Original Research Article

Stimulatory effect of ZnO nanoparticles as a nanofertilizer on growth and yield of pearl millet (*Pennisetum glaucum*)

ABSTRACT

A field experiment was conducted during *kharif* season of 2023 at the Agronomy Farm, S.K.N. College of Agriculture, Shri Karn Narendra Agricultural University, Jobner, Jaipur (Rajasthan). The experiment was conducted using randomized complete block design with nine different treatments and three replications. Among different soil and foliar treatments, application of seed priming with 800 ppm nano ZnO for 2 hours and foliar application of 600 ppm nano ZnO has recorded significantly higher growth parameters, grain, stover yield and higher net return of pearl millet which remained statistically at par with seed priming with 800 ppm nano ZnO for 2 hours along with foliar application of 500 ppm nano ZnO. These findings suggest that nano ZnO can be a valuable tool in sustainable agriculture practices, boosting crop productivity and nutritional value. Our results have important implications for improving food security and farm profitability.

Keywords: nano zinc, pearl millet, seed priming, profitability

INTRODUCTION

Pearl millet is one of the world's hardiest warm season cereal crops and widely cultivated cereal crop in Africa and Asia, (Akbar *et al*., 2019) serving as a primary food source for millions of people. Pearl millet is aptly designated as a "nutri-cereal" due to its exceptional nutritional content, providing a substantial source of energy, macronutrients, and essential micronutrients (Rakesh *et al*., 2021). Among the cereals, pearl millet widely known as poor man's crop, is gaining importance due to its climate resilience and high nutritional value compared to major food crops (Paschapur *et al*., 2021). Pearl millet is also recognized for its adaptability to harsh environments, including drought and poor soil conditions, making it a vital crop for sustainable agriculture and food security (Tonapi *et al*., 2024). India is the largest producer of pearl millets in the world (APEDA, 2023). India comes in third terms of area after rice and wheat and is the world's largest producer of pearl millet (Syed *et al*., 2023) In India, it is cultivated in about 75.72 lakh ha with the production of 114.31 lakh tonnes with an average productivity of 1510 kg/ha (Annual Report, 2023). During this period, Rajasthan state occupies nearly 45.71 lakh ha area with average production of about 51.05 lakh tonnes and productivity of 1117 kg/ha (Anonymous, 2022-23). As per FAO (Food and Agriculture Organization of the United Nations), there will be more than 9 billion people on the planet by 2050 (Dholariya *et al*., 2023). The existing agricultural practices may fail to fulfill the need of predicted food demand because of several issues like incorrect fertilizer use, industrial waste, rapid use of pesticides, heavy metals, and change in climatic conditions (Tonapi *et al*., 2024). Modern techniques of nanotechnology to use nanoparticles as nanofertilizers are gaining attention from the scientific communities (Neme *et al.,* 2021). Nanoparticles are metal particles that are spherical or faceted and are generally 100 nm in size. These nanoparticles have a high surface area (30-50 m^2/g), high activity, a better catalytic surface, a quick chemical reaction, are rapidly dispersible and absorb a large amount of water (Saraswathi *et al*., 2019). Nanofertilizers are being proved to be a boom to the agriculture sector as they improve nutrient efficiency, enhance nutrient uptake and customize delivery of required nutrients, reduce environmental impact on crops. ZnO-NPs are proved to be a beneficial tool in agriculture for increase in the crop yield, biological safety, biological compatibility, nontoxic, and ecologically friendly (Akbar *et al*., 2019; Meena *et al*., 2017). ZnO nanoparticles could be used to increase crop yields, helping to fulfill the world's increasing food need. Farmers are using both sulphates and chelated Zn (with ethylene di ammine tetra acetic acid, EDTA) for soil and foliar applications; however, the efficacy is low. The present study was taken up to investigate the promotionary or inhibitory effects of various concentrations of ZnO nanoparticles which can be an effective and eco-friendly technique that could improve the faster emergence, more uniform plant population and increasing yield with improved seed nutrient content. Nanoparticles with small size and extensive surface area are expected to be the perfect forms for use as a Zn fertilizer in plants (Adhikari *et al*., 2016).

