RESEARCH PAPER

Phyto-Assisted Synthesis Of Zinc Oxide Nanoparticles Using Raw Banana (*Musa Paridisoca* L.) Fruit Peel Extract And Their Assessment Of Antibacterial Activity

Aryaman Singh[1], Sekhar Tiwari[2*], Manoj Pallakandi[3], Ashutosh Kumar[2], Anish Kumar Sharma[2], Vimal Patel[4], Shivangiben Baldha[5], Aditee Pandya[5], Nisha Choudhary[6], Vinod Prabhu[7], Himanshu Singh[8]

[1]Datum Laboratories, 103, Yogi Estate Road-4, Near GEB Substation, GIDC, Ankleshwar-393002

[2*]Department of Biotechnology, School of Sciences, P P Savani University, Dhamdod, Dist- Surat, Gujarat, India-394125

[3]School of Biosciences and Technology, VIT, Vellore- 632014 TamilNadu, India

[4]School of Pharmacy, P P Savani University, Dhamdod, Dist- Surat, Gujarat, India-394125

[5]Department of Microbiology, School of Sciences, P P Savani University, Dhamdod, Dist- Surat, Gujarat, India-394125

[6]Chemical Engineering, Marwadi University, Rajkot, Gujarat, India

[7]Department of Research, Chettinad Hospital and Research Institute, Chettinad Academy of Research and Education, Kelambakkam, Tamil Nadu, 603103, India

[8]Department of Chemistry, School of Sciences, P P Savani University, Dhamdod, Dist- Surat, Gujarat, India-394125

ABSTRACT

Green synthesis of zinc oxide nanoparticles (ZnO NPs) using plant extracts is an eco-friendly and sustainable alternative to conventional methods. Raw banana peel contains phytochemicals that can act as natural reducing and capping agents. ZnO nanoparticles were synthesized using aqueous extract of raw banana peels and zinc sulphate heptahydrate ($ZnSO_4 \cdot 7H_2O$). The nanoparticles were characterized by UV-Vis spectroscopy, X-ray diffraction (XRD), Fourier transform infrared (FTIR) spectroscopy, and field emission scanning electron microscopy (FESEM). Antibacterial activity was assessed against *Escherichia coli* and *Pseudomonas aeruginosa*. UV-Vis analysis showed a characteristic absorption peak at 380 nm, confirming ZnO nanoparticle formation. XRD revealed a hexagonal wurtzite crystalline structure with an average crystallite size of 30.41 nm. FTIR confirmed the involvement of phytochemicals in nanoparticle synthesis. The synthesized ZnO nanoparticles exhibited antibacterial activity with inhibition zones of 5.20 mm against *E. coli* and 5.00 mm against *P. aeruginosa*.

Keywords: Antibacterial activity, Raw banana peel; ZnO nanoparticles, *Escherichia coli*, *Pseudomonas aeruginosa*

How to cite this article: Singh A, Tiwari S, Pallakandi M, Kumar A, Sharma A K, Patel V, Baldha S, Pandya A, Choudhary N, Prabhu V, Singh H. Phyto-Assisted Synthesis Of Zinc Oxide Nanoparticles Using Raw Banana *(Musa Paridisoca* L.) Fruit Peel Extract And Their Assessment Of Antibacterial Activity. Int J Drug Deliv Technol. 2026;16(79s):687-694. DOI: 10.25258/ijddt.16.79s.130

