OPEN ACCESS

IJABR

International Journal of Advanced Biotechnology and Research (IJABR)
ISSN 0976-2612, Online ISSN 2278–599X,
Vol-15, Issue4, 2024, pp14-25
DOI: 10.5281/zenodo.14202259

Research Article

Harnessing Nature: Green Synthesis of Zinc Oxide Nanoparticles from Banana Peel and Their Impact on Seed Germination

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Received: 09/11/2024
Accepted: 19/11/2024
Published: 22/11/2024

DOI: 10.5281/zenodo.14202259

Abstract

This study investigates the green synthesis of zinc oxide nanoparticles (ZNP) using banana peel extracts (BPE) and evaluates their effects on seed germination and growth in millet (Eleusinecoracana). ZNP were synthesized through an eco-friendly method involving the reaction of zinc acetate with BPE, followed by characterization using UV-Vis spectroscopy, Fourier-Transform Infrared Spectroscopy(FTIR), X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), nergy-Dispersive X-Ray Spectroscopy (EDX), and Dynamic Light Scattering (DLS). The UV-Vis spectra revealed distinct absorption peaks indicative of ZnO formation, while FTIR analysis confirmed the presence of organic compounds in the BPE that stabilize the nanoparticles. XRD results showed a hexagonal wurtzite structure, and SEM images exhibited predominantly rod-shaped nanoparticles. EDX analysis indicated a composition of 32.88% zinc and 67.12% oxygen, affirming the purity of the synthesized ZNP. Dynamic Light Scattering measurements revealed an average nanoparticle size of 102.5 nm. The phytotoxicity assessment demonstrated that lower concentrations of ZNP (30 mg/L) significantly enhanced germination rates and root and shoot lengths, while higher concentrations (90 mg/L) inhibited germination and growth, suggesting potential toxicity. Notably, fungal contamination was observed at 70 mg/L, indicating concentration-dependent effects. These findings highlight the potential of banana peel extract for sustainable nanoparticle synthesis and underscore the importance of optimizing nanoparticle concentrations to maximize beneficial effects on plant growth while minimizing toxicity. This research contributes to the growing interest in eco-friendly practices within nanotechnology and agriculture, promoting the use of plant-derived materials for enhancing crop resilience.**.**

Key words: zinc oxide nanoparticles, banana peel extract, UV-Vis spectroscopy, FTIR, XRD, SEM, EDX, DLS

Cite This article: Anne Veronica Suresh, Manohar Jebakumar Ravikumar and Savita Murthy, 2024. Harnessing Nature: Green Synthesis of Zinc Oxide Nanoparticles from Banana Peel and Their Impact on Seed Germination, International Journal of Advanced Biotechnology and Research (IJABR), ISSN 0976-2612, Online ISSN 2278–599X, Vol-15, Issue4, 2024, pp14-25 DOI: 10.5281/zenodo.14202259

Introduction

The increasing demand for sustainable agricultural practices has driven significant research into innovative methods for enhancing crop growth and health. One promising area of exploration is the use of nanotechnology, particularly the application of metal nanoparticles, which have demonstrated potential for improving plant growth, disease resistance, and nutrient uptake [1]. Among various nanoparticles, zinc oxide (ZnO) nanoparticles (ZNP) have garnered attention due to their unique properties, including antimicrobial activity, UV protection, and their role in promoting plant growth [2]. Recent studies have shown that ZNP can positively influence seed germination and plant development, with effects varying depending on concentration [3].

However, while low concentrations of ZNP can enhance growth parameters, higher concentrations may induce phytotoxic effects, leading to reduced germination rates and overall plant health [4]. Understanding the concentration-dependent effects of these nanoparticles is essential for their safe application in agriculture. The synthesis of ZNP using environmentally friendly methods has become increasingly important, as conventional chemical synthesis often involves hazardous materials that pose risks to human health and the environment [5]. Green synthesis methods utilize plant extracts as reducing and stabilizing agents, thereby minimizing environmental impact while maximizing the biological activity of the resulting nanoparticles [6]. Among potential plant sources, banana peels (Musa paradisiaca Linn) are particularly appealing due to their rich content of bioactive compounds, such as flavonoids, phenolics, and carotenoids, which can facilitate the synthesis and stabilization of nanoparticles [7]. The present study aimed to explore the green synthesis of ZNPs using banana peel extract (BPE) and evaluate their phytotoxic effects on seed germination in millet (Eleusinecoracana). By employing various characterization techniques, including UV-Vis spectroscopy, Fourier-transform infrared (FTIR) spectroscopy, X-ray diffraction (XRD), scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), and dynamic light scattering (DLS), the study sought to confirm the successful synthesis and properties of the ZNPs. Furthermore, the study examined the effects of different concentrations of ZNP on seed germination and plant growth over a ten-day period, providing insights into their potential application in sustainable agriculture.