MATERIAL AND METHODS

The experiment was conducted at the Agronomy Farm, S.K.N. College of Agriculture, SKNAU, Jobner, Jaipur (Rajasthan) during kharif season of the year 2023. Which is situated in South Eastern part of Rajasthan at an altitude of 427 metre above mean sea level with 26° 05' N latitude and 75° 28' E longitude and this area falls under agro-climatic zone III-A (Semi-Arid Eastern Plain) of Rajasthan. This zone is characterized by climate of this region is a typically semi-arid, characterized by extremes of temperature during both summers and winters. The average annual rainfall of this tract ranges between 400-500 mm, most of which is contributed by the south-west monsoon during the months of July and August. The relative humidity fluctuates between 43 to 87 per cent. The soil of the experimental site was sandy loam in texture with low in organic carbon (0.21%), low in available nitrogen (124.7 kg/ha), low in available phosphorus (17.12 kg/ha), medium in available potassium (155.3 kg/ha) and low in available DTPA extractable zinc (0.40 ppm) in 0-30 cm soil depth with pH 8.37. The experiment was laid out in a RBD having nine treatments with three replications (Plot size = 13.5 × 5.4 m2) including different soil and foliar sprays viz., T1 : Seed priming with Nano ZnO @ 800 ppm for 2 hrs, T2 : T1 + Foliar application of Nano ZnO @ 200 ppm, T3 : T1 + Foliar application of Nano ZnO @ 300 ppm, T4 : T1 + Foliar application of Nano ZnO @ 400 ppm, T5 : T1 + Foliar application of Nano ZnO @ 500 ppm, T6 : T1 + Foliar application of Nano ZnO @ 600 ppm, T7 : Foliar application of $ZnSO_4$ @ 0.5%, T8 : Soil application of $ZnSO_4$ @ 10 kg/ha and T9 : Recommended dose of fertilizer. Pearl millet variety 'Pusa Composite-701' was sown during the second week of July. The management practices and fertilizers were applied according to the package of practices. After reaching the physiological maturity level, the plants were manually harvested, where the grain as well as stover samples were collected for examination.

RESULTS AND DISCUSSION

Growth parameter

The data presented in Table 1 indicate that the tallest pearl millet plants were observed in the treatment seed priming with 800 ppm nano ZnO for 2 hours and foliar application 600 ppm nano ZnO (129.60 cm),closely followed by the same seed priming with foliar applications 500 ppm nano ZnO (123.83 cm) and 400 ppm nano ZnO (120.80 cm). In respect of dry matter accumulation at harvest, the combination of seed priming with 800 ppm nano ZnO for 2 hou.llrs and foliar application at 600 ppm resulted in the highest dry matter accumulation/plant (95.43 g) followed closely by the seed priming with 800 ppm nano ZnO for 2 hours with foliar applications at 500 ppm (93.29 g) and 400 ppm (89.85 g)nano ZnO particles. These treatments corresponded to significant increases of 49.43%, 46.08% and 40.69%, respectively over recommended dose of fertilizer. The higher growth parameters at harvest in seed priming with 800 ppm nano ZnO for 2 hours and foliar application at 600 ppm treatment might be due to zinc's positive effect on root development, leading to increased uptake of other essential nutrients from the soil, which is then distributed to the plant's aerial parts, promoting healthy vegetative growth, characterized by increased plant height, leaf area and dry matter production. A concurrent increase in plant height and photosynthetic leaf area, facilitated by nano zinc oxide, may have contributed to enhance dry matter accumulation, potentially augmented by the synergistic effects of inherent nutrients like magnesium, iron and sulphur (Koti *et al*., 2009). Zinc plays a crucial role in plant growth, activating enzymes and driving auxin biosynthesis, leading to increased cell production, dry matter accumulation and ultimately, seed yield. This is consistent with findings by Rahman *et al*. (2021) and Slaton *et al*. (2018) in rice and Faruk *et al*. (2016) in bread wheat, Meena *et al*. (2017) in rabi sorghum. Adhikari *et al*. (2016) in maize, who reported increased dry matter production, yield and seed zinc content with external zinc application, highlighting the potential of nano zinc oxide to enhance plant growth beyond conventional zinc fertilizers.