Source of support: Nil

Conflict of interest: None

1. INTRODUCTION

Nanoparticles, now a days has been a topic of research owing to their remarkable properties and utilization in numerous applications ranging from food, medicines and agriculture.1 Among the various routes for green synthesis of nanoparticles, phytosynthesis has emerged as a quick and sustainable method for capping and reduction of nanoparticles owing to formation of primary and secondary metabolites such as amino acids, polysaccharides, group of polyphenolic compounds comprised of flavanoids, terpenoids, alkaloids etc.2 Synthesis of zinc oxide (ZnO) nanoparticles has shown favourable potential in numerous applications including photocatalysis, antimicrobial, dietary supplement, biomedical applications, cosmetics, well as food additives and packaging. 3-4 The phytosynthesis of ZnO nanoparticles employing green synthesis route has been reported by many investigators. Reduction of zinc acetate dihydrate using leaf extracts of *Deverra tortuosa* has been reported.5 Similarly, phyto-assisted formation of ZnO nanoparticles was reported through fruit peels including those of *Punica granatum* 6, *Mangifera indica* 7, *Citrus sinensis* 8 and different species of banana like *Musa sapientum* 9-10, *Musa acumniata* 11-13, *Musa paradisiaca* 12. Banana, a widely consumed horticultural crop is a rich source of nutrients is consumed as a fruit in ripe form across the countries and as a part of traditional foods in parts of African Great Lakes and South-eastern Asian regions including North Eastern part of India 14-15. Its peels are discarded as a waste which contain substantial quantities of phytochemicals that could be utilized for nanoparticle synthesis. Although, mostly synthesis of ZnO nanoparticles using ripe banana peels derived from different species of banana have been reported, the present work was endeavoured with specifically with raw banana peels (unripe) derived from *Musa paradisica* L. for synthesis of ZnO nanoparticles. Since, variations in chemical composition in different grades of peels (unripe and ripe) of different species of banana may influence the ability to facilitate the synthesis of nanoparticles, as different compounds might serve as a better reducing or stabilizing agents depending on their chemical structure. Moreover, exploring the antibacterial efficacy of ZnO nanoparticles synthesized from raw banana peels (unripe) can provide insights into their suitability for diverse applications in various sector.

2. MATERIALS AND METHODS

Raw (unripe) peels were collected from bananas from the local fruit market, Bharuch Gujarat. Zinc sulphate heptahydrate ($ZnSO_4.7H_2O$) was purchased from HiMedia, India with analytical grade. All the experiments were carried out using distilled water purchased from the company i.e., VITSZEE, Chennai.

2.1 Preparation of raw (unripe) banana peel extracts & synthesis of nanoparticles

Preparation of unripe banana peel extracts & synthesis of nanoparticles was done following protocol12 with slight modifications (Fig.1).

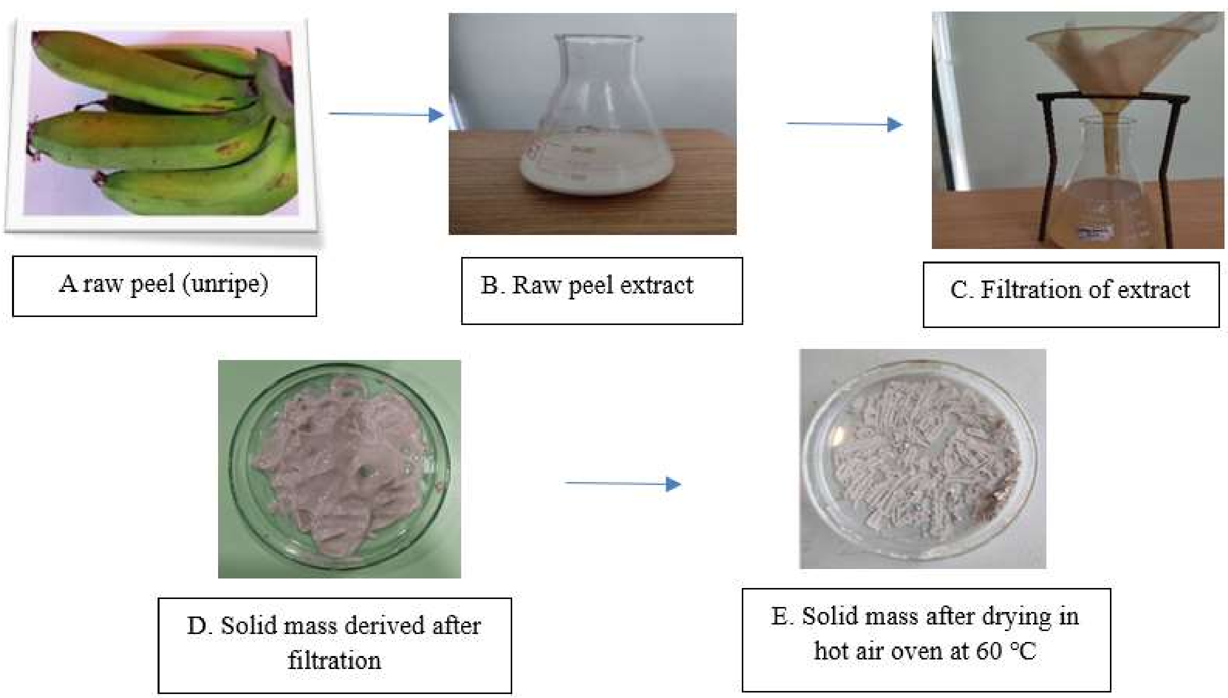

Figure 1. Schematic illustration of ZnONP preparation using raw (unripe) banana peel

2.2 Nanoparticle characterization

The synthesized particles were subjected to UV-visible spectroscopy (GENESYSTM 10S UV-Vis, Thermo-Fisher Scientific, USA). The crystalline structure of ZnO nanoparticles was determined using XRD (Rigaku MiniFlex 600, Netherlands). FTIR spectroscopy was rigorously performed using an instrument (Spectrum, S6500, Perkin Elmer, USA). The morphology and size of the nanoparticles was evaluated with FE-SEM (EVO 18 Research, Germany).