The findings of this research not only contribute to the understanding of ZNP synthesis and characterization using plant extracts but also highlight the importance of optimizing nanoparticle concentrations to maximize beneficial effects while minimizing toxicity. This work aligns with the growing body of literature advocating for eco-friendly practices in nanotechnology and agriculture, promoting further exploration of plant-derived materials for nanoparticle synthesis and their potential roles in enhancing crop growth and resilience [8,9].

Materials and methods

Preparation of banana peel extract

The banana peel extract (BPE) was prepared from the half ripened banana [7]. Briefly, the banana peels (*Musa paradisiaca*Linn) were washed and dried overnight to remove excess moisture.

Afterward, the peels were powdered, and 25 grams of the powder were added to 250 milliliters of ultra-pure water in a 400-milliliter beaker. The beaker was covered with aluminum foil and heated at a constant temperature of 70°C for 30 minutes, while being stirred using a magnetic stirrer set at 1000 rpm. Following this, the mixture was filtered to remove the excess banana peel.

Fabrication of Zinc Oxide Nanoparticles

Firstly, 0.1M solution of zinc acetate was prepared in a round-bottom flask [10]. Subsequently, 20 milliliters ofBPEwere mixed with 180 milliliters of the zinc acetate solution in a 1:9 ratio.

The pH of the mixture was then adjusted to 12 using 1M sodium hydroxide. The mixture was boiled at a constant temperature of 70°C for one hour while being stirred with a magnetic stirrer. During this process, the mixture turned yellow, and a white precipitate formed at the bottom of the beaker. After boiling, the precipitate was dried in a hot air oven and stored in a glass bottle for further use.

Phytotoxic effects of ZnO Nanoparticles

Millets seeds (*Eleusinecoracana*) were used to study the seed germination effects of ZNP on the millets which was synthesized from BPE[11]. The millets were initially soaked in distilled water to remove any contaminants. Various concentrations of zinc oxide nanoparticles were prepared, specifically 10 mg/ml, 30 mg/ml, 50 mg/ml, 70 mg/ml, and 90 mg/ml. Approximately 10 millet seeds were evenly placed in a petri dish containing a piece of filter paper.

Different concentrations of the ZNP suspension were then added to moisten the filter paper. The petri dishes were sealed to prevent evaporation. The analysis was conducted in triplicate, and the number of seeds that germinated was counted over a period of 10 days. At the end of the 10th day, the lengths of both the roots and shoots were measured.

Characterization of Zinc oxide nanoparticles using UV-Vis spectroscopy

The UV-Vis spectroscopy was used to characterize ZNP [7]. First, the synthesized nanoparticles were dispersed in ultra-pure water to create a stable suspension.

A UV-Vis spectrophotometer was calibrated using ultra-pure water as a blank. The sample suspension was then placed in a quartz cuvette, and the absorbance spectrum was recorded over a wavelength range of 200 to 800 nm.

Characterization of ZNP using Fourier-transform infrared (FTIR) spectroscopy

The characterization of zinc oxide nanoparticles was performed using Fourier-transform infrared (FTIR) spectroscopy [12]. First, the dried ZNP were mixed with potassium bromide (KBr) in a 1:100 ratio to create a pellet. This mixture was then pressed into a thin disc using a hydraulic press. The FTIR spectrometer was calibrated, and the background spectrum was recorded. The KBr pellet containing the ZNP was placed in the sample holder, and the FTIR spectrum was acquired over a wavenumber range of 400 to 4000 cm^{-1}.

Characterization of ZNP using XRD

The characterization of ZNP was conducted using X-ray diffraction (XRD) [13]. First, the synthesized nanoparticles were carefully ground into a fine powder to ensure uniformity. A small amount of the powder was then placed on a glass sample holder. The XRD equipment was calibrated, and the scan parameters were set to a 2θ range of 20° to 80°, with a scanning rate of 2° per minute. The sample was subjected to X-ray radiation, and the diffraction pattern was recorded.

Characterization of ZNP using SEM

The characterization of ZNP was performedusing scanning electron microscopy (SEM)[14].