Yield

Crop yield is the end result of an intricate interplay between various biological and chemical processes that shape the development and growth of plants, ultimately determining their productivity. According to Table 1 application of seed priming with 800 ppm nano ZnO for 2 hours and foliar application nano zinc oxide at 600 ppm gave higher yield of pearl millet. Highest yield (2077 kg/ha grain yield, 5569 kg/ha stover yield and 7646 kg/ha biological yield, respectively) of pearl millet was recorded significantly under seed priming with 800 ppm nano ZnO for 2 hours and foliar application nano zinc oxide at 600 ppm which found at par with seed priming with 800 ppm nano ZnO for 2 hours and foliar application nano zinc oxide at 500 ppm. The higher grain yield and stover yield with application of seed priming with 800 ppm nano ZnO for 2 hours and foliar application nano zinc oxide at 600 due to ZnO NPs are readily adsorbed onto cell surfaces and quickly absorbed into cells, where they interact with biological proteins and are efficiently translocated to the sink. Similarly, this study found that seed priming with nano ZnO particles resulted in increased effective tillers/plant, ear head length and grain and stover yield, likely due to the small size and large surface area of nanoparticles, which enabled easy penetration and uptake of zinc. Zinc plays a crucial role in plant growth, activating enzymes and auxin biosynthesis, leading to increased cell production and dry matter accumulation in seeds and stover. These findings are consistent with previous research by Parmar snehal bhai (2016), Prasad *et al*. (2012), Zhang *et al*. (2021), Adil *et al*. (2022), and Uma *et al*. (2019), highlighting the potential of nano ZnO in enhancing plant growth and productivity.

Economics

The treatment that combined seed priming with 800 ppm nano zinc oxide for 2 hours alongwith foliar application of nano zinc oxide at 600 ppm resulted in the highest net return, amounting to ₹45,785/ha, indicating the most profitable and economically viable treatment for pearl millet cultivation**.** The increased grain yield and lower cost in these treatments led to higher net returns, making them more profitable than the other treatments. This finding is consistent with the research of Uma *et al.* (2019) and Dholariya *et al*. (2023), who also reported higher returns to investment with the application of nano zinc oxide in crops. The results suggest that the use of nano ZnO as a seed treatment and foliar spray can be a profitable and sustainable agricultural practice. These results are in conformity with the findings of Pandao *et al*. (2021), Mohammed *et al*. (2021) and Apoorva *et al*. (2017).

CONCLUSION

Seed priming with 800 ppm nano zinc oxide for 2 hours and foliar application of nano ZnO at increasing concentration up to 600 ppm would improve the growth and yield of pearl millet. Maximum net return (₹45,785/ha) was recorded by the effective combination of seed priming with 800 ppm nano zinc oxide for 2 hours and foliar application of nano zinc oxide at 600 ppm, indicating the most profitable and economically viable treatment for pearl millet cultivation.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc have been used during writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

REFERENCES

Adhikari T, Kundu S, Subba Rao A (2016) Zinc delivery to plants through seed coating with nano zinc oxide particles. *Journal of Plant Nutrition* 39(1): 136-146.

Adil M, Bashir S, Bashir S, Aslam Z, Ahmad N, Younas T, Asghar RM, Alkahtani J, Dwiningsih Y, Elshikh MS (2022) Zinc oxide nanoparticles improved chlorophyll contents, physical parameters, and wheat yield under salt stress. *Frontiers in Pant Science* 13: 932861.