2.3 Assessment of antibacterial effect against *E. coli* & *P. aeruginosa*

The antibacterial assay was performed using standard disc diffusion method. Luria Broth Agar was prepared and autoclaved at 121^0C for 15 minutes and then the media was poured onto the petri plate in the Laminar Air Flow bench (Lab Fit, UK) and kept under 30 minutes for solidification. Simultaneously, 0.5 % soft agar in LB was also prepared and was autoclaved at 121^0C. Then bacterial stock culture (0.2 ml inoculum) of *E. coli* was added into soft agar and then poured over the LB agar plates. Similarly, separate bacterial culture (0.2 ml inoculum) of *Psudomonas aeruginosa* was added on separate soft agar and was poured onto LB plates. The time duration for solidification of LB plates was about 30 minutes. Following 30 minutes of solidification, Whattman filter discs were dipped into 0.005 mg/ml nanoparticle suspension solutions for about 30 minutes. Following 30 minutes, the discs were taken out by sterile forceps and were kept onto LB culture plates of *E. coli* and *P. aeroginosa* and pressed lightly. Subsequently, plates were sealed with paraffin tapes and incubated at 37^0C for about 24 hours. Following incubation for 24 hours, zone of inhibition was evaluated.

3. RESULTS AND DISCUSSION

Synthesis of ZnO using raw (unripe) banana peel extract is a promising approach that highlights the role of natural compounds found in banana peels as capping and reducing agents. This technique is eco-friendly and cheap making it an alternative to conventional chemical synthesis methods. This process involves use of banana peel extract to reduce zinc salts, such as zinc acetate in ZnO NPs, followed by thermal treatment to increase the stability and crystallinity in the ZnO NPs. The banana peel extract containing various phytonutrients like polyphenols, flavonoids, and alternative organic compounds acts as a reducing agents that convert zinc ions into ZnO NPs.

3.1 Nanoparticle characterization

UV-visible spectroscopy

Using UV-visible spectroscopy, the measurement was done at a scanning range of 300 nm-800 nm. Sample peaks were observed at 380 nm (Figure 2) serving as critical side of evidence that confirms the synthesis for ZnO nanoparticles which is in agreement with several reports 7, 16-18

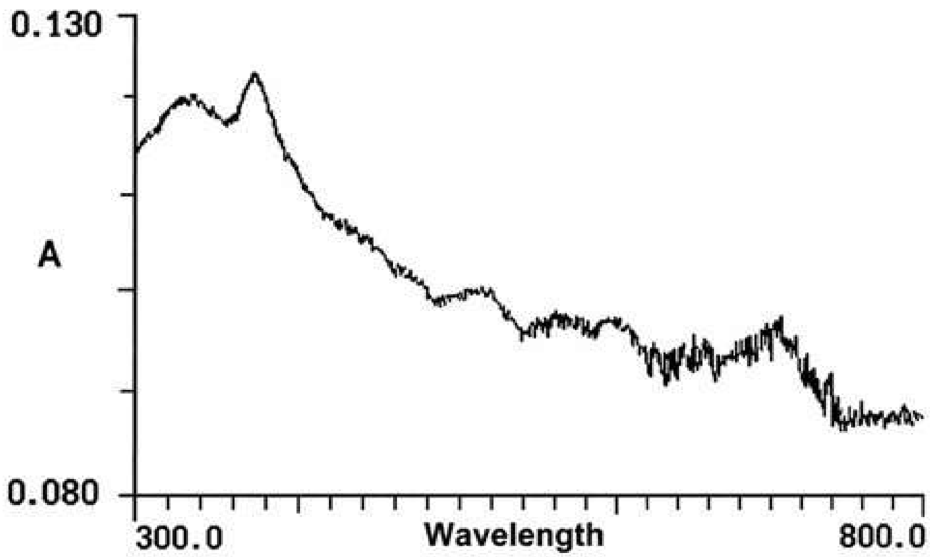

Figure 2. UV-visible spectral analysis of green synthesized ZnO nanoparticles derived using extract of raw (unripe) banana peels

