Short communications

Zinc oxide nanoparticles for enhanced seed germination and growth performance in maize.

Dipali Ingavale[1] and P.D. Shiragave[2]*

Department of Agrochemicals and Pest Management, Devchand College, Arjunnagar. Via Nipani. Tal. Kagal Dist. Kolhapur 416 216, Maharashtra. India.
Department of Agrochemicals and Pest Management, Shivaji University, Kolhapur 416 004, Maharashtra. India.

Received on 16 November 2024; received in revised form 16 April 2025, accepted 24 April 2025.

Abstract
Zinc oxide nanoparticles (ZnO NPs),synthesized using the Sol-Gel method,by varying the pH and keeping the annealing time (3 hours) and temperature (400°C) constant, were characterized and evaluated fortheir effect on seed germination (SG) and early growth performance in *Zea mays*. This experiment was conducted at DST-FIST laboratory of Devachand College Arjunnagar, Nipani from Dec 2023 to Jan 2024. Structural and crystalline studiesby X-ray diffraction spectrometer (XRD) revealed the hexagonal wurtzite structure of the ZnO (JCPDS card No. 36–1451). The increased peak intensity of the diffraction peaks assigned to the (101) plane indicated particle-like properties of the product. The priming of seeds by soaking in 10ppm nanoparticle solution enhanced germination percentage, and soil drenching at 10ppm concentration after one week of germination enhanced the growth parameters of maize crop.

Key words : Nanofertilizer, Plant growth performance, Seed germination, Sol-Gel, ZnO nanoparticles.

Plants require mineral nutrients for their healthy growth, and at least 14 mineral elements are required for proper nutrition, along with O, CO_2, and H_2O (Marschner, H., 1995, Mengel, K. et al., 2001). Lack of any essential mineral elements can restrict plant development and hinder crop production. In most cases, plants derive these nutrients from the soil. Additionally, fertilizers that contain vital mineral elements for human nutrition are sometimes applied to crop to boost their levels in edible parts, promoting better human health (Nandal, Solanki, 2021). Nano fertilizers promise avital future to agriculture in improving the crop yield, improving the nutrient use efficiency, while minimizing the overuse of chemical fertilizers. The nanofertilizers contain both macronutrients and micronutrients, released to plants in small quantities on a regular basis and promote environmental sustainability. Due to their unique characteristics and potential application in diverse fields, zinc oxide NPs have garnered significant attention in recent years(Islam, F. et al., 2022). The ZnONPs have demonstrated positive effects on plant growth and crop yield (Sarkhosh, S., et al., 2022). Zinc is necessary for enzyme activity, hormone synthesis and DNA replication but its deficiency in soils can result in lower crop yield and diminished nutritional quality (Nandal, Solanki, 2021). The ZnO NPs have been shown to enhance photosynthetic process by increased carbon assimilation and higher biomass accumulation (Ahmad, F. et al., 2019). The application of ZnO nanoparticles to maize and wheat plants as a fertilizer show radical change in the development of the plants which can lead the crops to better yields ensuring increased productivity. Zinc oxide nanoparticles are being increasingly studied for their potential use in agriculture, particularly as nanofertilizers. The application of ZnO nano particles to crops such as maize and wheat has shown several affects on growth parameters (Patil et al. 2023). Nanotechnology has helped to develop nanofertilizers, which are used in soil to improve its quality and help plants grow better[15]. The presence of ZnO-NPs enhances antioxidant systems and accelerated proline accumulation, contributing to plant stability and improved photosynthetic efficiency (Faizan, M. et al., 2018).

Maize is a crucial cereal and versatile crop in Poaceae family, utilized for human consumption, animal and poultry feed and in various industrial application including the production of maize starch, dextrose, maize syrup and maize flakes (Saritha, A. et al, 2020).

In present research, we synthesized pH variated ZnONPs by adopting sol gel method. This method offered the formation of small sized nanoparticles enough to be absorbed easily by the roots and yielded phase-pure nano-structured zinc oxide powder. The physico-chemical characterization of pH

* Author for Correspondences: Phone:93415 70575 Email : drpanditds@gmail.com

variated ZnO NPs was performed using XRD technique. The effect of pH variated ZnO NPs on the seed germination, shoot and root length and leaf area in *Zea mays* was studied.