Characterization of Zinc oxide nanoparticles using EDX and DLS

The characterization of ZNP using Energy dispersive x-ray analysis (EDX) and Dynamic light scattering (DLS) was performed [15].

Results

Preparation of banana peel extract

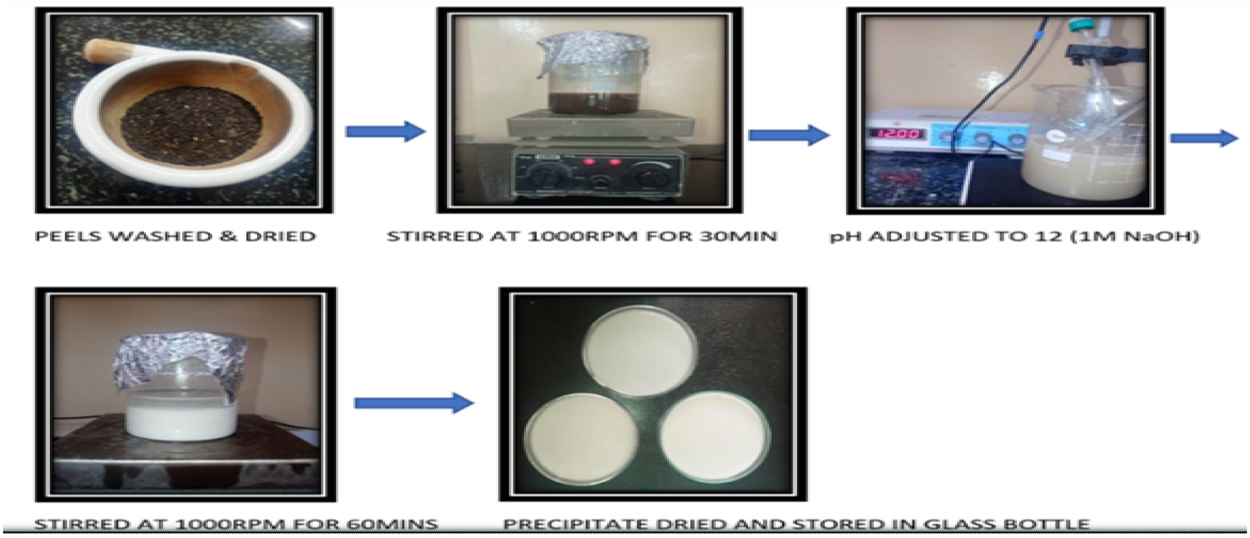

Figure 1. Preparation of banana peel extract

The resulting extract exhibited a deep yellow color and a characteristic aroma, indicating the successful extraction of bioactive compounds from the banana peels (Figure 1).

Synthesis of ZnO Nanoparticles and confirmation through UV vis spectroscopy

The intensity of the absorption peaks correlated with the concentration of nanoparticles formed. The ZNP synthesized from banana peel extract were analyzed using a UV-Visible spectrophotometer in the wavelength range of 190 to 1100 nm. The spectra displayed distinct absorption characteristics, with the maximum absorption peaks observed between 190 and 265 nm (Figure 2).These peaks indicate the presence of ZNP and are consistent with the expected optical properties of these materials. The peak at approximately 200 nm suggests the formation of zinc oxide, while the shifts in absorption at higher wavelengths indicate the influence of the organic components present in the banana peel extract, which may stabilize the nanoparticles during synthesis.

