ISSN 1062-3590, Biology Bulletin, 2026, Vol. 53:191. © Pleiades Publishing, Inc., 2026.

Zınc Oxide Nanoparticles Produced from *Rosa canina* (Rosehip) and *Viburnum opulus* (Gilaburu)-DNA Cleavage, DNA Binding, Topoisomerase I Enzyme Inhibition, Antibacterial Activity Properties

Nilgün Güler[a], Halime Güzin Aslan[b, *], Ercan Karaköse[c], Mithat Güllü[d], Zeshan Hassan[e], Muhammad Shahid Iqbal[f, #], Muhammad Uzair[f], Ayesha Abbas[f], Anam Sajjad[f], and Tahira Abbas[g]

[a] *Department of Chemistry and Chemical Processing Technology, Vocational School of Mustafa Çıkrıkçıoğlu, Kayseri University, Kayseri, TR-38250 Türkiye*

[b] *Department of Chemistry, Faculty of Science, Erciyes University, Kayseri, TR-38250 Türkiye*

[c] *Faculty of Engineering, Kayseri University, Kayseri, TR-38250 Türkiye*

[d] *Department of Biology, Faculty of Science, Erciyes University, Kayseri, TR-38250 Türkiye*

[e] *Department of Plant Production and Biotechnology, University of Layyah, Layyah, 31200 Pakistan*

[f] *Department of Botany, University of Layyah, Layyah, 31200 Pakistan*

[g] *Department of Horticulture, Faculty of Agriculture Sciences and Technology, University of Layyah, Layyah, 31200 Pakistan*

******e-mail: mithatgullu23@gmail.com*

Received December 4, 2025; revised June 24, 2026; accepted June 24, 2026

Abstract—The use of natural phytochemicals in obtaining various metal oxides and use of these oxides in industrial and health fields is an interesting phenomenon. Zinc mineral is particularly remarkable because it plays a role in regulating metabolic activities. In this study, *Rosa canina* (rosehip) and *Viburnum opulus* (gilaburu) extracts in water were used to synthesize nano Zinc oxide by green synthesis method. ZnO-NPs formation was confirmed by analysis methods such as XRD, SEM and FTIR. In addition, Topoisomerase-I enzyme inhibition, DNA cutting and binding analyses were performed by agar gel electrophoresis method. Antimicrobial activity analysis of nano ZnO particles was performed using two grams positive and two gram negative bacteria. Pure ZnO was formed in hexagonal structure. Peaks belonging to aromatic structure in FTIR analysis indicate trace amounts of phenolic residues in nano ZnO structure. In SEM, images of nano ZnO particles were observed.

Keywords: chemical methods, green synthesis, nanotechnology, spectroscopic, Turkey

DOI: 10.1134/S1062359025614120

INTRODUCTION

Nanotechnology has recently attracted intense attention applications in biotechnology, biochemistry and industrial fields (Pelaz et al., 2012; Singh et al., 2008; Whitesides, 2005). Even advances other areas include medicine, gene technology, nanomedicine, biosensing, biofilm have opened new horizons in these fields (Jianrong et al., 2004; Zhang et al., 2009). Nano-sized particles have properties such as catalytic reactivity, chemical stability and thermal conductivity. One of these features is area/density ratios (Karam and Abdulrahman, 2022; Kundu et al., 2022; Veeranna et al., 2021; Yao et al., 2002). Therefore, it causes a difference in activity between the atoms on the surface and the center (Barth et al., 2005; Yin et al., 2004). Many different methods are used in their synthesis, application and source. It requires various physical and chemical methods, special equipment and skilled labor (Nadagouda and Varma, 2008; Virkutyte and Varma, 2011). Especially Plant-mediated nanoparticle (NPs) synthesis is named green synthesis a biological and innovative method (Rani et al., 2023; Singh et al., 2023). In this green synthesis method, extracts of plant divisions and non-hazardous biomaterials have used (Behravan et al., 2019; Rajiv et al., 2013; Shinde, 2015). Various metal salts are used in this application and in recent studies of Zn, Au, Cu, Ag, etc. Biosynthesis of metal oxides takes place (Aslan, 2022; Chung et al., 2017; Moodley et al., 2018). Synthesis of zinc oxide nanoparticles were carried out using extracts of different plants in studies like *Deverra tortuosa* (Selim et al., 2020), *Grewia asiatica* (Aziz et al., 2023), *Salvia officinalis* (Abomuti et al., 2021). No study has been found on the production of zinc oxide nanoparticles using *Rosa canina* (rosehip) and *Viburnum opulus* (gilaburu) extracts specific to Turkey. The aims of this study are (i) to obtain zinc oxide nanoparticles by innovative biosynthesis with rosehip and gilaburu extract (ii) to understand the

[#] Nilgun Guler and Muhammad Shahid Iqbal are Co-first aurhors.

Table 1. Organism names and culture codes

Microorganisms	Organism code
Bacillus cereus	NRLL B-3008
Escherichia coli	ATCC 25922
Klebsiella pneumonia	ATCC 13883
Staphylococcus epidermidis	ATCC 12228

anti-microbial activity on different bacteria, DNA—enzyme performance of obtained zinc oxide nanoparticles, (iii) characterization of obtained nano zinc oxide by advanced spectroscopic and microscopic devices, and methods.