Material:Analytical grade Zinc nitrate (Qualigens) and Ammonia (SRL).
Plant material: *Zea mays* L.

Synthesis and characterization of nano structured ZnO fertilizer using sol-gel method

The NPs of zinc oxide were synthesized using the sol-gel technique (Bokov, D. et al., 2021) . Zinc nitrate was used as precursor and ammonia as a complexing agent in solution. The pH was varied from neutral to basic (pH 6,8,10 and 12). 1M Zinc nitrate solution of 50ml was prepared with constant stirring for 20 min. To maintain aimed pH, ammonia (30%) was added drop wise and the solution was kept on hot plate with constant stirring for conversion of sol in gel. Heating was continued till the conversion of gel into dry powder. The synthesized dry material was groundin a mortar for 15 minutes and fine powder was kept in crucible for annealing treatment (3hours at 400^0C). The morphology of the ZnO nanoparticles was characterized using a combination of techniques, including X-ray model AXS D8 advance, Energy dispersive X-ray analysis and scanning electron microscopy (SEM) on JSM-IT200 made JEOL. The average crystallite size of the nanoparticles was calculated using the Debye/Scherrer formula. $D = 0.9\ \lambda / \beta \cos \theta$

Where, 'D' is the average crystalline size of nanoparticles, 'λ' is the wavelength of CuKá radiation λ = 1.5406A°), 'β' is (FWHM of the diffraction peak, and 'θ' is the diffraction angle. The FTIR (model FT/IR-4600, Jasco manufacturer (Jaysingpur college, Jaysingpur)analysis was performed to study surface chemistry, functional group and molecular interactions of nanoparticles.

Evaluation of the nano structured ZnO fertilizer

Seed germination

The pH variated ZnO nanoparticles were used to treat maize seeds. Twenty seeds were carefully washed with water and then rinsed with alcohol to prevent contamination. The pre-sterilized seeds were treated for 24 hours with pH variated ZnO nanoparticles. The seeds presoaked in waterfor three hours were used as control. The analysis was performed by using IBM-SPSS for calculating standard deviation and standard error. Seed germination was observedafter 7^{th} day of treatment.

Plant growth performance

The maize seeds (20) were sown at 2 cm deep in the potted soil (Square pots 15cm in length and 15cm in width) and experiment was conducted in laboratory. The ZnO NPs synthesized at varying pH were drenched at10ppm concentration in to the pot after one week of germination. Control was set without treatment. The effect of zinc nanoparticles was assessed by observing shootlength, root length, root to shoot ratio and leaf area at twenty days after treatment. The treatmentswere arranged in triplicate and average values were recorded and analysis was conducted using IBM-SPSS

Characterization of ZnO nanoparticles

The XRD was utilized to confirm the structure of the material and characterize the particle size of the prepared ZnO NPs. The diffraction pattern (Fig. 1) of ZnO NPs shows three unique diffraction peaks at angles of 31.76, 34.42, and 36.24°, which may be indexed with the planes (100), (002), and (101) of the hexagonal wurtzite type structure of ZnO (JCPDScard No. 36-1451) (Nieder, R. et al., 201). The increased peak intensity of diffraction peaks assigned to the (101) plane indicated particle-like properties of the product. Meanwhile, no additional peaks were identified, indicating that the produced ZnO NPs were highly pure. The particle size of ZnO nanoparticles at pH6, pH8, pH10, and pH12 were 61.14nm, 57.20nm, 52.20nm, and 43.88nm, respectively.

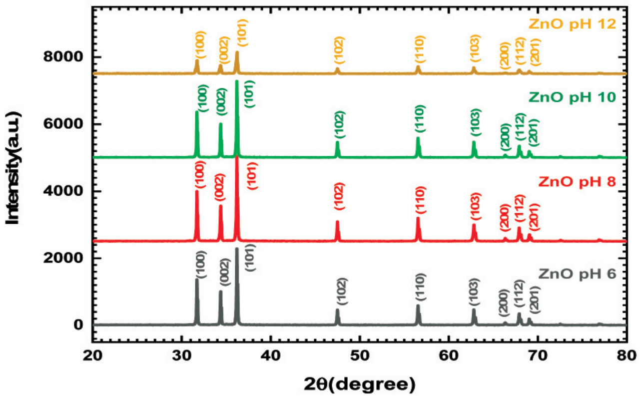

Figure 1. XRD of ZnO nanoparticles synthesized at various pH.

