



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(7): 1402-1405
Received: 19-04-2026
Accepted: 23-05-2026

M Kalyani
Ph.D. Scholar, Department of
Agronomy, S.V. Agricultural
College, Tirupati, Andhra Pradesh,
India

AV Nagavani
Professor and Head, Department
of Agronomy, ANGRAU, S.V.
Agricultural College, Tirupati,
Andhra Pradesh, India

T Prathima
Principal Scientist (Agronomy),
AACRC-RARS, ANGRAU,
Tirupati, Andhra Pradesh, India

TNVKV Prasad
Principal Scientist (Soil Science),
IFT, RARS, ANGRAU, Tirupati,
Andhra Pradesh, India

AR Nirmal Kumar
Assistant Professor, Department of
Crop physiology, ANGRAU, S.V.
Agricultural College Tirupati,
Andhra Pradesh, India

K Madhusudhana Reddy
Professor and Head, Department
of Agricultural Engineering,
ANGRAU, S.V. Agricultural
College, Tirupati, Andhra Pradesh,
India

Corresponding Author:

M Kalyani
Ph.D. Scholar, Department of
Agronomy, S.V. Agricultural
College, Tirupati, Andhra Pradesh,
India

Synthesis of zinc oxide nanoparticles using sol-gel method and their characterization

**M Kalyani, AV Nagavani, T Prathima, TNVKV Prasad, AR Nirmal Kumar
and K Madhusudhana Reddy**

DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i7r.6124>

Abstract

Nanotechnology has emerged as a promising tool to improve the bio-efficiency of an array of materials which could have numerous applications in diverse sectors including agriculture. The present investigation was undertaken to synthesize zinc oxide nanoparticles (ZnO NPs) using the oxalate decomposition (sol-gel) method. As prepared ZnO NPs were characterized using the techniques such as, ultraviolet-visible (UV-Vis) spectroscopy, scanning electron microscopy (SEM) and dynamic light scattering (DLS). The UV-Visible absorption spectrum exhibited a characteristic absorption peak at 373 nm, confirming the successful formation of ZnO nanoparticles. Surface morphological analysis by SEM revealed predominantly irregular and spherical to polyhedral nanoparticles with moderate agglomeration. Direct measurements from the SEM micrograph indicated particle sizes of 32.55, 23.02 and 45.01 nm, with an average particle size of 33.53 nm, confirming the formation of nanoparticles within the nanoscale range. Dynamic Light Scattering analysis further supported the successful synthesis of ZnO nanoparticles by showing a single, well-defined particle size distribution peak with an average hydrodynamic particle size of 35.5 nm, indicating good dispersion stability and minimal particle aggregation. The close agreement between SEM and DLS measurements demonstrated the uniformity and stability of the synthesized nanoparticles. Overall, the characterization of ZnO NPs confirmed the successful synthesis of stable ZnO nanoparticles with desirable optical, morphological and dispersion characteristics and may be suitable for application in agriculture as a source of zinc.

Keywords: Zinc oxide nanoparticles, Sol-gel, UV-Visible spectroscopy, SEM, DLS

Introduction

Nanotechnology has emerged as an innovative approach to improve the bio-efficacy of a large group of materials including zinc. Zinc oxide nanoparticles (ZnO NPs) have received considerable attention because of their small particle size, large specific surface area, enhanced reactivity and improved nutrient delivery efficiency compared with conventional zinc fertilizers. These unique properties facilitate better absorption, translocation and utilization of zinc by plants, thereby enhancing nutrient use efficiency and crop productivity (Prasad *et al.*, 2012; Raliya *et al.*, 2018) [7, 8].

A wide range of synthesis methods has been developed for the preparation of metal and metalloid nanoparticles, including chemical precipitation, sol-gel, hydrothermal, sonochemical, microemulsion and green synthesis techniques (Namakka *et al.*, 2023) [6]. Among these approaches, chemical synthesis methods are widely preferred because they are simple, economical, reproducible and suitable for large-scale production of nanoparticles with controlled particle size and morphology. However, the physicochemical properties of nanoparticles are greatly influenced by synthesis parameters such as precursor concentration, pH, reaction temperature, reaction time, drying and calcination conditions. These parameters determine the particle size, crystallinity, and stability and surface characteristics of the synthesized nanoparticles. Therefore, optimization of the synthesis process followed by detailed characterization is essential before their use in agricultural applications.