Akbar.A , M.B. Sadiq, I. Ali, N. Muhammad, Z. Rehman, M.N. Khan, J. Muhammad, S.A. Khan, F U. Rehman, A.K. Anal 2019. Synthesis and antimicrobial activity of zinc oxide nanoparticles against foodborne pathogens *Salmonella typhimurium* and *Staphylococcus aureus*. *Biocatalysis and Agricultural Biotechnolog*y 17;36-42.

Annual Report, 2023. Department of Agriculture & Farmers Welfare Ministry of Agriculture & Farmers Welfare Government of India Krishi Bhawan, New Delhi; www.agricoop.nic.in

Apoorva MR, Rao PC, Padmaja G (2017) Effect of zinc with special reference to nano zinc carrier on yield, nutrient content and uptake by rice (*Oryza sativa* L.). *International Journal Current Microbiology and Applied Sciences* 6(8): 1057-1063.

Dholariya H, Zinzala V, Thesiya N, Patel J, Kumar N (2023) Effect of zinc on growth, yield and economics of finger millet [*Eleusine coracana* (L) Gaertn.] on hilly area of South Gujarat. *Annals of Plant and Soil Research 25(4): 630-634*

Faruk O, Bulent T, Cakmak I (2016) Effect of zinc flumate on growth of soybean and wheat in zinc deficient. *Communications In Soil Science and Plant Analysis*137:2769-78.

Koti RV, Mummigatti UV, Nawalgatti CM, Savita FH, Guled MB, Anand A (2009) Complimentary effect of zinc application on iron content in sorghum genotypes. *Indian Journal of Plant Physiology* 14 (1): 78-81.

Mohammed SB, Dzidzienyo DK, Yahaya AL, Umar M, Ishiyaku MF, Tongoona PB, Gracen V (2021) High soil phosphorus application significantly increased grain yield, phosphorus content but not zinc content of cowpea grains. *Agronomy* 11(4): 802.

Meena, D. S., Jayadeva, H. M., Gautam, C. and Meena, H. M. 2017. Effects of nano zinc oxide (ZnO) particles on germination of maize (*Zea mays* L.) seeds. *International Journal of Plant Soil Science* 16(1): 1-5.

Neme Kumera , Ayman Nafady, Siraj Uddin and Yetenayet, Tola. 2021 Application of nanotechnology in agriculture, postharvest loss reduction and food processing: food security implication and challenges. Heliyon; 7, p. e08539, 10.1016/j.heliyon.2021.e08539

Pandao MR, Sajid M, Katore J, Patil SS, Nirgulkar MB (2021) Effect of nano zinc oxide on growth, yield and uptake of nutrient by linseed. *Int JChem Stud* 9(1): 176-179.

Parmar Snehalbhai J (2016) Effect of Zno nanoparticles on germination, growth and yield of groundnut (*Arachis hypogaea* L.). *PhD (Agri)* thesis Submitted to Anand Agricultural University, Anand.

Paschapur AU, Joshi D, Mishra KK, Kant L, Kumar V, Kumar A (2021) Millets for life: a brief introduction. *Millets and millet technology* pp. 1-32.

Prasad TN, Sudhakar P, Sreenivasulu Y, Latha P, Munaswamy V, Reddy KR, Sreeprasad TS, Sajanlal PR, Pradeep T(2012) Effect of nanoscale zinc oxide particles on the germination, growth and yield of peanut. *Journal of Plant Nutritions* 35: 905-927.

Rahman A, Yassen M, Akram M, Awan ZI (2021) Response of rice to zinc application and different sources in calcareous soil. *Pakistan Journal of biological science* 8(1): 285-287.

Rakesh K, Umesha C, Balachandra Y (2021) Influence of nitrogen and zinc levels on pearl millet (*Pennisetum glaucum* L.). *Pakistan Journal of biological science* 1 3(1):128-132.