Characterization of ZnO nanoparticles by Scanning Electron Microscope (SEM)

Scanning electron microscope was employed to examine the surface morphology and determine the grain size of the synthesized powder. The average grain size of ZnO nanoparticles at pH 6, pH 8, pH 10, and pH 12 were529nm, 849nm, 616nm and 865nm respectively.

Characterization of ZnO nanoparticle by EDAX

The EDAX confirmed the stoichiometric ratio decided for study of Zinc oxide nanoparticles.The atomic percentage revealed by EDAX for zinc is 83.69% (Fig. 2). This confirms the stoichiometry is maintained throughout the experiment.

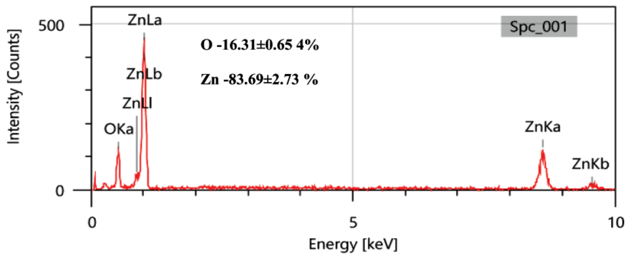

Figure 2. EDAX of synthesized ZnO nanoparticle.

Characterization of ZnO nanoparticle by FTIR analysis

The FTIR spectrum of the zinc nanoparticles (ZnO NPs) exhibited characteristic peaks in the range of 400-600 cm-1 corresponding to the Zn-O stretching vibration of zinc oxide (ZnO) (Fig. 3). A broad absorption band around 3200-3600 cm-1 was observed, indicative of surface hydroxyl groups (OH), suggesting surface hydroxylation or moisture interaction. Additionally, peaks near 960 cm-1 were noted, associated with Zn-OH bending vibrations. If surface functionalization was present additional peaks corresponding to C=O (~1700cm-1) or N-H (~3200-3400 cm-1) stretches were observed, depending on the specific capping agents or coatings used. The result confirms the presence of zinc oxide nanoparticles.

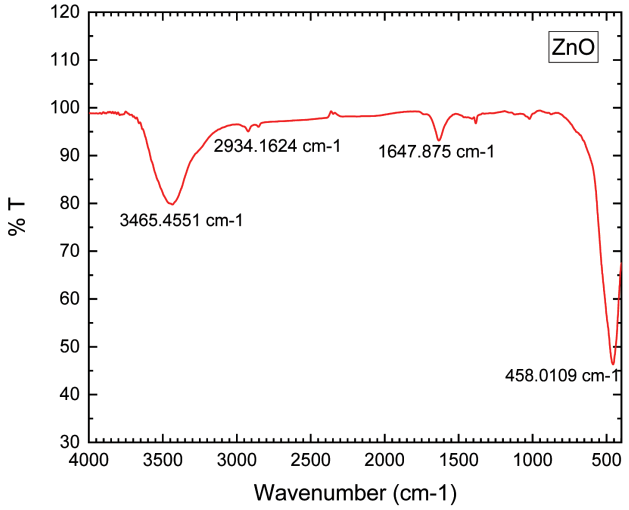

Figure 3. FTIR spectrum of ZnO nanoparticles

Table.1 Effect of pH variated ZnO NPs on per cent seed germination in maize.

pH variated ZnO NPs	No. of seeds treated	No. of seeds germinated (Mean± SE)	No.of non - germinated seeds	Per cent germination (%)
pH-6	20	18.0 ± 0.58	2.0 ± 0.58	90.0 ± 2.5
pH-8	20	18.2 ± 0.45	1.8 ± 0.45	91.0 ± 1.8
pH-10	20	19.0 ± 0.00	1.0 ± 0.00	95.0 ± 0.0
pH-12	20	18.1 ± 0.29	1.9 ± 0.29	90.5 ± 1.2
Control	20	16.5 ± 0.71	3.5 ± 0.71	82.5 ± 3.1