MATERIALS AND METHODS

Materials

Plants obtained from Kayseri and its surroundings, such as rosehip (S1), and gilaburu (S2), were got to obtain ZnO-NPs in Zinc nitrate with hydrous (Sigma).

Preparation of gilaburu and rosehip extracts. It is started to process by cleaning and crushing of rosehip, and gilaburu to obtain its extracts. Plants are taken in 25 g. It is mixed by magnetic stirrer with 100 mL of distilled H_2O for 1 h at 95°C. The resulting extract is cooled to 25°C and filtered. It is filtered two times with filter paper to remove large particles. Extracts are stored in cold medium to use other analyses.

Green synthesis of ZnO NP's. How ZnO-NPs are synthesized is shown in Graphical Abstract. A little solvent (H_2O) and 5 g Zinc nitrate hydrous are added into extract at 100°C and magnetically stirred until the ZnO structure is formed, then the mixture is annealed in the oven at 400°C for 120 min. ZnO-NPs in powder form are thus obtained. The resulting light yellow powder was used for subsequent biological studies. FE-SEM, XRD, and FT-IR analyzes were performed for the characterization of powder ZnO-NPs synthesized from two different plants (Jayachandran et al., 2021).

Characterization of ZnO Nanoparticles

Analysis

SEM analysis. The powder S1, S2 samples to be examined are placed separately in a conductive sample carrier and, if necessary, the surface is coated with gold or carbon to ensure conductivity. The sample is then placed in the SEM (FEI Quanta brand model) unit and the system is vacuumed. When the vacuum reaches a certain value, adjustment is made according to the voltage value previously determined according to the sample properties and the device is increased to high voltage. The image formed as a result of the interaction between the resulting electron beam and the sample is followed on the screen, and by moving the sample holder in the *X*, *Y*, and *Z* axes, the area to be examined is found and sharpening and focusing settings are made at the desired magnifications with an image resolution up to 1 nm.

XRD analysis. Qualitative and quantitative examinations of rocks, crystalline materials, thin films and polymers can be made with the Beam Diffraction device. Nano Zinc oxide powder samples are ground thoroughly in a mortar and further turned into powder. Powder samples are placed in special sample holders and placed in the sample holder of the XRD device and analyzed. XRD analyzes of the samples were performed according to the procedure applied at Erciyes University Technology Research and Application Center.

FT-IR analysis. Fourier transform infrared (FTIR) technology relies on the arrangement of mirrors that create interferograms that split the light into two separate paths and recombine the light. Here, a spectrum that can be interpreted and analyzed is produced thanks to the Fourier transform algorithm. According to the wave number data in the spectrum, the relevant structures are taken from the library and interpreted (Shaban et al., 2024). FTIR analyzes of the samples were performed according to the procedure applied at Erciyes University Technology Research and Application Center.

Anti-Bacterial Activity

Microorganism samples. In this study, four bacteria were used to determine the antimicrobial activities of nano ZnO synthesized from extracts obtained from two different plant samples. The names of the microorganisms used and their culture collection codes are shown in Table 1.

***Bacillus cereus*:** It is a gram-positive, rod-shaped, endospore-forming, facultative aerobic bacterium, 1 × 3–4 μm in size. *Bacillus cereus*, a soil bacterium, can cause food poisoning by affecting many types of food by secreting emetic and enterotoxin (Ultee et al., 2000; Yan et al., 2024).

***Escherichia coli*.** It is a gram-negative bacillus type bacterium. Some strains have capsules or microcapsules. They do not form spores and are facultative anaerobes (De Fazio et al., 2024; El-Khawaga et al., 2025).

***Klebsiella pneumonia*.** It is a gram-negative bacterium that can cause many diseases. Pneumonia, blood infections, wound or surgical site infections, and meningitis are some of these diseases (Arafa and Kandil, 2024; Aslan et al., 2011).

***Staphylococcus epidermidis*.** *Staphylococcus epidermidis*, a type of bacteria among the *staphylococci* whose seeds are found in clusters. It is gram positive,

Table 2. FTIR band analysis results of ZnO NP's obtained by green synthesis method

Peaks	ZnO, cm^{-1}	Assignments	Refs.
1	526–551	Stretching of (Zn–O) bond	[20–22]
2	624	Stretching of (Zn–O) bond, C–H vibration, OH out-of-plane deformation vibration	[21–23]
3	3435	O–H stretching vibration	[21]

catalase positive and coagulase negative. It is naturally found in the person upper respiratory tract. They are resistant to a wide range of antibiotics, including penicillin and methicillin (Güzin et al., 2013; Rigopoulos et al., 2024).

Culture Medium Information

Müller Hinton agar medium (g/L): 2.0 g meat extract, 17.5 g casein hydrolyzate, 1.5 g starch, 17.0 g agar were all taken into a bottle and sterilized by autoclaving at 121°C for 15 min.

Müller Hinton liquid medium (g/L): 2.0 g meat extract, 17.5 g casein hydrolyzate, 1.5 g starch were all taken into a bottle and sterilized by autoclaving at 121°C for 15 min.

