha⁻¹ at 30 and 60 DAT recorded significantly higher number of tillers per plant (4.42) followed by the treatment which received T₇: T₂ + Foliar Nano ZnO @ 100 ppm ha⁻¹ at 30 and 60 DAT (3.58), the lowest number of tillers per hill was recorded by T₁ Absolute control (2.02)

The significant increment in the number of tillers m⁻² with the foliar application of nano fertilizers was due to the fact that nano fertilizers instigated the activity of nitrate reductase, chloroplast (Hong *et al.*, 2005) [15] and antioxidant enzyme system (Nekrasova *et al.*, 2011) [24] which might be the possible mechanisms that enhanced the growth and resulted in higher number of tillers. These findings were in accordance with the findings of Rathnayaka *et al.* (2018) [31]

Leaf Area

The leaf area of a plant represents its source size, which was closely related to grain yield. The data regarding Leaf area is presented in Table 1

At Harvest highest leaf area (1002.67 cm² plant⁻¹) was noticed by T₈ i.e. T₂ + Foliar Nano ZnO @ 150 ppm ha⁻¹ at 30 and 60 DAT followed by T₇ i.e. T₂ + Foliar Nano ZnO @ 100 ppm ha⁻¹ at 30 and 60 DAT (871.89 cm² plant⁻¹). The lowest leaf area was recorded by T₁ i.e. control (586.98 cm² plant⁻¹).

The leaf area differed according to zinc application in different concentrations and the increased leaf area was ascribed to foliar application of Nano zinc oxide at 30 and 60 DAT which might have helped in fast absorption of zinc through leaf and further helped in enhancement of cell division, elongation and photosynthetic activity.

SCMR (SPAD chlorophyll meter reading)

The data on SCMR is presented in Table 1. At harvest, treatment T₈: T₂ + Foliar Nano ZnO @ 150 ppm ha⁻¹ at 30 and 60 DAT showed highest (SCMR 34.60). Whereas the lowest SCMR was noticed in control (T₁) (25.80) followed by T₃: T₂ + Soil application ZnSO₄.7H₂O @ 50 kg/ha (at sowing). Zinc is being a co-factor in numerous enzymes which might have helped in the synthesis of more chlorophyll pigments in leaves. Nano ZnO promoted seed germination, seedling vigor, early flowering and higher chlorophyll content in leaf.

The probable reason might be because Zn may facilitate the uptake of essential nutrients by plants. Adequate nutrient availability can enhance chlorophyll synthesis and improve overall plant health, contributing to increased SPAD values. similar findings were reported by Zhang *et al.* (2021) [44].

Days to 50% Flowering

The data on days to 50 percent flowering in Finger millet was recorded and furnished in the Table 1.

There was a significant difference in the days taken for 50% flowering due to treatments effect of application of nano zinc oxide. The shorter number of days taken for 50% flowering observed in treatment T₈ (T₂ + Foliar Nano ZnO @ 150 ppm ha⁻¹ at 30 and 60 DAT) (57.66) followed by the treatment T₇ (T₂ + Foliar Nano ZnO @ 100 ppm ha⁻¹ at 30 and 60 DAT) (59.01). However, a greater number of days taken for 50 percent flowering was recorded in control (T₁).

Among the Nano zinc application treatments, significant differences in days to 50 percent flowering were observed. The treatment T₈: T₂ + Foliar Nano ZnO @ 150 ppm ha⁻¹ at 30 and 60 DAT recorded significantly least number of days to 50 percent flowering (57.66) and followed by T₇: T₂ + Foliar Nano ZnO @ 100 ppm ha⁻¹ at 30 and 60 DAT (59.01) and T₅: (T₃ + T₄ + T₅) (60.14). However, control (T₁) had recorded more number of days (68.09) compared to other treatments. The application of Nano zinc oxide appears to have positively impacted the plant's physiology and biochemical pathways, thereby facilitating more efficient floral development. The specific mechanisms through which Nano zinc oxide operates to expedite flowering might involve its role in enhancing various physiological processes, including hormone regulation, nutrient uptake, and cellular signalling. These processes collectively contribute to the acceleration of floral initiation and development. Similar results were also reported by (Mohanasundar *et al.*, 2021) [23] in Finger millet.