Evaluation of ZnO nanoparticles on seed germination

The data on germination of maize seeds treated with pH variated ZnO NPs are presented in Table 1. The ZnO NPs treated seeds showed significant germination as compared to the control. The ZnO nanoparticles synthesized at pH-10 resulted inhigher (95%) seed germination as compared to other treatments. The size of nanoparticles is critical factor influencing their integration with seeds and their subsequent biological effects including germination (Vijay, F.V. et al., 2022). The application of ZnO Nps has been shown to enhance chilli germination rates and promote early seedling growth by improving nutrient uptake, antioxidant activity and stress tolerance (Afrayeem, S.M. and Chaurasia, A.K., 2017). Zinc nanoparticles have demonstrated a significant influence on the seed germination of *Camelina sativa* and *Brassica napus* (Sarkhosh, S. et al., 2022). Zinc oxide nanoparticles enhanced maize seed germination and vigor by promoting water absorption, improving nutrient availability (Itroutwar, P.D. et al., 2020).

The ZnO nanoparticles synthesized at pH8 and pH10 exhibited highershoot and root length of 27.50 cm respectively. The effect of pH variated ZnO nanoparticles on leaf area is represented in Table 2. A higher leaf area was exhibited by plants treated with ZnO nanoparticles synthesized at pH 12 as compared to 22.80 cm^2, 24.18 cm^2 and 24.60 cm^2 respectively for those synthesized at pH6, pH8 and pH10. The leaf area in controlwas 19 cm. The present results of ZnO nanoparticles correlate with research published (Tarafdar, J.C. et al., 2014) in pearl millet. Similar results with boosting of plant growth and yield in maize (Azam, M. et al., 2022) after application of zinc nanoparticles have been reported. Zinc oxide nanoparticles have emerged as a promising seed priming agent in plant growth applications, demonstrating positive benefits on both plant development and output (Kusale, S.P. et al., 2021). Zinc oxide nanofertilizers improved plant development and yield in maize crops (Vijay, F.V. et al., 2022). The application of nano zinc oxide as a fertilizer has been found to significantly enhance the growth of maize crops, resulting in improved

Table 2. Effect of pH variated ZnO NPs on growth performance of maize

Parameters	pH-6	pH-8	pH-10	pH-12	Control	CD (5%)
Stem length	24.00±0.00	27.50±1.44	27.50±1.44	26.00±1.52	19.00±1.52	4.70
Root length	6.00±1.52	6.90±1.06	6.80±1.24	6.50±1.04	4.70±1.23	1.90
Root-stem ratio	0.23±0.88	0.23±0.88	0.23±0.88	0.23±0.88	0.23±0.88	0.31
Width of leaf	1.20±0.20	1.30±0.30	1.20±0.20	1.40±0.40	0.90±0.26	0.69
Leaf area	22.8±1.8	24.1±1.4	24.6±1.7	29.4±1.9	13.5±2.5	2.96

plant health and increased yields (Adhikari et al., 2015).

Conclusion

The ZnO nanoparticles were manufactured at varying pH, using the sol gel technique. Seeds treated with ZnO NPs synthesized at pH-8 and 10 demonstrated higher germination and growth performance in maizethan those synthesized atpH 6, 12 and control group. Zinc is a vital micronutrient for crops. Zinc deficiency resulted in chlorosis, stunted growth, dwarfing, and deformity in crops. The ZnO nanoparticles could serve as maize seed priming agents, which promote early crop growth and increased leaf area, resulting in increased crop productivity. Hence, ZnO nanoparticles could be used as nanofertilizers.

Acknowledgement

We are thankful to DST-FIST, Science Instrumentation Facility Centre (SIFC), Devchand College, Arjunnagar for providing laboratory facility. Grateful to the Government of Maharashtra (India) for the financial support under Chhatrapati Shahu Maharaj National Research Fellowship (CSMNRF-2023)

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