Saraswathi, Y.V.S., Dinesh Kumar, M. and Gurumurthy, K.T. 2019. Effect of nano ZnO on growth and yield of finger millet (*Eleusine coracana* L.). *International Journal of Current Microbiology and Applied Science* **8**: 1365-1371.

Slaton, N.A., Wilson, C.E., Ntamatungiro, S., Norman, R. J., Boothe, D. L. (20018) Evaluation of zinc seed treatments for rice. *Agronomy Journal* 93(1):152-7.

Syed A., Sarwar, G., Shah, S. H., and Muhammad, S. (2023). Soil salinity research in 21st century in Pakistan: its impact on availability of plant nutrients, growth and yield of crops. Communication in Soil Science and Plant Analysis 52:183–200.

Tonapi VA, Thirunavukkarasu N, Gupta SK, Gangashetty PI, Yadav OP (2024) Pearl Millet in the 21st Century. Springer Nature: Singapore.

Uma V, Jayadeva HM, Rehaman HA, Kadalli GG, Umashankar N (2019) Influence of nano zinc oxide on yield and economics of maize (*Zea mays* L.). *Mysore Journal of Agriculture Science* 53(4): 44-48.

Zhang H, Wang R, Chen Z, Cui P, Lu H, Yang Y, Zhang H (2021) The effect of zinc oxide nanoparticles for enhancing rice (*Oryza sativa* L.) yield and quality. *Agriculture* 11(12): 1247.

Table 1. Growth parameters of pearl millet as influenced by different nano zinc oxide particles

Treatment	**Plant height (cm)**	**Dry matter accumulation (g/plant)**	**Effective tillers/ plant**	**Grain yield (kg/ha)**	**Stover yield (kg/ha)**
T_1: Seed priming with Nano	170.67	74.79	2.67	1672	4464

ZnO @ 800 ppm for 2 hrs					
T_2: T_1+Foliar application of Nano ZnO @ 200 ppm	179.17	84.07	3.07	1761	4736
T_3: T_1+Foliar application of Nano ZnO @ 300 ppm	185.53	87.81	3.32	1807	4860
T_4: T_1+Foliar application of Nano ZnO @ 400 ppm	189.33	89.85	3.49	1848	4991
T_5: T_1+Foliar application of Nano ZnO @ 500 ppm	196.63	93.29	3.60	1997	5413
T_6: T_1+Foliar application of Nano ZnO @ 600 ppm	207.87	95.43	3.95	2077	5569
T_7: Foliar application of $ZnSO_4$ @ 0.5 %	172.90	76.08	2.88	1731	4657
T_8: Soil application of $ZnSO_4$ @ 10 kg/ha	177.00	80.92	2.98	1748	4701
T_9: Recommended dose of fertilizer	165.10	63.86	2.42	1647	4381
SEm±	6.57	2.50	0.16	63	192
C.D. at 5 %	19.70	7.50	0.47	189	577
CV (%)	6.23	5.23	8.58	6.02	6.85

Table 2. Economics of pearl millet as influenced by different nano zinc oxide particles

Treatments	Net returns (₹/ha)	B:C ratio
T_1: Seed priming with Nano ZnO @ 800 ppm for 2 hrs	40079	2.77
T_2: T_1+Foliar application of Nano ZnO @ 200 ppm	39993	2.52
T_3: T_1+Foliar application of Nano ZnO @ 300 ppm	40224	2.45
T_4: T_1+Foliar application of Nano ZnO @ 400 ppm	40403	2.38
T_5: T_1+Foliar application of Nano ZnO @ 500 ppm	44640	2.45
T_6: T_1+Foliar application of Nano ZnO @ 600 ppm	45785	2.42
T_7: Foliar application of $ZnSO_4$ @ 0.5 %	41599	2.77
T_8: Soil application of $ZnSO_4$ @ 10 kg/ha	41647	2.73
T_9: Recommended dose of fertilizer	39698	2.80
SEm±	2491	0.10
C.D. at 5 %	NS	0.30
CV (%)	10.38	6.59