Prasad *et al.* (2012) [28] concluded that nano ZnO promoted seed germination, seedling vigor, early flowering and higher chlorophyll content in leaf. They also observed beneficial effects of NPs in enhancing plant growth, development and yield in peanut at lower doses, but at higher concentrations

ZnO NPs were detrimental just as the bulk nutrients.

Crop Growth Rate (CGR) (g m⁻² d⁻¹)

The crop production was determined by crop growth rate which indicates the dry matter accumulated per unit land per unit time (Watson *et al.*, 1952) [43]. Grain yield was found to have a strong relationship with LAI, LAD, and CGR.

The CGR of Finger millet was computed from 20 DAT to harvest at 20 days Interval and furnished in Table 1.

The data revealed that CGR increased till 60 DAT and further decreased gradually till harvest due to declined leaf area in all the treatments. At all stages of crop development, the CGR differed among the zinc application treatments (except at 60 to harvest).

At 60 DAT to harvest, T₈: T₂ + Foliar Nano ZnO @ 150 ppm ha⁻¹ at 30 and 60 DAT recorded significantly higher CGR (28.24 g m⁻² d⁻¹). Whereas, the lowest CGR was recorded by (T₁) control (12.56 g m⁻² d⁻¹). The increased CGR was ascribed to increased leaf area index, light interception, photosynthetic rate and dry matter production. From the highest value, CGR reduced till maturity stage due to reduced number of leaves (Nicknejad *et al.*, 2009) [25]. These findings are similar with Seyedsharifi and Khorramdel (2015) [35]

The observed increase in Crop Growth Rate (CGR) can be attributed to several interrelated factors that likely resulted from the application of zinc. This includes the enhancement in the activity of carbonic anhydrase, along with improvements in plant height, Leaf Area Index (LAI), and Leaf Area Duration (LAD). Collectively, these factors likely contributed to a more efficient process of photosynthesis, which was facilitated by the application of zinc. This phenomenon aligns with findings reported by Sharath (2016) [36].

Table 1: Effect of different sources of zinc on growth, physiological parameters of Finger millet.

Treatments	Plant height (cm)	No. of Tillers	Leaf area (cm ² plant ⁻¹)	SCMR	CGR (g m ⁻² d ⁻¹)	Days to 50% Flowering
T ₁ : Absolute control (Water spray)	57.87	2.02	586.98	25.80	12.56	68.09
T ₂ : RDF (Recc NPK + FYM)	67.58	2.73	655.67	28.04	17.32	63.03
T ₃ : T ₂ + Soil application ZnSO ₄ .7H ₂ O @ 50 kg/ha (at sowing)	79.57	2.91	723.22	27.61	16.74	64.08
T ₄ : T ₂ + Foliar ZnSO ₄ .7H ₂ O @ 0.2% at 30 and 60 DAT	85.96	3.12	860.94	29.55	19.27	62.57
T ₅ : (T ₂ + T ₃ + T ₄)	89.33	3.27	830.17	29.09	22.43	60.14
T ₆ : T ₂ + Foliar Nano ZnO @ 50 ppm ha ⁻¹ at 30 and 60 DAT	74.29	2.93	675.65	30.96	18.86	63.47
T ₇ : T ₂ + Foliar Nano ZnO @ 100 ppm ha ⁻¹ at 30 and 60 DAT	93.36	3.58	871.89	33.81	25.15	59.01
T ₈ : T ₂ + Foliar Nano ZnO @ 150 ppm ha ⁻¹ at 30 and 60 DAT	97.10	4.42	1002.67	34.60	28.24	57.66
T ₉ : T ₂ + Foliar Nano ZnO @ 200 ppm ha ⁻¹ at 30 and 60 DAT	72.34	2.67	667.95	29.89	15.63	65.89
T ₁₀ : T ₂ + Foliar Nano ZnO @ 250 ppm ha ⁻¹ at 30 and 60 DAT	69.98	2.85	683.93	28.61	14.83	64.72
SE m±	1.02	0.083	20.801	0.344	0.651	0.397
CD 5%	3.04	0.245	61.804	1.023	1.935	1.180

Yield attributes of finger millet

Number of Productive Tillers per Plant

Number of productive tillers per plant is one of the most condemnatory yield components. More the number of fruitful tillers better will be the yield. The data on number of productive tillers per plant influenced by zinc application was recorded at harvest and presented in Table 2.