3.2 XRD

The crystalline structure of ZnO nanoparticles synthesized from extract was determined using XRD (Rigaku MiniFlex 600, Netherlands) equipped with an X'celerometer for identification of crystallinity and the data was plotted by using software (OriginPro, 2024). The diffraction pattern recorded the 2-theta range from 20–80 by through a filter K-beta (x1) with scanning speed/duration time: 10.0 degree/min., s 30 kV voltage, and a current of 2 mA. The crystallite size of ZnO nanoparticles was calculated by using the Scherrer formula ($D=k\lambda/\beta Cos\theta$; where, D is crystalline size, k = constant (0.9), and β = the FWHM values of the diffracted peaks) which was found to be 30.41nm. The XRD pattern (Figure 3) showed typical bands at 2 theta peaks, 31.0, 34.0, 36.0, 47.0, 56.0, 63.0, 68.0 and 69.0º. Out of all these peaks, the major and sharp intensity peaks were observed at 36.0º followed by 31.0 and 34.0º. This pattern of diffraction peaks aligns with the phase of standard ZnO, specifically JCPDS card no. 36-1451, corresponding to the hexagonal wurtzite structure with lattice planes (100), (002), (101), (102), (110), (103), and (112). In the current study, the three strongest peaks were detected at 31.8, 34.5, and 36.4, demonstrating close agreement with the findings 19. The distinct and sharp peaks indicated the purity and crystalline nature of the phytonano fabricated ZnO particles. Similar peaks were also obtained at 2θ = 31.50°, 34.01°, 36.07°, 47.01°, 56.34°, 62.67°, 66.01°, 67.51°, 69.22°, and 76.91° correspond to the crystallographic planes of (100), (002), (101), (102), (110), (103), (200), (112), (201), and (202), respectively for the ZnO NPs synthesized from scallion peel 20.