Anti-bacterial activity analysis. Antimicrobial activity analyzes of two nano ZnOs obtained from plant samples were analyzed by the agar well diffusion method. 2 gram-positive and 2 gram-negative bacteria were used in the study (Table 1). Bacteria from stock cultures were grown in Mueller Hinton medium by incubating at 37°C for 24 h. Each microorganism culture developed in liquid medium was re-inoculated at a rate of 1% into tubes containing liquid medium and grown for 18 h until it reached the exponential phase, and the densities of the cultures were adjusted according to Mc Farland (Chung et al., 2017). 100 μL of the microorganisms whose density was adjusted and planted on Muller Hinton agar medium by spring cultivation, and then wells with a diameter of 6 mm were opened. 100 μL of nano ZnO powders dissolved in DMF (3 mg/mL) was added to the opened wells and incubated. Effects were determined by measuring the diameter of inhibition zones after incubation (Perez, 1990).

DNA and enzyme analysis. All biological and chemical agents and liquids had obtained sigma and thermos-scientific suppliers in analytical gradient and quality.

Deoxyribonucleic acid separation analysis. In this study, samples were brought together with supercoiled pBR322 plasmid DNA (100 μg, Sc) and their interactions were examined. While the plasmid DNA remained at a constant concentration, solutions of the samples in different percentages of DMF were used. The sample and plasmid DNA brought together in PCR were kept in the oven at 37°C for 120 min. The mixture was loaded into agarose gel wells. The gel was subjected to Electrophoresis and images were obtained.

DNA binding analysis. The S1, S2 nano ZnO samples were put together by DMF solvent to get 100 μM mixtures. In this study, the samples were brought together with Calf thymus nucleic acid and their interactions were examined by electrophoresis experiment. Different concentrations of Calf thymus nucleic acid (2–1 mg/mL) were prepared in Buffer placed in PCR tubes and a 3% (mg/μL) solution of the fixed sample dissolved in DMF was added. The final volume in the PCR was completed to 25 μL with buffer. It was kept in the oven at incubation temperature for one day. The solutions were put into the gel wells as 10 μL each. The system has been started. Gel images were obtained.

Topoisomerase enzyme inhibition. In this study, Topo-enzyme inhibition assay was designed from literature with little changes (Jayachandran et al., 2021). The topoisomerase inhibitor effect of the nano Zn samples (S1, S2) were investigated by measuring the relaxation of supercoiled pBR322 plasmid DNA (100 μg) in the absence/presence of samples (3–0.75%) in buffer (10× TGS). The eppendorf's containing samples and others were incubated at 37°C for 1 h and stopped by addition of 4 μL of 5× loading buffer solution consisting of 4.5% SDS, 0.25% bromophenol blue, and 45% glycerol. Electrophoresis was carried out in 1% agarose gel in 1× TEA at 80 V for 60 min (Selim et al., 2020).

RESULTS AND DISCUSSION

Scanning Electron Microscopy (SEM) Analysis

Table 2 is the FTIR band analysis results of ZnO NP's obtained by green synthesis method. FTIR analysis is a technique used to obtain information about chemical structures in a material. The band positions and the number of absorption peaks depend on the crystal structure, type of chemical structure, and also morphology. The characteristic peaks exhibited by the FTIR spectra of ZnO nanoparticles are shown in Fig. 4. The main, broad absorption bands around 2700–3500 and 1092 cm^{-1} belong to the normal poly-