More number of productive tillers per plant was noticed in the treatment T₈. This was because of zinc as a constituent of various metalloenzymes might have controlled the

senescence of leaves and contributed towards increase in the number of tillers (Barak and Helmke, 1993) [7]. However, the difference was non-significant between them and similar results were obtained by Patel *et al.* (2019) [26]. The increased productive tillers per plant might also be due to formation of more photosynthates which helped in production of more tillers and growth under zinc fortification treatments duly supported by more green leaves (Verma and Neue, 1984) [40]. The increased tiller production might be due to more zinc uptake and translocation owing to

zinc fertilization and further helped in enhancement of photosynthetic rate. These results were homogeneous with the results reported by (Ravikiran and Reddy, 2004) [32].

The experimental data revealed that, there was significant difference among the zinc application treatments. The treatment T₈: T₂ + Foliar Nano ZnO @ 150 ppm ha⁻¹ at 30 and 60 DAT recorded more number of productive tillers per plant (3.63) followed by T₇: T₂ + Foliar Nano ZnO @ 100 ppm ha⁻¹ at 30 and 60 DAT (3.41) and T₉: T₂ + Foliar Nano ZnO @ 200 ppm ha⁻¹ at 30 and 60 DAT recorded (2.39) which was on par with T₁₀: T₂ + Foliar Nano ZnO @ 250 ppm ha⁻¹ at 30 and 60 DAT (2.53). However, the lowest number of productive tillers per plant was recorded by control (T₁) (1.83). Similar results were obtained by Ramaiyan *et al.* (2023). The more number of productive tillers per plant might be ascribed to optimum supply of zinc which might have increased the uptake and availability of other essential nutrients. This resulted in improvement of plant metabolic process and improved the crop growth.

When nano-urea was applied, it increased the nutrient uptake through the stomatal openings and nutrient translocation within the plant. This increased nutrient uptake resulted in increased cell division, meristematic activity and cell elongation stimulation, producing more productive tillers plant⁻¹. The number of effective tillers produced is a good indicator as it is the major yield determinant. According to Benzon *et al.* (2015) [8], the number of reproductive tillers in rice was significantly affected by applying conventional fertilizer in combination with nano fertilizer and also enhanced availability of nutrients by easy penetration of nano fertilizers through stomata of leaves via gas uptake. Similar results were revealed by (Abdel-Aziz *et al.*, 2018) [1] (Jassim *et al.*, 2019) [16].

1000 grain weight (g)

Data on 1000 grain weight is presented in Table 2. 1000 grain weight is an important indicator for prediction of yield (Deivasigamani and Swaminathan, 2018) [11]. It is also a very important measure of seed quality, which is effective on sprouting, seed potential, seedling growth and plant performance (Afshari *et al.*, 2011) [2]. This quality depends on the size of embryo and reserved nutrient quantity used for sprouting and growth (Ebadi and Hisoriev, 2011) [12] (Cao *et al.*, 2011) [9].

Maximum weight of 1000 seeds observed in treatment T₈ while the minimum weight was recorded in treatment T₁. The increase in 1000-grain weight may be due to the reason that nano fertilizers promote the plant to absorb the water of soil and nutrients, then the photosynthesis is improved. The higher 1000 grain weight could be due to complete utilization of starch towards more seed set and developing grains. Rahaman *et al.* (2011) reported that the application of zinc might have helped in execution of zinc in various metabolic processes which are involved in the production of healthy grains. Similar results were also obtained by (Gouis, 1992) [20].

Data on zinc application treatments revealed that, there was difference in 1000 grain weight was maximum in T₈ i.e. T₂

+ Foliar Nano ZnO @ 150 ppm ha⁻¹ at 30 and 60 DAT (3.13g) and was followed by T₇ i.e. T₂ + Foliar Nano ZnO @ 100 ppm ha⁻¹ at 30 and 60 DAT (3.10g) and T₅ i.e. (T₂ + T₃ + T₄) (2.95 g) followed by T₄: T₂ + Foliar ZnSO₄.7H₂O @ 0.2% at 30 and 60 DAT (2.86 g) Whereas, the lowest 1000 grain weight was seen in control (T₁) (2.01g). Results are in accordance with (Mohanasundar *et al.*, 2021) [23].