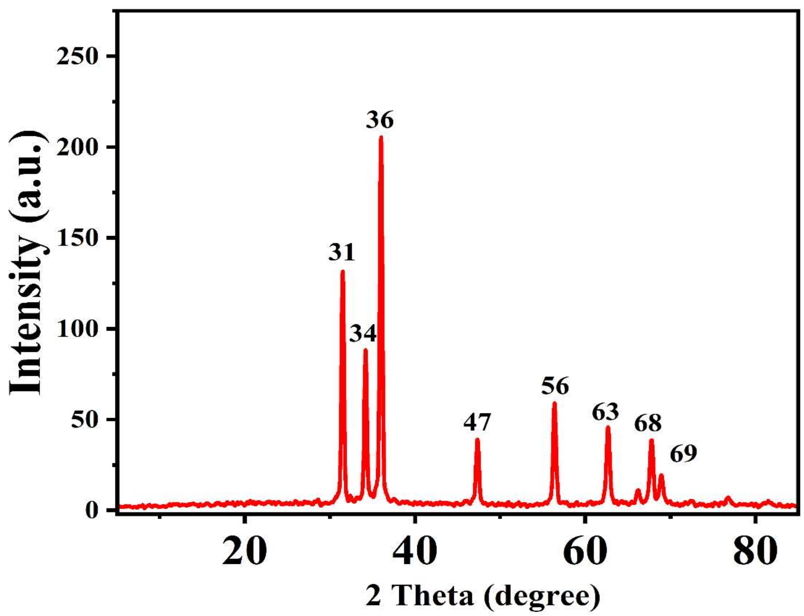

Figure 3. XRD pattern of green synthesized ZnONPs showing sharp peaks

3.3 FTIR

Within the FTIR spectrum, ZnO nanoparticles recorded at a scale from 4000-400 cm-1, is depicted in Fig 4. From the spectrum, different distinct bands and peaks were identified, clarifying chemical composition and functional groups present in synthesized ZnO nanoparticles. Specially, the peaks observed within the scale from 400 to 700 cm^{-1} i.e., fundamentally attributed towards stretching modes for ZnO, revealing their characteristic vibrations associated within matter which is in agreement with 8. Furthermore, this spectrum exhibited a prominent peak at 1049 $cm^{-1,}$ corresponding the stretching vibrations for C-O bonds generally present in polysaccharides, carbohydrates, glycosides, alcohols and phenols**.** Additional peaks at definite wave numbers gave information about the composition of nanoparticles. Further, peak at 3738 cm^{-1} indicates O-H stretching due to presence of free hydroxyl ion(O-H) groups in alcohols or phenols. Similarly, the workers 7 reported the presence of O-H bonds indicating the entanglement of phenolic compounds in the phyto-assisted synthesis of ZnO nanoparticles. Peak at 3461 cm^{-1} indicated O-H stretching (hydrogen-bonded) representing O-H stretching vibrations in hydroxyl groups that are involved in hydrogen bonding common in alcohols, phenols. Similarly, peak at 3090 cm^{-1} indicated C-H stretching associated with aromatic compounds. Peak at 1520 cm^{-1} indicating C=C stretching vibrations in aromatic compounds particularly associated with nitro or other substituents. Specific bands and peaks in FTIR spectrum offered clue for functional groups and additive-free molecules involved in the bio reduction process, contributing an extensive explanation about formation of ZnO nanoparticles.

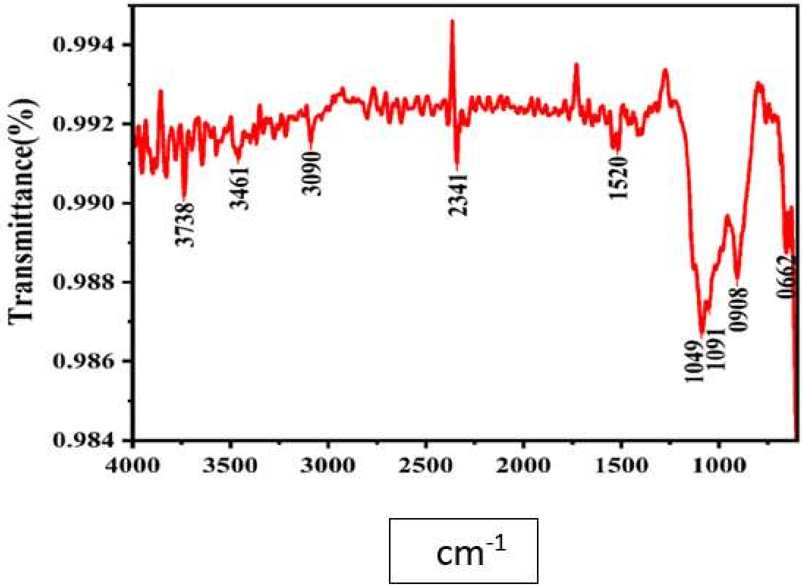

Figure 4. FTIR spectra for green synthesized ZnONPS showing functional groups

3.4 Morphology, size and charge of zinc oxide nanoparticles

Using FESEM, surface-based morphology analysis for ZnONPs was done (Figure 5). The investigation revealed agglomeration of nanoparticles. FESEM micrographs depicted the nano crystals in ZnONPs shown were rod shaped, spherical shaped and hexagonal at specific magnifications.