Figure 2. UV-Vis Spectroscopy analysis confirming the presence of ZNP

Confirmation of ZNP through FTIR

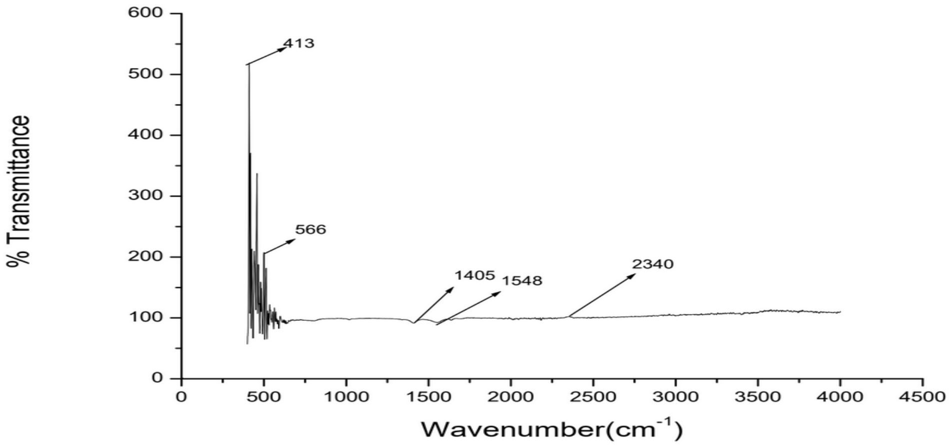

Figure 3. FTIR spectrum confirming functional group presence in ZNP

The analysis of the green-synthesized zinc oxide nanoparticles (ZnO NPs) from banana peel extract was conducted using Fourier Transform Infrared (FTIR) spectroscopy, covering a range from 400 cm^{-1} to 4000 cm^{-1}. The resulting spectra revealed several significant absorption peaks, specifically at 2340 cm^{-1}, 1548 cm^{-1}, 1405 cm^{-1}, 566 cm^{-1}, and 413 cm^{-1}. The peak at 2340 cm^{-1} was attributed to C≡C stretching vibrations, indicating the presence of alkynes or other unsaturated carbon compounds in the banana peel extract that may have played a role in stabilizing the nanoparticles during synthesis (Figure 3). The peaks at 1548 cm^{-1} and 1405 cm^{-1} corresponded to C=C stretching vibrations, which further supports the presence of various organic compounds in the extract. These organic molecules can contribute to the stabilization and functionalization of the ZNPs, enhancing their properties for various applications. Additionally, the peaks at 566 cm^{-1} and 413 cm^{-1} are characteristic of Zn-O stretching vibrations, confirming the successful formation of ZnO. These vibrations indicate the crystalline nature of the synthesized nanoparticles, which is essential for their desired properties

Confirmation of ZNP through XRD

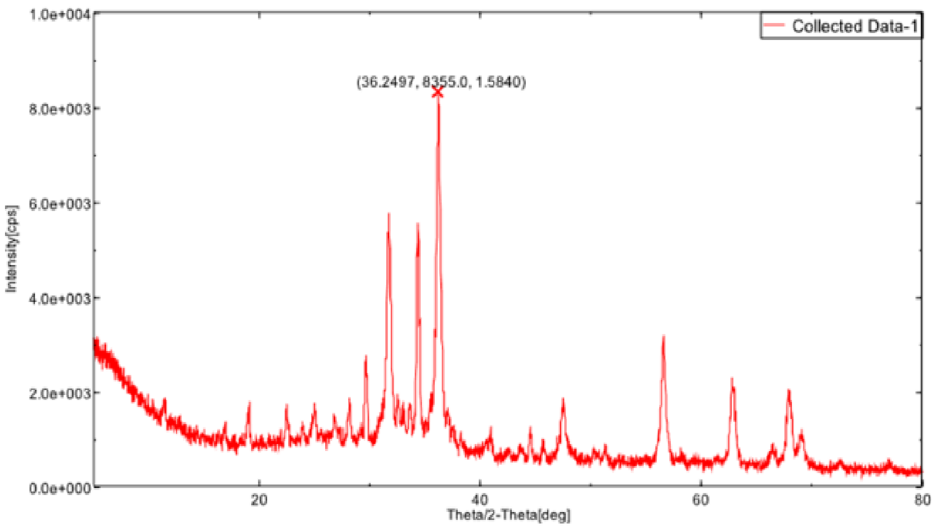

Figure 4. X-ray Diffraction analysis confirms the crystalline nature of the ZnO nanoparticles.

The XRD (X-ray Diffraction) pattern shown in the image confirms the crystalline nature of the ZnO nanoparticles produced from banana peel extract. The peaks observed in the graph correspond to specific planes of ZnO, typically indexed to standard ZnO crystal planes, indicating the presence of hexagonal wurtzite structure of ZnO (Figure 4). The sharp and intense peaks imply that the nanoparticles are well-crystallized. The peak around 36 degrees (likely corresponding to the (101) plane) is a characteristic peak for ZnO nanoparticles, and it's commonly used as confirmation of ZnO formation in XRD studies. The intensity and position of peaks in the XRD pattern align with the reference pattern for ZnO, thereby confirming the successful synthesis of ZnO nanoparticles. This result supports the formation of ZnO nanoparticles from the banana peel extract as a green synthesis method.