The grain development in Zn-applied treatments largely increased, possibly as a result of increased levels of IAA and proteins which might have enhanced the plant growth by increased photosynthetic translocation. Further, this might be due to the fact that Zn is an active ingredient in enzymes involved in energy metabolism pathway of plants. It also plays a major role in photosynthesis and is a structural constituent of many intermediaries in photosynthesis and carbohydrate metabolism. Similar findings were also obtained by (Chowdary and Patra, 2019) [10].

NPs could up-regulate the expression of aquaporin genes, thus facilitating water and H₂O₂ diffusion. Meanwhile, elevated ROS, especially H₂O₂ observed in nano-primed seeds during germination could act as signal molecules for stimulating germination process. Additionally, NPs penetrated into seeds, could possibly interact with α-amylase enzyme or act as nano catalyst. Thereby enhancing seed starch degradation for seed germination and seedling growth (Mahakkam *et al.*, 2016) [22].

Grain Yield

The data revealed that, all the treatments recorded significantly higher grain yield over control (T₁). However, T₈ i.e. T₂ + foliar of Foliar Nano ZnO @ 150 ppm ha⁻¹ at 30 and 60 DAT was recorded highest grain yield (2438 kg ha⁻¹), followed by T₇ i.e. T₂ + foliar Nano ZnO @ 100 ppm ha⁻¹ at 30 and 60 DAT (2281 kg ha⁻¹). Whereas, the lowest grain yield (1453 kg ha⁻¹) was shown by control (T₁) i.e. without fertilizers and manures followed by T₂ i.e. NPK and FYM (1664 kg ha⁻¹).

The increment in the grain yield was also attributed to the improved physiology of plants with the added Zn which consequently involved in the efficiency of different enzymes, synthesis of chlorophyll and IAA and improved the nitrate assimilation in plant system. Further it was also observed that ZnO NPs enhanced chlorophyll synthesis in leaves by affecting the activities of glutamyl-tRNA reductase and protoporphyrinogen oxidase (Siddiqui *et al.*, 2019) leading to higher grain yields and better rice qualities of ZnO NPs treatments (Zhang *et al.*, 2021) [44].

Straw Yield

the treatment T₈: T₂ + Foliar Nano ZnO @ 150 ppm ha⁻¹ at 30 and 60 DAT recorded highest straw yield (4941 kg ha⁻¹) followed by T₇ i.e. T₂ + Foliar Nano ZnO @ 100 ppm ha⁻¹ at 30 and 60 DAT with straw yield of (4763 kg ha⁻¹). The highest straw yield might be attributed to continuous availability of macro and micro which might have enhanced the plant height, leaf area, total dry matter. Similar results were obtained by Arulmozhiselvan *et al.* (2013) [4].

Table 2: Effect of different sources of zinc on yield parameters of Finger millet.

Treatments	No. of productive tillers	No. of fingers per plant	Test weight (g)	Grain yield (kg ha ⁻¹)	Straw yield
T ₁ : Absolute control (Water spray)	1.83	11.99	2.01	1373	3762
T ₂ : RDF (Recc NPK + FYM)	2.43	13.67	2.19	1664	4121
T ₃ : T ₂ + Soil application ZnSO ₄ .7H ₂ O @ 50 kg/ha (at sowing)	2.62	15.37	2.73	1892	4303
T ₄ : T ₂ + Foliar ZnSO ₄ .7H ₂ O @ 0.2% at 30 and 60 DAT	2.81	17.02	2.86	2052	4495
T ₅ : (T ₂ + T ₃ + T ₄)	3.22	21.33	2.95	2209	4679
T ₆ : T ₂ + Foliar Nano ZnO @ 50 ppm ha ⁻¹ at 30 and 60 DAT	2.59	13.73	2.25	1734	4128
T ₇ : T ₂ + Foliar Nano ZnO @ 100 ppm ha ⁻¹ at 30 and 60 DAT	3.41	21.51	3.10	2281	4763
T ₈ : T ₂ + Foliar Nano ZnO @ 150 ppm ha ⁻¹ at 30 and 60 DAT	3.63	23.33	3.13	2438	4941
T ₉ : T ₂ + Foliar Nano ZnO @ 200 ppm ha ⁻¹ at 30 and 60 DAT	2.39	13.52	2.26	1595	4069
T ₁₀ : T ₂ + Foliar Nano ZnO @ 250 ppm ha ⁻¹ at 30 and 60 DAT	2.53	13.20	2.14	1531	3987
SE m±	0.061	0.526	0.042	40.990	59.026
CD 5%	0.182	1.563	NS	121.248	174.129

Zinc Content (mg kg⁻¹)

Data on Zinc Content (mg kg⁻¹) in grains as influenced by Nano Zinc in Finger millet was analyzed after harvest and presented in Table 3 and Fig 4.