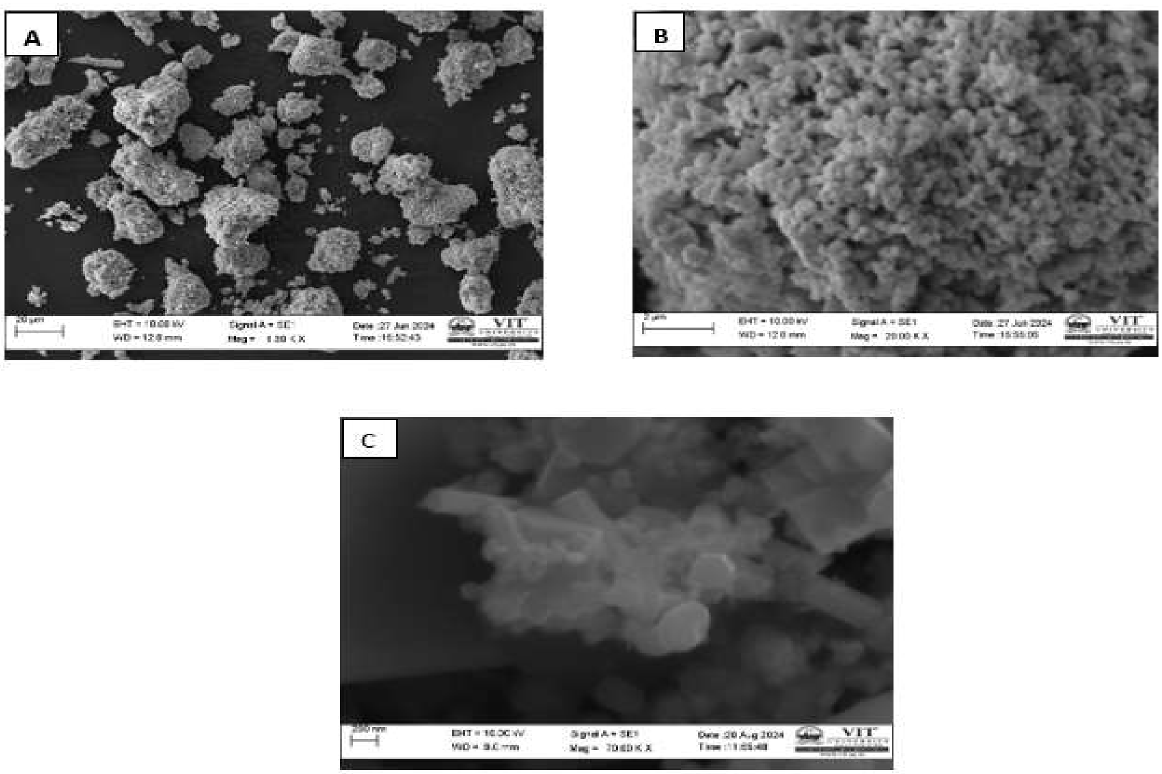

Figure 5. Scanning electron microscope for ZnONPs (A), (B), (C) with specific magnifications exhibiting its crystalline shape

3.5 Assessment of antibacterial activity

The phyto-syththesis of ZnO nanoparticles confirmed the positive reaction that was indicated by the clear zone around the well. The inhibition zones were found to be 5.20 mm on *E. coli* and 5.0 mm on *P. aeroginosa* respectively. Mechanism of antibacterial activity for biosynthesized ZnO nanoparticles ascribed the adherence of nanoparticles into bacterial cell wall that caused disruption of membrane, and lysis of cell 21-23.