Confirmation of ZNP through SEM

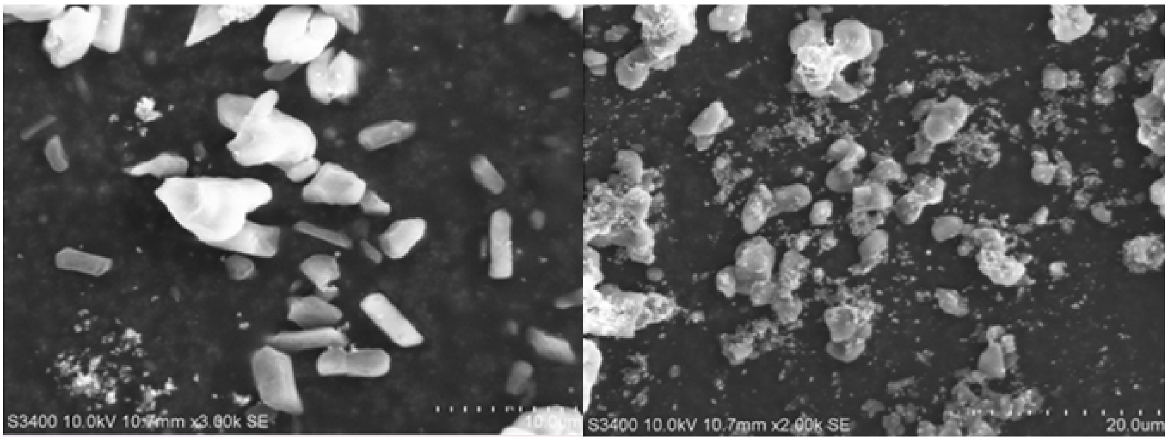

Figure 5. SEM analysis shows the structural characteristics of ZNP

The scanning electron microscopy (SEM) analysis was conducted to elucidate the structural characteristics of the ZNP synthesized from banana peel extract. The SEM images revealed a predominantly rod-shaped morphology, with individual nanoparticles clearly discernible (Figure 5). The presence of distinct rod-shaped particles, the images also indicated the formation of aggregates, suggesting that the nanoparticles tended to cluster together during synthesis.

Confirmation of ZNP through EDX and DLS

The energy-dispersive X-ray spectroscopy (EDX) analysis was performed to ascertain the elemental composition of the synthesized ZNP derived from banana peel extract. The EDX results confirmed that the samples predominantly contained pure ZnO phases, affirming the successful synthesis of the nanoparticles. The analysis distinctly identified the presence of both zinc (Zn) and oxygen (O) in the samples, as illustrated in the accompanying graphs (Figure 6b). The elemental composition quantified via EDX revealed that the synthesized ZnO nanoparticles contained approximately 32.88% zinc and 67.12% oxygen (Figure 6a).

Quantitative Results for: Base(977)

Element Line	Weight %	Weight % Error	Atom %
O K	67.12	± 1.25	89.30
Zn K	32.88	± 4.38	10.70
Zn L	---	---	---
Total	100.00		100.00