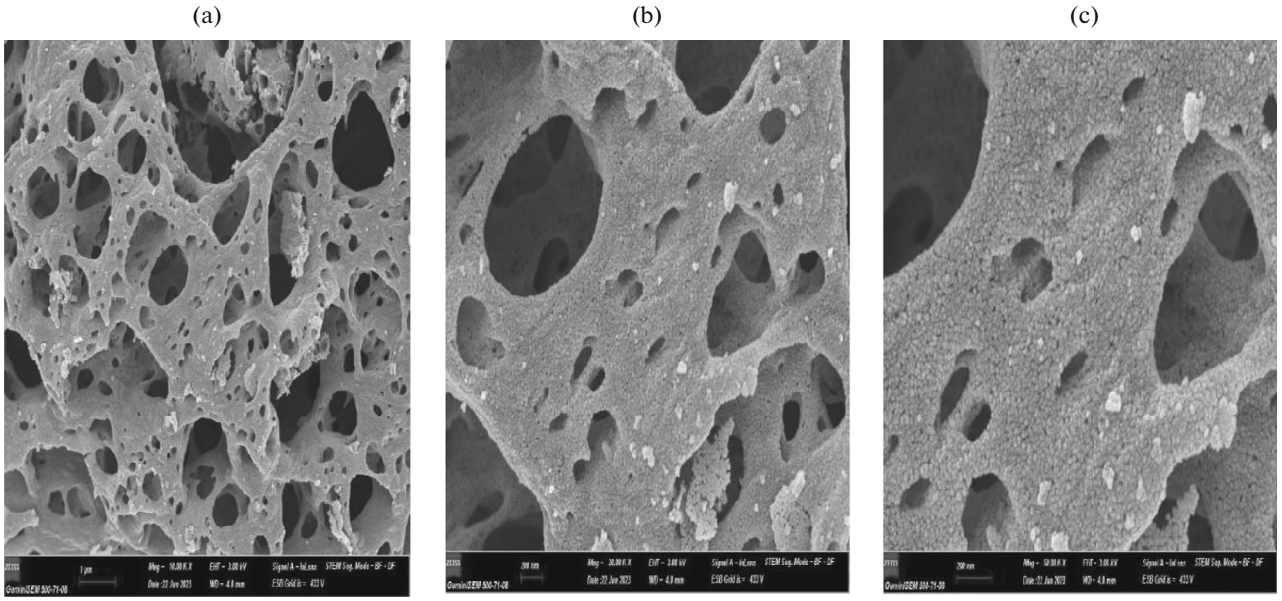


Fig. 1. Shows the ZnO NP's produced from rosehip extract; SEM images are shown at (a) 10000, (b) 30000, and (c) 50000 times magnification. While a void structure similar to the images obtained from apple extract is observed in Figs. 1a and 1b, dot ZnO particles with dimensions of 1–3 nm attract attention in Fig. 1c.

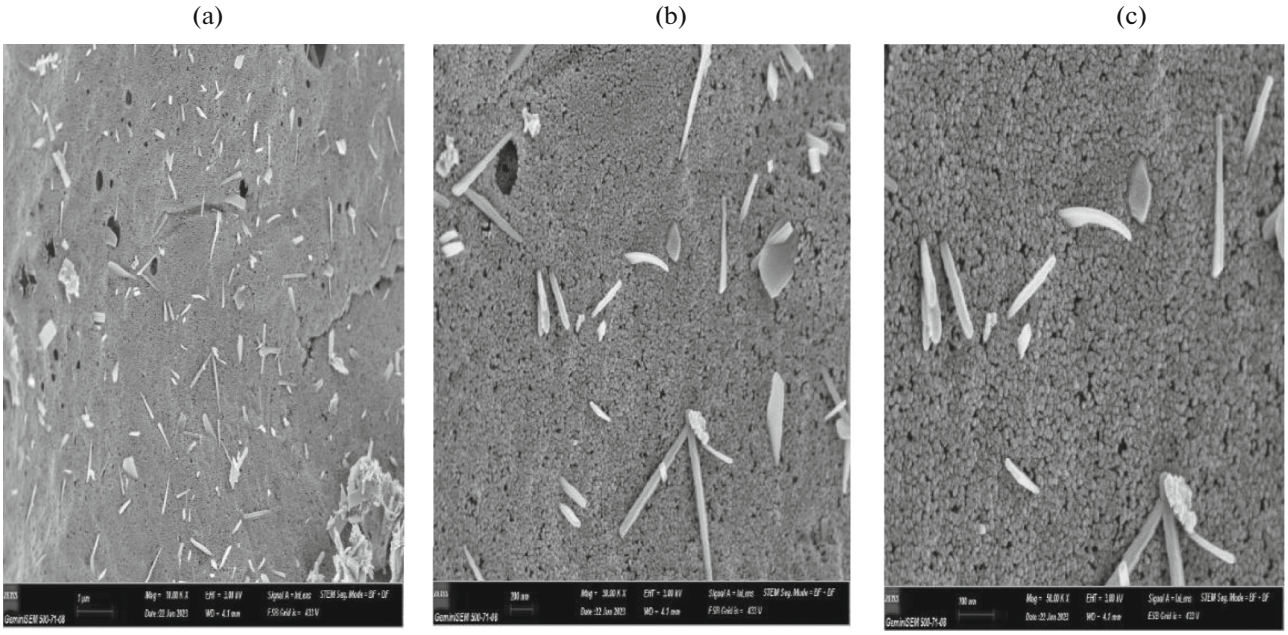


Fig. 2. Shows the ZnO NP's produced from gilaburu extract; SEM images are shown at (a) 10000, (b) 30000, and (c) 50000 times magnification. In Figs. 2a and 2b, unlike the images obtained from apple and rosehip extract, ZnO nanorods were detected along with point particles without gaps. In Fig. 2c, dot ZnO particles and nanorods with dimensions of 1–3 nm are located together.

meric O–H stretching vibration of H_2O in the Zn–O lattice. Another sharp peak around 1696 cm^{-1} belongs to the H–O–H bending vibration, which is attributed to the small amount of H_2O in ZnO nanoparticles. The absorption peak between 2344 and 2352 cm^{-1} is due to the presence of CO_2 molecule in the air. Since the measurement is carried out under an air atmosphere at room temperature, the absorption of H_2O from the moisture content and CO_2 from the atmosphere is inevitable.