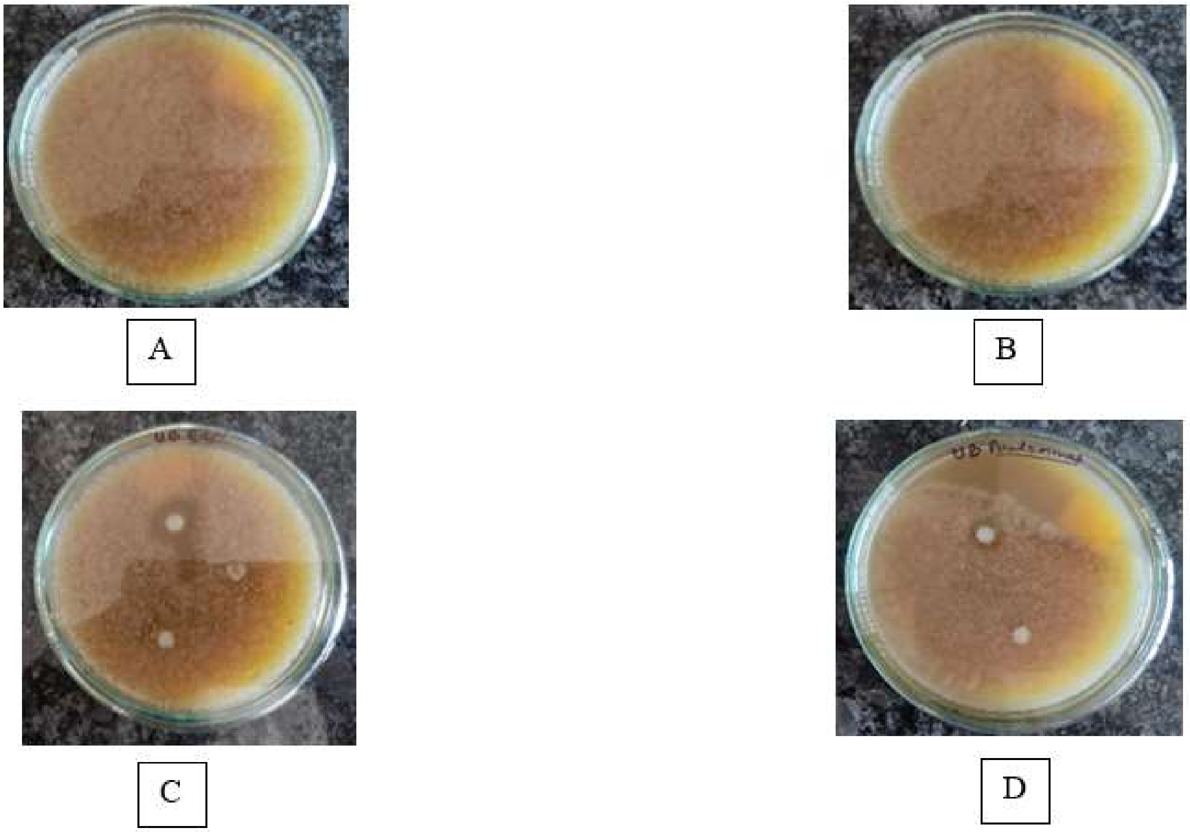

Figure 6. (A) Control culture of *Escherichia coli* (B) Control culture of *Pseudomonas aeruginosa*. (C) Zone of inhibition exhibited by ZnONPs on *E. coli*. (D) Zone of inhibition exhibited by ZnONPs on *P. aeruginosa*

4. CONCLUSION

ZnO nanoparticles were prepared through green synthesis route employing raw (unripe) banana peel extract. Presence of unique peaks at 380 nm in the UV-visible spectrum confirmed the synthesis of ZnO nanoparticles. The hexagonal wurtzite structure for biosynthesized ZnO was confirmed through XRD and the nano size of ZnO was confirmed by FESEM evaluation. The FTIR spectrum revealed that range of chemicals like polysaccharides, carbohydrates, glycosides, alcohols and phenols and aromatic substances could be involved in the biosynthesis process. The study demonstrated raw (unripe) banana peel could be used sustainably for eco-friendly synthesis of ZnO nanoparticles.

ACKNOWLEDGEMENTS

The authors are thankful to P P Savani University, Surat.

Funding Sources

The work was not funded.

Conflict of Interest

The authors declare that there is no conflict of interest.

REFERENCES

1. Tiwari S, Verma SK, Bhagat P, Yadav S, Sharma R, Aseri G, et al. An overview of the phytosynthesis of various metal nanoparticles. 3 Biotech. 2021;11(11):478. DOI: 10.1007/s13205-021-03014-0.

2. Ali MA, Ahmed T, Wu W, et al. Advancements in plant and microbe-based synthesis of metallic nanoparticles and their antimicrobial activity against plant pathogens. Nanomaterials. 2020;10(6):1146. DOI: 10.3390/nano10061146.

3. Hussien NA, Al Malki JS, Al Harthy FAR, Mazi AW, Al Shadadi JAA. Sustainable eco-friendly synthesis of zinc oxide nanoparticles using banana peel and date seed extracts, characterization, and cytotoxicity evaluation. Sustainability. 2023;15(13):9864. DOI: 10.3390/su15139864.

4. Fujihara J, Nishimoto N. Review of zinc oxide nanoparticles: toxicokinetics, tissue distribution for various exposure routes, toxicological effects toxicity mechanism in mammals, and an approach for toxicity reduction. Biol Trace Elem Res. 2023. DOI: 10.1007/s12011-023-03644-w.

5. Selim YA, Azb MA, Ragab I, Abd El-Azim M. Green synthesis of zinc oxide nanoparticles using aqueous extract of Deverra tortuosa and their cytotoxic activities. Sci Rep. 2020;10:1-9. DOI: 10.1038/s41598-020-60541-1.

6. Ozcakir G. Green synthesis of zinc oxide nanoparticles using pomegranate peels: an overview. Eng Proc. 2023;56(1):12. DOI: 10.3390/ASEC2023-15280.

7. Endah ES, Saraswaty V, Ratnaningrum D, Kosasih W, Ardiansyah A, Risdian C, et al. Phyto-assisted synthesis of zinc oxide nanoparticles using mango (Mangifera indica) fruit peel extract and their antibacterial activity. IOP Conf Ser Earth Environ Sci. 2023;1201(1):012081. DOI: 10.1088/1755-1315/1201/1/012081.

8. Sumithranand VB, Roxy MS, Vaishnavi G. Green synthesis of ZnO nanoparticles using sweet orange peels and their antibacterial properties. Orient J Chem. 2024;40(2). DOI: 10.13005/ojc/400221.

9. Ruangtong J, Jiraroj T, Thienprasert NP. Green synthesized ZnO nanosheets from banana peel extract possess antibacterial and anticancer activity. Mater Today Commun. 2020;24:101224. DOI: 10.1016/j.mtcomm.2020.101224.