Among the zinc application treatments, the data revealed that, there was significant difference in grain zinc content. The higher zinc (34.96 mg kg⁻¹) content was noticed in T₈: T₂ + Foliar Nano ZnO @ 150 ppm ha⁻¹ at 30 and 60 DAT, followed by T₇ i.e. T₂ + Foliar Nano ZnO @ 100 ppm ha⁻¹ at 30 and 60 DAT (32.41 mg kg⁻¹). However, the lowest zinc (14.82 mg kg⁻¹) content was noticed in control (T₁) and by T₆: T₂ + Foliar Nano ZnO @ 50 ppm ha⁻¹ at 30 and 60 DAT (19.34 mg kg⁻¹). Similar results were obtained by (Kumar *et al.*, 2021) [18]. The probable reason might be because of the high uptake and translocation efficiency of nano zinc oxide than bulk zinc form. Similarly, increased grain zinc content

might be ascribed to the increased absorption through foliar spray of zinc and further translocated to the grain rapidly without any fixation losses. Bala (2018) found that foliar application of nano-zinc oxide in rice cv. PR-121 and Basmati-1509 enhanced grain zinc content.

Lin and Xing (2008) also found that ZnO nanoparticles were primarily adsorbed onto the cell surface and then their uptake is followed further quickly and efficiently translocated to the sink. The increased quality parameters with zinc application might also be due to higher zinc assimilation in plants compared to control. Similar results were also obtained by Stalin *et al.* (2011) [37] and also were in agreement with Prasad *et al.* (2012) [28] wherein the accumulation of zinc in the kernels of peanut was high with the use of nanoscale zinc oxide particles.

Table 3: Effect of different sources of zinc on zinc content in grains of Finger millet

Treatments	Zinc content in grains mg kg ⁻¹
T ₁ : Absolute control (Water spray)	14.82
T ₂ : RDF (Recc NPK + FYM)	23.60
T ₃ : T ₂ + Soil application ZnSO ₄ .7H ₂ O @ 50 kg/ha (at sowing)	26.24
T ₄ : T ₂ + Foliar ZnSO ₄ .7H ₂ O @ 0.2% at 30 and 60 DAT	29.78
T ₅ : (T ₂ + T ₃ + T ₄)	27.59
T ₆ : T ₂ + Foliar Nano ZnO @ 50 ppm ha ⁻¹ at 30 and 60 DAT	19.34
T ₇ : T ₂ + Foliar Nano ZnO @ 100 ppm ha ⁻¹ at 30 and 60 DAT	32.41
T ₈ : T ₂ + Foliar Nano ZnO @ 150 ppm ha ⁻¹ at 30 and 60 DAT	34.96
T ₉ : T ₂ + Foliar Nano ZnO @ 200 ppm ha ⁻¹ at 30 and 60 DAT	22.91
T ₁₀ : T ₂ + Foliar Nano ZnO @ 250 ppm ha ⁻¹ at 30 and 60 DAT	20.78
SE m±	0.469
CD 5%	1.393

Protein Content (%)

Data on protein content (%) in grains as influenced by Nano Zinc in Finger millet was analyzed after harvest and presented in Table 4

Among all the treatments used T₈ i.e. T₂ + Foliar Nano ZnO @ 150 ppm ha⁻¹ at 30 and 60 DAT recorded more protein content (8.92%) and next highest is T₇: T₂ + Foliar Nano ZnO @ 100 ppm ha⁻¹ at 30 and 60 DAT (8.58%) and less protein (5.84%) was recorded by control (T₁). The higher grain protein content might be ascribed to foliar application of Zn in plants. Results are in accordance with (Kisan *et al.*, 2015) who opined that those plants treated with ZnO nano particles at the concentration of 500 and 1000 ppm showed higher values of protein and dietary fibre content in comparison to control.