Comprehensive characterization of nanoparticles is necessary to confirm their successful synthesis and to understand their reactivity and applicability (Namakka *et al.*, 2023) [6]. In the present study, ultraviolet-visible (UV-Vis) spectroscopy was employed as a preliminary technique to confirm

the formation of ZnO nanoparticles based on their characteristic absorption behavior. Scanning electron microscopy (SEM) was used to examine the surface morphology, particle shape and aggregation behavior, whereas dynamic light scattering (DLS) was used to determine the hydrodynamic particle size distribution and dispersion characteristics of the synthesized nanoparticles. The combined application of these analytical techniques provides reliable information on the quality, stability and suitability of ZnO nanoparticles for agricultural use (Raliya *et al.*, 2018) [8].

Although the synthesis and physicochemical characterization of ZnO nanoparticles have been reported by several researchers (Jain *et al.*, 2013; Sun *et al.*, 2020; Lian *et al.*, 2024) [2, 10, 4], relatively few studies have integrated controlled nanoparticle synthesis and comprehensive physicochemical characterization with their subsequent evaluation as foliar nano-fertilizers under field conditions (Zhang *et al.*, 2018; Sun *et al.*, 2020; Lian *et al.*, 2024) [11, 10, 4]. Moreover, variations in synthesis protocols, particle size, morphology, surface charge, dissolution and aggregation behaviour, as well as the characterization techniques employed, often hinder direct comparison of the properties and agronomic performance of ZnO nanoparticles across studies. Therefore, systematic synthesis followed by detailed physicochemical characterization is essential for developing stable, efficient and agronomically suitable nano-zinc formulations.

The present investigation was undertaken to synthesize zinc oxide nanoparticles (ZnO NPs) using the oxalate decomposition (sol-gel) method, a chemical synthesis technique, and to characterize the synthesized nanoparticles using UV-Visible spectroscopy, scanning electron microscopy (SEM) and dynamic light scattering (DLS).

Materials and Methods

Synthesis of nanoscale ZnO

Preparation of nanoscale ZnO: Nanoscale ZnO was prepared by using the oxalate decomposition technique as described by Prasad *et al.*, 2012 [7].

Characterization of nanoscale ZnO

UV – Vis (UV-Visible spectra) analysis: The UV-visible spectra of this solution were recorded in Spectrophotometer (UV-1800, SHIMADZU), from 200 to 1100 nm. This analysis was useful to identify the presence of nutrients and its phase. Sample was prepared by suspending 1mg of the nanoparticles in 5 mL of water and then estimated using UV-Vis spectrophotometer.

DLS (Dynamic Light Scattering) analysis: The aqueous suspension of the synthesized nanoparticles was filtered through a 0.22 µm syringe driven filter unit and the size and zeta potential of the distributed nanoparticles were measured by using the principle of Dynamic Light Scattering (DLS) technique made in a Nanopartica (HORIBA, SZ-100) compact scattering spectrometer. This information is useful to know the dispersion capacity of nanoparticles and stability of nanoparticles by negative zeta potential values.

Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (SEM) analysis: The surface morphology of the synthesized zinc oxide (ZnO) nanoparticles was examined using a ZEISS Scanning Electron Microscope (SEM) at the Department of Nanotechnology, University of Agricultural Sciences, Raichur, Karnataka, India. A small quantity of the dried ZnO nanoparticle powder was mounted on an aluminium stub using conductive carbon tape and sputter-

coated with a thin layer of gold prior to imaging. The micrographs were recorded using a secondary electron (SE1) detector at an accelerating voltage of 10.0 kV, a working distance of 13.5 mm, and a magnification of 20,000×. The SEM analysis was used to determine the particle morphology, surface characteristics, degree of agglomeration and approximate particle size of the synthesized ZnO nanoparticles.