10. Fernanda OD, Putri TF, Marfuah S, Aliyatulmuna A, Fajaroh F. Utilization of banana peel extracts in the synthesis of ZnO nanoparticles. AIP Conf Proc. 2021;2330:070004. DOI: 10.1063/5.0043386.

11. Sin JC, Ong KW, Lam SM, Zeng H. Musa acuminata peel extract mediated eco-friendly synthesis of solar light-active ZnO nanosponge for enhanced dyeing wastewater degradation. E3S Web Conf. 2020;167:01003. DOI: 10.1051/e3sconf/202016701003.

12. Marfu'ah S, Rohma SM, Fanani F, Hidayati EN, Nitasari DW, Primadi TR, et al. Green synthesis of ZnO nanoparticles using banana peel extract as capping agent and its antibacterial activity. IOP Conf Ser Mater Sci Eng. 2020;833(1):012076. DOI: 10.1088/1757-899X/833/1/012076.

13. Al-Khaial MQ, Chan SY, Abu-Zurayk RA, Alnairat N. Biosynthesis and characterization of zinc oxide nanoparticles (ZnO-NPs) utilizing banana peel extract. Inorganics. 2024;12(4):121. DOI: 10.3390/inorganics12040121.

14. Tsatsenko NA, Kakunze AC, Tsatsenko LV, Mbonihankuye C. A review of traditional foods produced from the banana plant: evidence from Asia and Africa. In: Samoylenko I, Rajabov T, editors. Innovations in Sustainable Agricultural Systems, Agriculture 4.0 and Precision Agriculture. Cham: Springer; 2025. DOI: 10.1007/978-3-031-94098-9_10.

15. Sarma U, Govila VK, Yadav A. Traditional and therapeutic use of banana and plant-based delicacies in Assamese cuisine and rituals. J Ethn Foods. 2020;7(1):21. DOI: 10.1186/s42779-020-00053-5.

16. Guzman O, Lemus C, Bugarin J, Bonilla J, Ly J. Composition and chemical characteristics of mangoes (Mangifera indica L.) for animal feeding in Nayarit, Mexico. Cuban J Agric Sci. 2013;47(3).

17. Castro-Vargas HI, Ballesteros-Vivas D, Ortega-Barbosa J, Morantes-Medina SJ, Aristizabal-Gutierrez F, Parada-Alfonso F. Bioactive phenolic compounds from the agroindustrial waste of Colombian mango cultivars 'Sugar Mango' and 'Tommy Atkins': an alternative for their use and valorization. Antioxidants. 2019;8(2):41. DOI: 10.3390/antiox8020041.

18. Faradilla P, Setiyanto H, Manurung RV, Saraswaty V. Electrochemical sensor based on screen printed carbon electrode-zinc oxide nanoparticles/molecularly imprinted polymer (SPCE-ZnONPs/MIP) for detection of sodium dodecyl sulfate (SDS). RSC Adv. 2021;12(2):743. DOI: 10.1039/d1ra06862h.

19. Urge SK, Dibaba ST, Gemta AB. Green synthesis method of ZnO nanoparticles using extracts of Zingiber officinale and garlic bulb (Allium sativum) and their synergetic effect for antibacterial activities. J Nanomater. 2023;2023:7036247. DOI: 10.1155/2023/7036247.

20. Soltani S, Gacem A, Choudhary N, Yadav VK, Alsaeedi H, Modi S, et al. Scallion peel mediated synthesis of zinc oxide nanoparticles and their applications as nano-fertilizer and photocatalyst. Water. 2023;15(9):1672. DOI: 10.3390/w15091672.

21. Ajila CM, Naidu KA, Bhatt SG, Rao UP. Bioactive compounds and antioxidant potential of mango peel extract. Food Chem. 2007;105(3):982-988. DOI: 10.1016/j.foodchem.2007.04.052.

22. Xing Y, Liao X, Liu X, Li W, Huang R, Tang J, et al. Characterization and antimicrobial activity of silver nanoparticles synthesized with the peel extract of mango. Materials. 2021;14(19):5878. DOI: 10.3390/ma14195878.

23. Abomuti MA, Danish EY, Firoz A, Hasan N, Malik MA. Green synthesis of zinc oxide nanoparticles using

Salvia officinalis leaf extract and their photocatalytic and antifungal activities. Biology. 2021;10(11):1075. DOI: 10.3390/biology101101075.