The application of micronutrients especially zinc might influenced the physiological and biochemical processes of plants, which significantly increased impacts the grain

quality and yield (Wang *et al.*, 2015) [43]. Similar results were also obtained by (Vijaykumar *et al.*, 2020) [41].

The increased protein content with zinc application during present study was in agreement with the hypothesis that protein represents a sink for zinc in the grain. Further, zinc fertilization might have enhanced the zinc availability to the plants, and which played pivotal role in protein synthesis. A thinkable reason for the improvement in quality and yield due to foliar applied Zn might be phloem mobile and could be easily translocated into the developing grains. Further, Zn was believed to be essential for RNA synthesis which in turn, helped in protein synthesis (Zuchi *et al.*, 2012) [45].

The application of nano-Zn fertilizer can increase Zn mobility in phloem, increasing its bioavailability in the endosperm and contributing to protein synthesis and other biochemical traits of crop plants (Rossi *et al.*, 2019) [33] (Ahmad *et al.*, 2020) [3].

Table 4: Effect of different sources of zinc on Protein content in grains of Finger millet.

Treatments	Protein content in grains (%)
T ₁ : Absolute control (Water spray)	5.84
T ₂ : RDF (Recc NPK + FYM)	7.13
T ₃ : T ₂ + Soil application ZnSO ₄ .7H ₂ O @ 50 kg/ha (at sowing)	7.49
T ₄ : T ₂ + Foliar ZnSO ₄ .7H ₂ O @ 0.2% at 30 and 60 DAT	8.14
T ₅ : (T ₂ + T ₃ + T ₄)	7.82
T ₆ : T ₂ + Foliar Nano ZnO @ 50 ppm ha ⁻¹ at 30 and 60 DAT	6.81
T ₇ : T ₂ + Foliar Nano ZnO @ 100 ppm ha ⁻¹ at 30 and 60 DAT	8.58
T ₈ : T ₂ + Foliar Nano ZnO @ 150 ppm ha ⁻¹ at 30 and 60 DAT	8.92
T ₉ : T ₂ + Foliar Nano ZnO @ 200 ppm ha ⁻¹ at 30 and 60 DAT	6.54
T ₁₀ : T ₂ + Foliar Nano ZnO @ 250 ppm ha ⁻¹ at 30 and 60 DAT	6.36
SE m±	0.095
CD 5%	0.283

Table 5: Effect of different sources of zinc on Gross energy in grains of Finger millet.

Treatments	Gross energy Kcal Kg ⁻¹
T ₁ : Absolute control (Water spray)	2856.03
T ₂ : RDF (Recc NPK + FYM)	2882.81
T ₃ : T ₂ + Soil application ZnSO ₄ .7H ₂ O @ 50 kg/ha (at sowing)	2879.54
T ₄ : T ₂ + Foliar ZnSO ₄ .7H ₂ O @ 0.2% at 30 and 60 DAT	3181.17
T ₅ : (T ₂ + T ₃ + T ₄)	3219.33
T ₆ : T ₂ + Foliar Nano ZnO @ 50 ppm ha ⁻¹ at 30 and 60 DAT	3243.29
T ₇ : T ₂ + Foliar Nano ZnO @ 100 ppm ha ⁻¹ at 30 and 60 DAT	3582.64
T ₈ : T ₂ + Foliar Nano ZnO @ 150 ppm ha ⁻¹ at 30 and 60 DAT	3343.92
T ₉ : T ₂ + Foliar Nano ZnO @ 200 ppm ha ⁻¹ at 30 and 60 DAT	3282.73
T ₁₀ : T ₂ + Foliar Nano ZnO @ 250 ppm ha ⁻¹ at 30 and 60 DAT	3152.97
SE m±	210.12
CD 5%	NS

Conclusion

Nano-zinc oxide at the concentration of 150 ppm showed the best results and caused maximum increase in plant height, No. of Tillers, SCMR, Grain yield and Straw yield compared to the control and zinc Sulphate treatment. Further indicates that the use of ZnO-NPs as a nano fertilizer for crops grown in Zn deficient soils will improve crop yield, food quality and address malnutrition, globally.

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