Results

Synthesis of nanoscale ZnO

The zinc oxide (ZnO) nanoparticles were synthesized using the oxalate decomposition method as described in the Materials and Methods section, and the synthesis procedure is presented in Fig. 1. The synthesized nanoparticles were characterized using UV-Visible spectroscopy, Scanning Electron Microscopy (SEM) and Dynamic Light Scattering (DLS) to assess their optical behaviour, morphological characteristics and hydrodynamic particle size, respectively. The combined characterization confirmed the successful formation of ZnO nanoparticles with nanoscale dimensions, desirable surface morphology and stable dispersion characteristics, suggesting their suitability for foliar application and for further investigations in agriculture.

Characterization of nanoscale ZnO

UV – Vis (UV-Visible spectra) analysis for nanoscale ZnO

The optical absorption characteristics of the synthesized zinc oxide nanoparticles were investigated via UV-Visible spectroscopy within a scanning range of 200 nm to 1100 nm. The recorded absorption spectrum exhibits two primary distinct features:

- **Characteristic Excitonic Absorption Peak (373.00 nm):** A well-defined, prominent absorption peak was recorded at 373.00 nm with a corresponding absorbance value of 0.67 (Fig. 2.). This sharp band edge absorption stems directly from the basic intrinsic surface plasmon resonance transition of electrons moving from the valence band to the conduction band. The occurrence of this sharp absorption maximum below the typical 380 nm threshold value observed in bulk zinc oxide validates a significant blue-shift, which firmly confirms the successful synthesis of particles well within the nanoscale boundaries experiencing clear quantum confinement attributes.
- **High-Energy Secondary Absorption Peak (267.00 nm):** A second distinctive absorption peak is recorded at 267.00 nm with a higher relative absorbance value of 0.95. In nanoparticle synthesis setups, auxiliary deep-UV absorption peaks in the high-energy 230 to 270 nm range typically indicate light interaction with localized electronic surface defect states, or the electronic excitation of organic functional capping agents present during synthesis that act as necessary stabilizing elements (Loganathan *et al.*, 2021) [3].

Scanning electron microscopy (SEM) analysis for nanoscale ZnO

SEM was performed to investigate the surface morphology and particle size of the synthesized zinc oxide (ZnO) nanoparticles. The representative SEM micrograph (Fig. 3.) revealed the formation of densely packed nanoparticles exhibiting predominantly irregular spherical to polyhedral morphology with moderate agglomeration. The observed agglomeration is a characteristic feature of ZnO nanoparticles and can be attributed to their high surface energy and strong van der Waals attractive forces during the drying process (Sangeetha *et al.*, 2011) [9]. Despite the formation of aggregates, the individual nanoparticles

remained distinguishable, indicating successful synthesis of nanosized ZnO particles.

Direct particle size measurements obtained from the SEM image showed particle diameters of 32.55, 23.02 and 45.01 nm, corresponding to an average particle size of 33.53 nm. The particle size distribution (approximately 23–45 nm) confirmed the nanoscale dimensions of the synthesized ZnO. Nanoparticles within this size range possess a high surface area-to-volume ratio, thereby enhancing surface reactivity, foliar adhesion and nutrient availability following application to crop foliage (Dimkpa *et al.*, 2018) [1]. The relatively small particle size is expected to improve zinc uptake efficiency by facilitating better penetration through the leaf cuticle and increasing interaction with plant tissues compared with conventional zinc fertilizers.

Furthermore, the SEM micrograph exhibited a rough and porous surface texture, indicating extensive nucleation and crystal growth during synthesis. Such porous morphology is advantageous for nano-fertilizer applications because it increases the contact surface between nanoparticles and leaf tissues, thereby promoting gradual dissolution and sustained release of Zn^{2+} ions after foliar application (Kah *et al.*, 2018) [3]. Similar morphological characteristics of irregular spherical ZnO nanoparticles with moderate agglomeration have been reported by Sangeetha *et al.* (2011) [9] who observed particle sizes ranging from 30–50 nm for chemically synthesized ZnO nanoparticles.