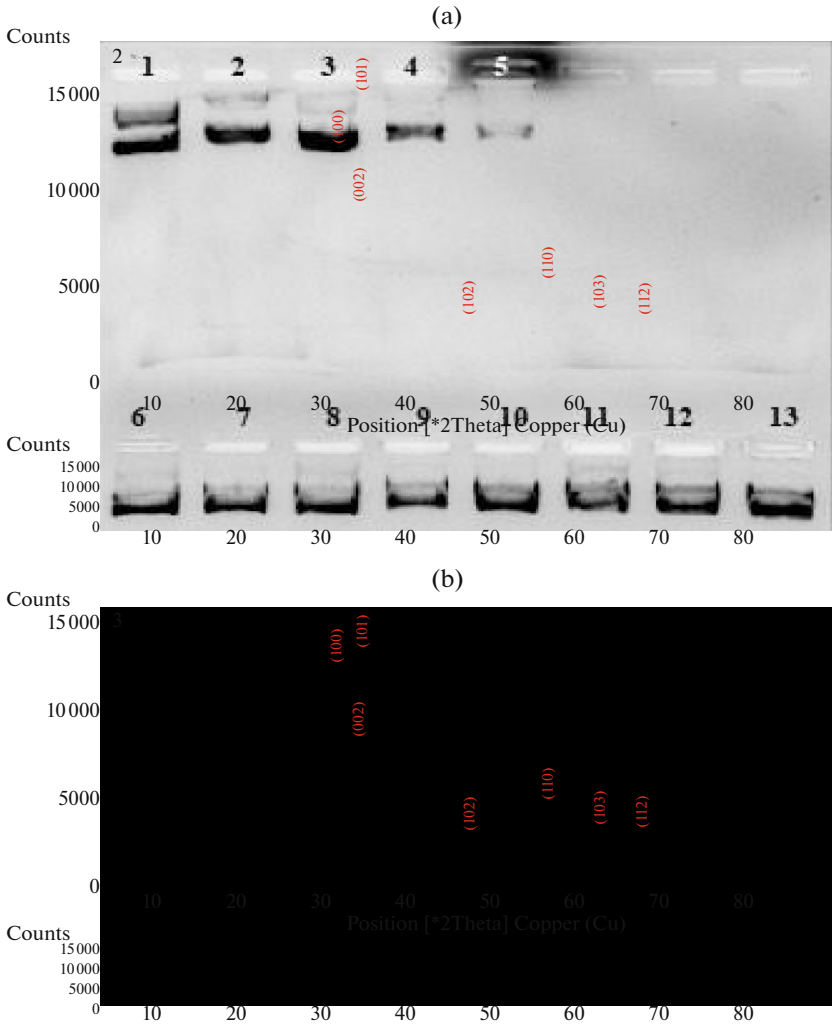


Fig. 3. Is the XRD analysis results of ZnO NP's produced from plant extracts and belongs to (a) Rosehip, (b) Gilaburu plants. Peaks of XRD 32.90°, 35.57°, 38.41°, 49.70°, 58.76°, 63.97°, 65.58°, 67.07°, 70.21°, 72.75°, 76.98°, and at 81.51° diffraction angle values (1 0 0), (0 0 2), (1 0 1), (1 0 2), (1 1 0), (1 0 3), (2 0 0), (1 1 It corresponds to 2), (2 0 1), (0 0 4), (2 0 2) and (1 0 4) planes, and this is the wurtzite (hexagonal) crystal structure. Again, the peaks obtained in Fig. 3 shows that there is no foreign matter or secondary diffraction peak other than the hexagonal ZnO structure. The peaks obtained from XRD analysis are in good agreement with previous studies.

The Result of CT-DNA Binding Analysis of S1, S2 Samples

The binding of two nano ZnO samples with CT-DNA was visualized using agarose gel electrophoresis. The results are shown in Fig. 5. In this study, all compounds were fixed concentrations at 100 μM whilst the concentration of CT-DNA was decreased from 2 to 1 mg/mL. All lines evaluated, according to sample-free CT-DNA brightness and damping conditions in lines 1, 5, 9 and 13. DNA binding or interaction did not occur at all concentrations of sample S2. Because brightness of lines showed stabil decreasing. But, S1 sample showed an extinction effect on the DNA brightness. The explain of this case, the neutralization occurred between the positive nano zinc in the sample structure with the negative DNA.

The Result of DNA Cleavage Analysis of S1, S2 Samples

DNA cleavage occurred in lines 1 and 5 due to the effect of water in pBR322 DNA, there was a less separation in other lines containing samples. There was poor DNA cleavage activity in all samples. The results of the study are included in Fig. 6.

The Result of Human Topoisomerase-I Inhibition Analysis of S1, S2 Samples

In number 1 well, it is seen that Topo enzyme separates DNA, that is, it works, while in well no. 5, irinotecan, as a positive control, does not separate DNA and shows its inhibition effect. It is seen that sample S1 in wells 8, 9 prevented topo enzyme separation and Form II formation like positive control. Since there is some separation in the DNA in wells 10, 11 sample S2