Figure 6a. The composition of ZNP in EDX analysis

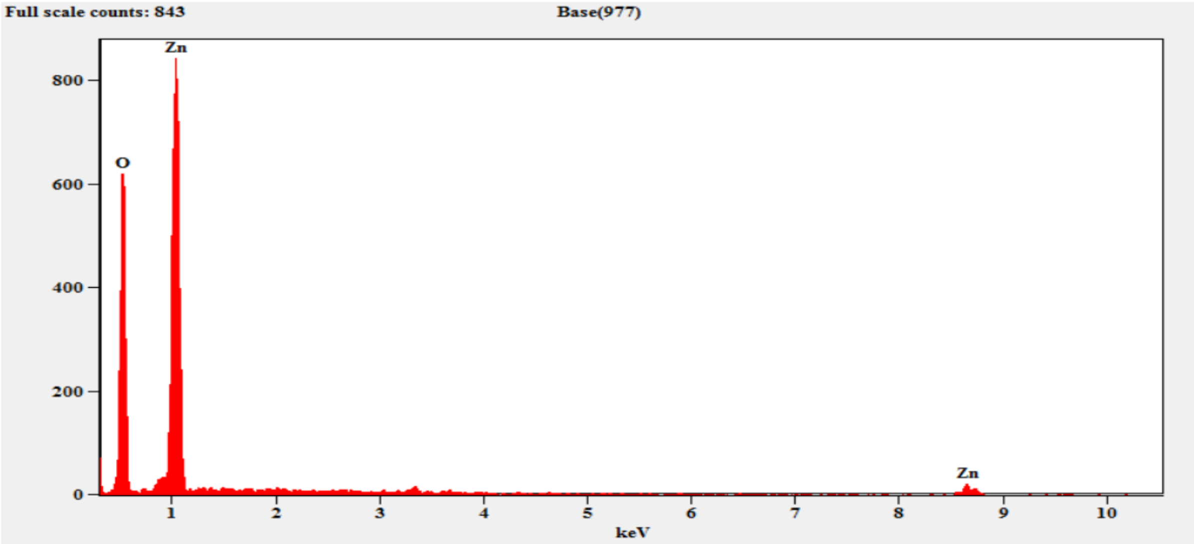

Figure 6b. EDX analysis of ZNP

Dynamic Light Scattering (DLS) measurements were conducted to determine the size distribution and average diameter of the ZNP synthesized from BPE. The DLS analysis revealed that the average diameter of the synthesized ZnO nanoparticles was found to be 102.5 nm (Figure 7).

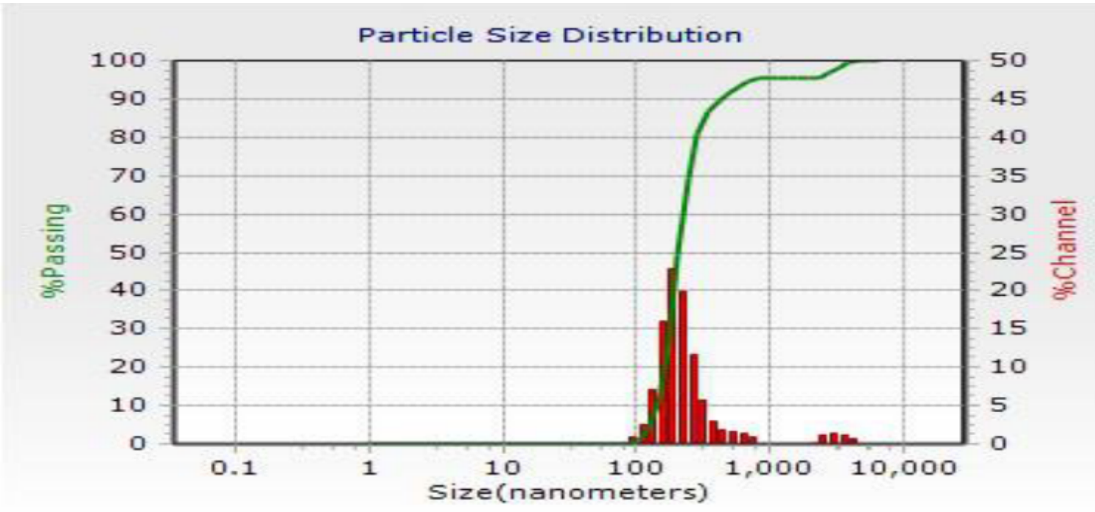

Figure 7. Dynamic Light Scattering (DLS) analysis indicates the average size of ZNP

Effects of ZNP on seed germination

The effect of ZNP synthesized from banana peel extract on seed germination and growth was analyzed over a period of 10 days. All tested concentrations of ZNP demonstrated an increase in germination percentage (Figure 8a), as well as improvements in root and shoot lengths, indicating a positive influence of the nanoparticles on plant growth (Figure 8b). Among the various concentrations tested, 30 mg/L ZNP exhibited the highest seed germination percentage, reaching 43.33%. In contrast, the 90 mg/L concentration resulted in the lowest germination percentage of 23.33%, which was significantly lower than the control group that achieved a germination rate of 36.66% (Figure 8c).