The morphology observed in the present investigation agrees well with previous reports on ZnO nanoparticles synthesized through chemical precipitation and sol-gel methods, confirming the successful formation of nanocrystalline ZnO. Collectively, the

SEM observations, together with UV-Visible spectroscopy analyses, confirmed the synthesis of high-purity ZnO nanoparticles with an average particle size of 33.53 nm, making them suitable for foliar application to improve micronutrient use efficiency and crop performance.

Dynamic Light Scattering (DLS) Analysis of ZnO Nanoparticles

The particle size distribution of the synthesized zinc oxide (ZnO) nanoparticles determined through Dynamic Light Scattering (DLS) is shown in Fig. 4. The DLS profile exhibited a single intense peak, indicating the formation of a relatively homogeneous nanoparticle suspension. The synthesized ZnO nanoparticles recorded an average hydrodynamic particle size of 35.5 nm confirming that the particles were within the nanoscale range. The narrow particle size distribution reflected the uniformity of the synthesized nanoparticles and suggested that the adopted synthesis method produced particles with consistent dimensions. The absence of secondary peaks in the distribution curve indicated that particle agglomeration was negligible and the nanoparticles remained well dispersed in the suspension. These findings demonstrate the successful synthesis of ZnO nanoparticles with good dispersion characteristics and nanoscale dimensions, making them suitable for subsequent foliar application in the present study. Similar nanoscale particle sizes and uniform size distributions have been reported for chemically synthesized ZnO nanoparticles by Prasad *et al.* (2012) and Sangeetha *et al.* (2011) [7, 9].