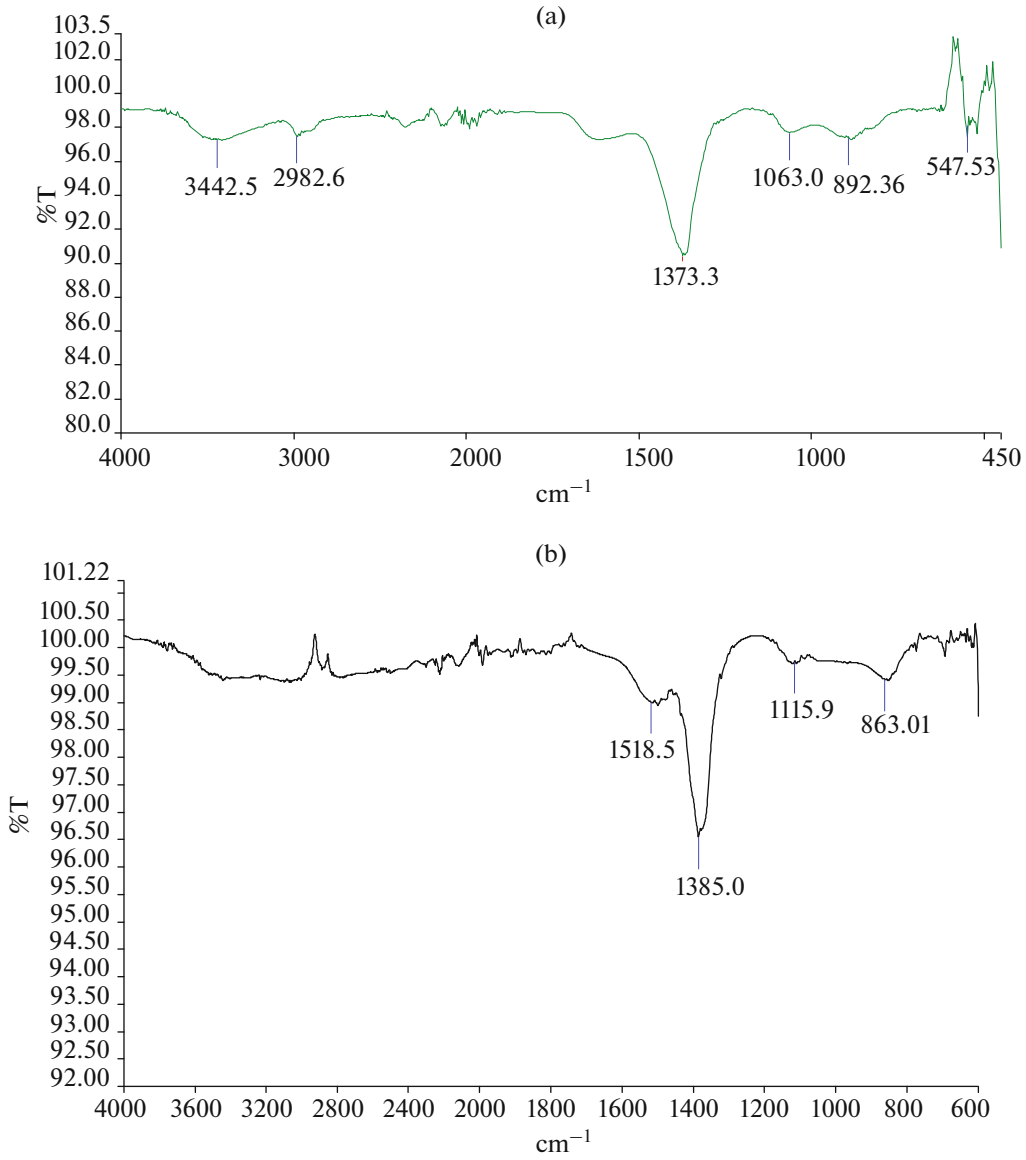


Fig. 4. Is the FTIR analysis results of ZnO nanoparticles produced from plant extract; (a) Rosehip, (b) Gilaburu.

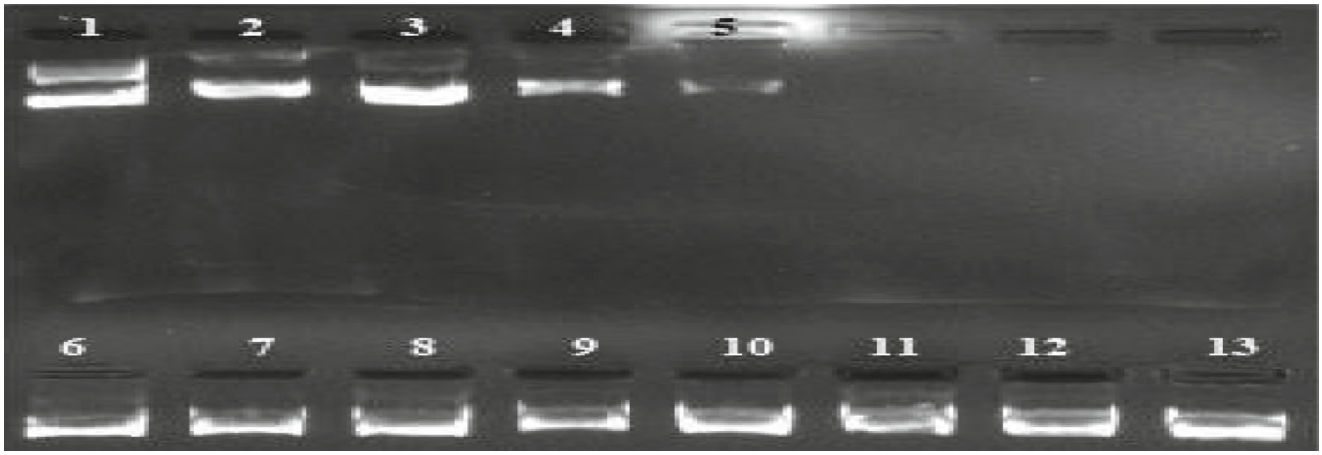


Fig. 5. Agarose gel electrophoresis of S1, S2 samples. Ingredients of lines. Line 1, 5, 9, 13: CT-DNA (2 mg/mL) in buffer (pH 7), Line 6–8: CT-DNA (2–0.5 mg/mL) + buffer + sample S1 (3%), Line 10–12: CT-DNA (2–0.5 mg/mL) + buffer + sample S2 (3%).