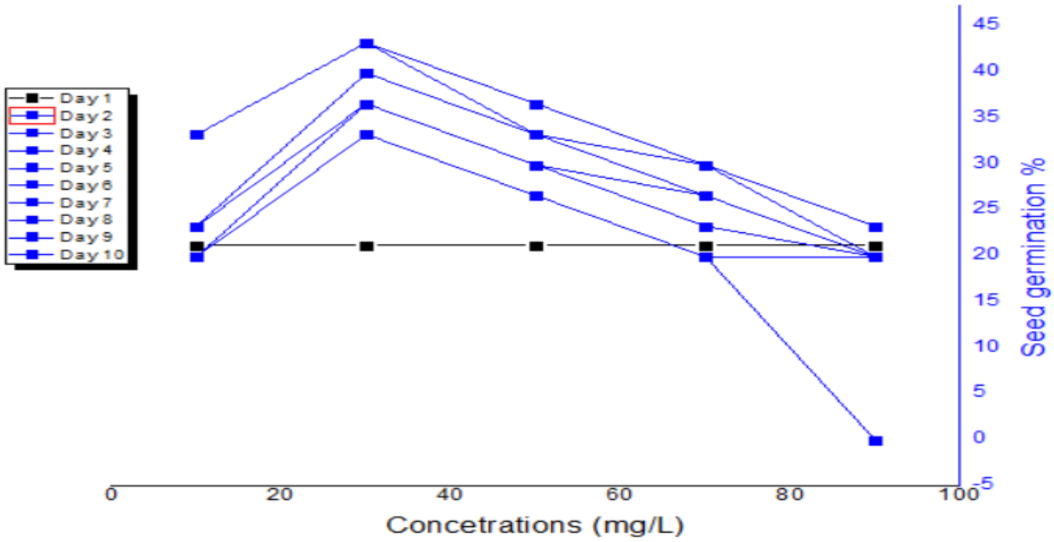

Figure 8a. Effects of different concentration of ZNP on seed germination

This suggests that the higher concentration of ZNP may inhibit germination to some extent, potentially due to toxicity or stress induced by elevated nanoparticle levels. The root and shoot lengths also reached their maximum growth at the 30 mg/L concentration, indicating that this level of ZNP optimally supported plant development.

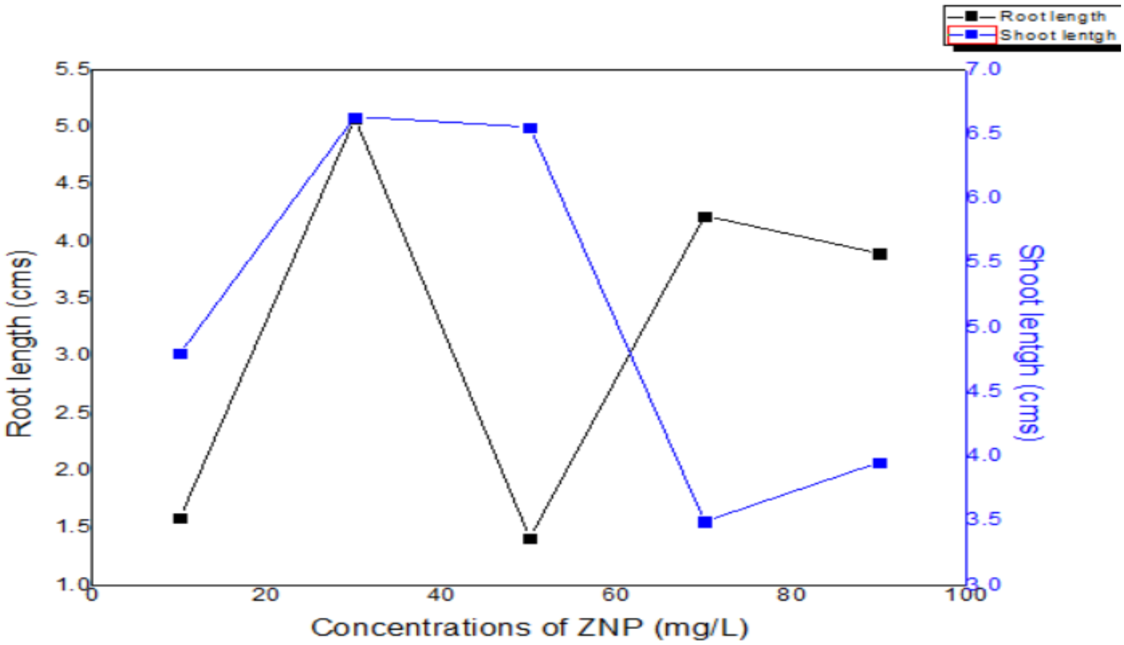

Figure 8b-Root and shoot length of germinated seeds of millets treated with ZNP

In comparison, at 70 mg/L, notable fungal contamination was observed on millet treatments, which may have affected the overall growth and viability of the plants at that concentration.