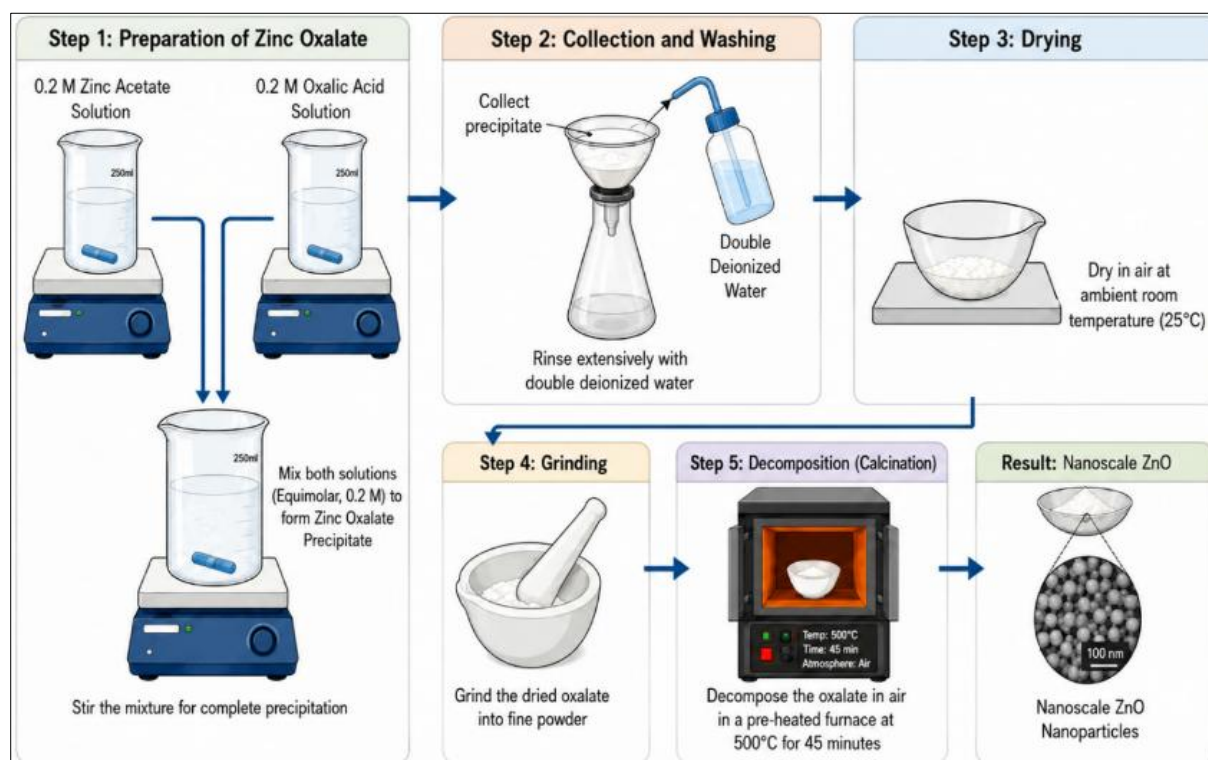


Fig 1: Synthesis of nanoscale ZnO by oxalate decomposition technique

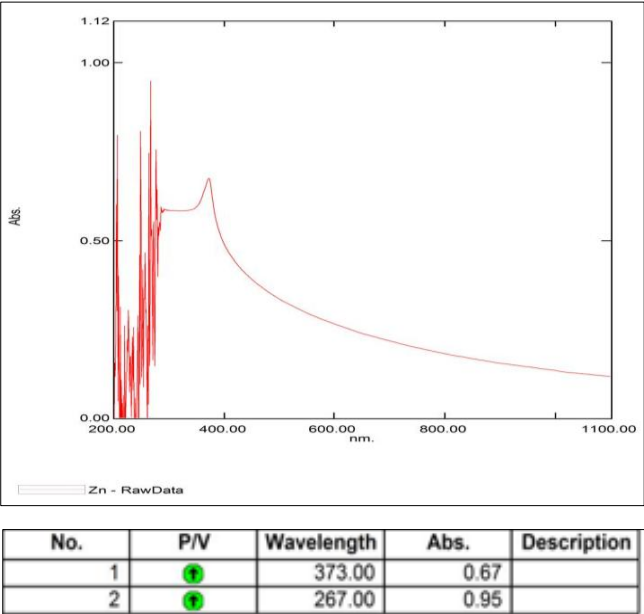


Fig 2: UV-Vis absorption peak of nanoscale ZnO

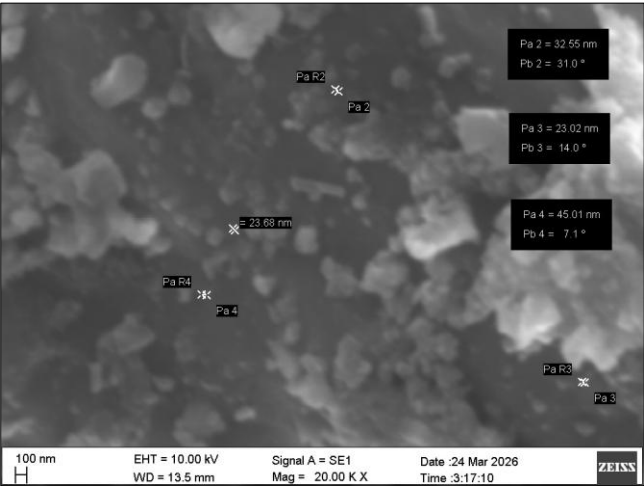


Fig 3: SEM image of nanoscale ZnO (bar scale 100 nm) with mean size 33.53 nm

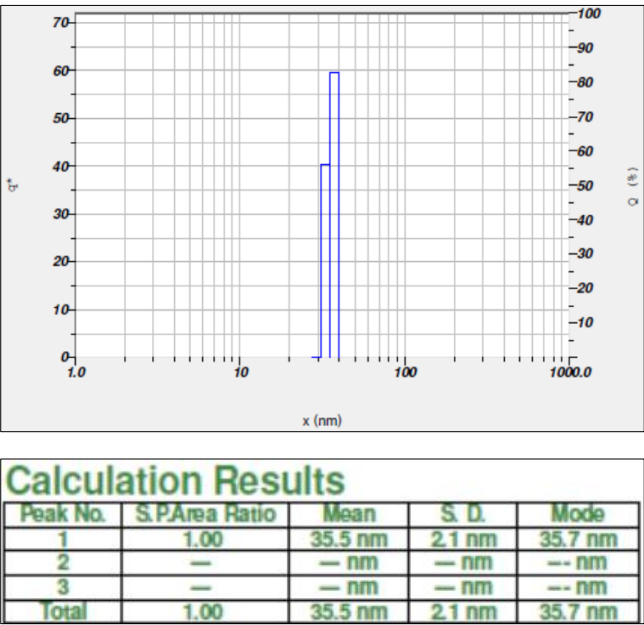


Fig 4: Micrograph representing particle size distribution pattern of nanoscale ZnO (35.5 nm)