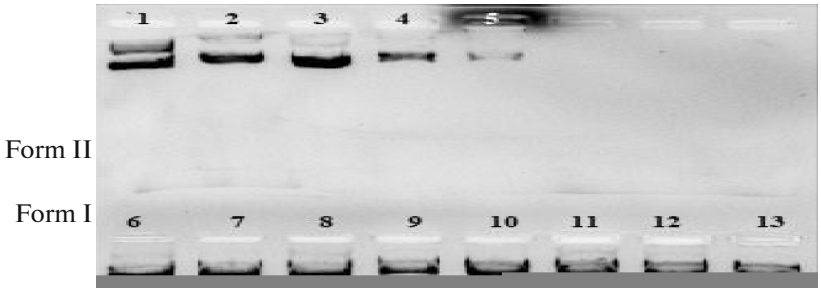


Fig. 6. Agarose gel electrophoresis showing the DNA cleavage activity of ZnO NPs synthesized from apple (S1) and linden (S2) extracts. Lane 1: pBR322 DNA in distilled water (control); lanes 2–4: pBR322 DNA treated with S1 at 3, 1.5, and 0.75%, respectively; lane 5: pBR322 DNA in distilled water (control); lanes 6–8: pBR322 DNA treated with S2 at 3, 1.5, and 0.75%, respectively.

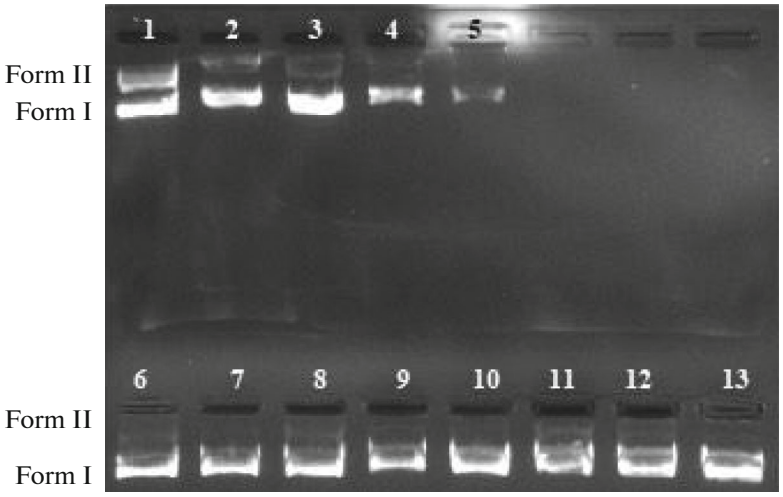


Fig. 7. The inhibitory effects against human topoisomerase I of S1, S2 samples. Lane 1: pBR322 DNA + 1 Unit Topo-I; Lane 2: pBR322 DNA in buffer (TGS); Lane 3: pBR322 DNA Control; Lane 4: pBR322 DNA + 1 Unit Topo I + buffer (TGS); Lane 5: pBR322 DNA + 1 Unit Topo I + buffer (TGS) + irinotecan (3%); Lane 8–9: pBR322 DNA + 1 Unit Topo I + buffer (TGS) + S1 (3–1.5%); Lane 10–11: pBR322 DNA + 1 Unit Topo I + buffer (TGS) + S2 (3–1.5%).

does not have the potential to be an inhibitor, but only S1 sample has the potential to be an effective human Topoisomerase-I enzyme inhibitor.

Anti-Bacterial Activity Results

Powder ZnO nanoparticles obtained from two plant extracts were dissolved in DMF (3 mg/mL) and two gram-positive and two negative bacteria were used. Antimicrobial activities were determined by the agar well method at a concentration of 100 ppm. It has been observed that ZnO nanoparticles (S1, S2) obtained from two different plant samples (rosehip, gilaburu) by the green synthesis method, which is a bio method, are effective against 4 different bacteria. Detailed results regarding the obtained zone diameters are given in Table 3. The effectiveness of the ZnO nanoparticle obtained from rosehip, numbered S1, with the lowest zone diameter (10 mm) was observed on *S. epidermidis* bacteria.

Table 3. Anti-bacterial effects of ZnO Nanoparticles synthesized from different plants

Microorganisms	S1 sample	S2 sample
B. cereus	15 mm	17 mm
E. coli	15 mm	13 mm
K. pneumonia	13 mm	16 mm
S. epidermidis	10 mm	12 mm