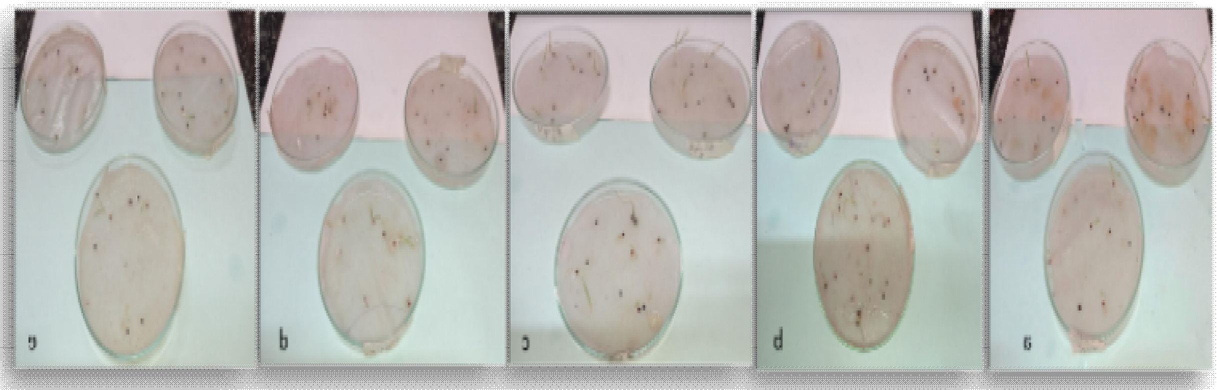

Figure 8c (a-e). Effects of ZNP on millet seed. a-10 mg/L, b-30mg/L, c-50mg/L, d-70mg/L, e-90mg/L.

Discussion

The study successfully demonstrated the green synthesis of zinc oxide nanoparticles (ZNP) using banana peel extract (BPE), highlighting both the synthesis process and the subsequent effects on seed germination. The preparation of BPE yielded a deep yellow solution, indicative of the extraction of bioactive compounds, which played a critical role in stabilizing the synthesized nanoparticles. Characterization techniques such as UV-Vis spectroscopy confirmed the formation of ZNP through distinct absorption peaks in the range of 190 to 265 nm, suggesting the active involvement of organic compounds in the stabilization process [16]. Fourier-transform infrared (FTIR) spectroscopy further supported these findings by identifying key absorption peaks corresponding to C≡C and C=C stretching vibrations, indicating the presence of various organic compounds in the extract that likely contributed to the functionalization of the nanoparticles [17]. X-ray diffraction (XRD) analysis confirmed the crystalline nature of the ZNP, showing sharp peaks consistent with the hexagonal wurtzite structure characteristic of ZnO [18]. Additionally, scanning electron microscopy (SEM) images revealed a predominantly rod-shaped morphology with some aggregation, suggesting the nanoparticles' tendency to cluster, which has implications for their behavior in biological systems [19, 20,21]. Energy-dispersive X-ray spectroscopy (EDX) analysis further validated the elemental composition of the ZNPs, showing a composition of 32.88% zinc and 67.12% oxygen, thus affirming the purity of the synthesized material [22]. Dynamic Light Scattering (DLS) measurements indicated that the average size of the ZNPs was approximately 102.5 nm, placing them within the expected range for nanoparticles and suggesting potential applications in agriculture [23]. The phytotoxicity assessment revealed that lower concentrations of ZNPs (30 mg/L) significantly enhanced germination rates and root and shoot lengths in millet seeds, aligning with findings from previous studies that have reported positive effects of nanoparticles on plant growth. However, higher concentrations (90 mg/L) inhibited germination, indicating potential toxicity likely due to stress induced by elevated nanoparticle levels[24]. This observation corroborated earlier research that highlighted the dual effects of nanoparticles on plant development, where low doses promoted growth while high doses resulted in detrimental effects [25,26]. The detection of fungal contamination at a concentration of 70 mg/L further emphasized that specific nanoparticle levels could disrupt plant health, underscoring the importance of careful concentration management in agricultural applications[27]. Overall, the study underscored the potential of using banana peel extract for the eco-friendly synthesis of ZNPs, demonstrating their beneficial effects on seed germination at optimal concentrations. These findings contribute to the growing body of literature advocating for sustainable practices in nanotechnology and agriculture, encouraging further exploration of plant-derived materials for nanoparticle synthesis and their potential applications in enhancing crop growth and health.

Conflict of Interest

No conflict

Authors Contributions

SM conceptualized the study and supervised the research; AVS synthesized zinc oxide nanoparticles and performed characterization conducted phytotoxicity experiments. MJR assisted with the literature review and statistical analysis support.

Acknowledgment:

We acknowledge department of Botany, Mount Carmel College for providing facilities to carry out this study.

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