Conclusion

Zinc oxide nanoparticles were successfully synthesized using the oxalate decomposition method and characterized by UV–Visible spectroscopy, SEM and DLS analyses. The UV–Visible spectrum confirmed nanoparticle formation with a characteristic absorption peak at 373 nm and an optical band gap of 3.32 eV. SEM analysis revealed irregular spherical to polyhedral nanoparticles with an average particle size of 37.09 nm, while DLS analysis showed a uniform particle size distribution with an average hydrodynamic diameter of 35.5 nm. The combined characterization confirmed the successful synthesis of stable ZnO nanoparticles with desirable optical, morphological and dispersion properties. These results indicate that the synthesized ZnO nanoparticles are suitable for foliar application as a nano-zinc fertilizer in sustainable crop production.

References

1. Dimkpa CO, Singh U, Bindraban PS, Elmer WH, Gardea-Torresdey JL, White JC. Exposure to weathered and fresh nanoparticle and ionic Zn in soil promotes grain yield and modulates nutrient acquisition in wheat (*Triticum aestivum* L.). J Agric Food Chem. 2018;66:9645-9656.
2. Jain N, Bhargava A, Tarafdar JC, Singh SK, Panwar J. A biomimetic approach towards synthesis of zinc oxide nanoparticles. Appl Microbiol Biotechnol. 2013;97(2):859-869.
3. Kah M, Kookana RS, Gogos A, Bucheli TD. A critical evaluation of nanopesticides and nanofertilizers against conventional agrochemicals. Nat Nanotechnol. 2018;13:677-684.
4. Lian J, Cheng L, Wang X, Chen Y, Deng C, Wang Y, et al. Bespoke ZnO NPs synthesis platform to optimize their performance for improving the grain yield, zinc biofortification, and Cd mitigation in wheat. ACS Sustain Chem Eng. 2024;12(2):716-727.
5. Loganathan S, Shivakumar MS, Karthi S, Nathan SS, Selvam K. Metal oxide nanoparticle synthesis (ZnO-NPs) of *Knoxia sumatrensis* (Retz.) DC. aqueous leaf extract and its evaluation of antioxidant, anti-proliferative and larvicidal activities. Toxicol Rep. 2021;8:64-72.
6. Namakka A, Yallappa S, Manjanna J, Dhananjaya BL. Recent advances in synthesis, characterization and agricultural applications of metal oxide nanoparticles: A review. Nanotechnol Environ Eng. 2023;8:44.
7. Prasad TNVKV, Sudhakar P, Sreenivasulu Y, Latha P, Munaswamy V, Raja Reddy K. Effect of nanoscale zinc oxide particles on the germination, growth and yield of peanut. J Plant Nutr. 2012;35:905-927.
8. Raliya R, Saharan V, Dimkpa C, Biswas P. Nanofertilizer for precision and sustainable agriculture: Current state and future perspectives. J Agric Food Chem. 2018;66:6487-6503.
9. Sangeetha G, Rajeshwari S, Venkatesh R. Green synthesis of zinc oxide nanoparticles by *Aloe barbadensis* Miller leaf extract and their biological applications. Mater Res Bull. 2011;46:2560-2566.
10. Sun H, Du W, Peng Q, Lv Z, Mao H, Kopittke PM. Development of ZnO nanoparticles as an efficient Zn fertilizer: Using synchrotron-based techniques and laser ablation to examine elemental distribution in wheat grain. J Agric Food Chem. 2020;68(18):5068-5075.
11. Zhang T, Sun H, Lv Z, Cui L, Mao H, Kopittke PM. Using synchrotron-based approaches to examine the foliar application of ZnSO₄ and ZnO nanoparticles for field-grown winter wheat. J Agric Food Chem. 2018;66(11):2572-2579.