CONCLUSIONS

Two separate zinc oxide nanoparticles obtained from aquatic extracts of rosehip and gilaburu plants were first analyzed with spectroscopic and microscopic methods. Choice of the calcination tempera-

ture is important here. Because this temperature has a great effect on the morphology, shape, size, crystal structure quality and optical properties of the nanoparticle (Karam and Abdulrahman, 2022; Pavithra et al., 2020; Suresh et al., 2018; Vidya et al., 2013). In this study, the most appropriate and most efficient calcination temperature, close to 450°C, was used. This situation was seen to be reflected in the analysis results. Point ZnO particles with sizes of 1–3 nm were seen in SEM, and high- quality hexagonal wurtzite nano zinc oxide structure was obtained in XRD. The presence of aromatic structure peaks in the FTIR results shows that there are abundant flavonoid and phenolic phytochemical structures that cause colorfulness in the structure of plants. These structures found in plant extracts play an active role in the production of nanoparticles. The effect of fixed concentration of zinc oxide nanoparticles against gram-positive-gram-negative bacterial strains was evaluated. High nanoparticle concentrations of 3 mg/mL effectively inhibited the growth of bacteria. Zinc oxide produced from rosehip and gilaburu extracts from the obtained inhibition zones showed consistency and inhibited all bacterial strains used in the analysis. In particular, nano zinc oxide obtained from rosehip extract was thought to be suitable as an antineoplastic because it inhibited human Topoisomerase-I enzyme activity. Based on these findings, we recommended further cytotoxicity, anticancer studies to determine the safety properties of these nanoparticles against cancer or other cells.

ACKNOWLEDGMENTS

This work was supported by the scientific Research project NAP at Kayseri University (TSA-2022-1066 and TSA-2020-1028). The author acknowledges the support from Erciyes University Technology Research Application Center (TAUM) for supporting characterization analysis.

AUTHOR CONTRIBUTION

Concept—NG; Design—NG; Resources—NG, HGA; EK; Materails—NG, MG, ZH, MSI, MU, AA, AS, TA; Data Collection and/or Processing—NG, MG, ZA, MSI, AA, AS, MU, HGA, EK; Analysis and/or Interpretation—NG, HGA, EK; Literature Search—NG, HGA, EK; Writing Manuscript—NG, HGA.; MG, ZH, MSI, MU, AA, AS, TA.

FUNDING

This work was supported by ongoing institutional funding. No additional grants to carry out or direct this particular research were obtained.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This work does not contain any studies involving human and animal subjects.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

REFERENCES

Abomuti, M.A., Danish, E.Y., Firoz, A., Hasan, N., and Malik, M.A., Green synthesis of zinc oxide nanoparticles using *Salvia officinalis* leaf extract and their photocatalytic and antifungal activities, *Biology*, 2021, vol. 10, no. 11, p. 1075.
https://doi.org/10.3390/biology10111075

Arafa, A.A. and Kandil, M.M., Antimicrobial activity of zinc oxide nanoparticles against ESBL producing *Klebsiella pneumoniae* isolated from equines in Egypt, *Pak. Vet. J.*, 2024, vol. 44, no. 1, pp. 176–182.
https://doi.org/10.29261/pakvetj/2023.121

Aslan, H.G., New sulfonyl hydrazones and their Pd(II) complexes: synthesis and cytotoxic activities in the MDA-MB-231 cell line, *Chem. Pap.*, 2022, vol. 76, no. 3, pp. 1413–1421.
https://doi.org/10.1007/s11696-021-01928-w

Aslan, H.G., Özcan, S., and Karacan, N., Synthesis, characterization and antimicrobial activity of salicylaldehyde benzenesulfonylhydrazone (Hsalbsmh)and its nickel(II), palladium(II), platinum(II), copper(II), cobalt(II) complexes, *Inorg. Chem. Commun.*, 2011, vol. 14, no. 9, pp. 1550–1553.
https://doi.org/10.1016/j.inoche.2011.05.024

Aziz, A., Memon, Z., and Bhutto, A., Efficient photocatalytic degradation of industrial wastewater dye by *Grewia asiatica* mediated zinc oxide nanoparticles, *Optik*, 2023, vol. 272, 170352.
https://doi.org/10.1016/j.ijleo.2022.170352

Barth, J.V., Costantini, G., and Kern, K., Engineering atomic and molecular nanostructures at surfaces, *Nature*, 2005, vol. 437, no. 7059, pp. 671–679.
https://doi.org/10.1038/nature04166

Behravan, M., Hossein Panahi, A., Naghizadeh, A., Ziaee, M., Mahdavi, R., and Mirzapour, A., Facile green synthesis of silver nanoparticles using *Berberis vulgaris* leaf and root aqueous extract and its antibacterial activity, *Int. J. Biol. Macromol.*, 2019, vol. 124, pp. 148–154.
https://doi.org/10.1016/j.ijbiomac.2018.11.101

Chung, I., Abdul Rahuman, A., Marimuthu, S., Vishnu Kirthi, A., Anbarasan, K., Padmini, P., and Rajakumar, G., Green synthesis of copper nanoparticles using *Eclipta prostrata* leaves extract and their antioxidant and cytotoxic activities, *Exp. Ther. Med.*, 2017, vol. 14, no. 1, pp. 18–24.
https://doi.org/10.3892/etm.2017.4466

De Fazio, R., Oppedisano, F., Caioni, G., Tilocca, B., Piras, C., and Britti, D., Plants with antimicrobial activity against escherichia coli, a meta-analysis for green veterinary pharmacology applications, *Microorganisms*, 2024, vol. 12, no. 9, p. 1784.
https://doi.org/10.3390/microorganisms12091784

El-Khawaga, A.M., Elsayed, M.A., Gobara, M., Suliman, A.A., Hashem, A.H., Zaher, A.A., Mohsen, M., and Salem, S.S., Green synthesized ZnO nanoparticles by *Saccharomyces cerevisiae* and their antibacterial activity and photocatalytic degradation, *Biomass Convers. Biorefin.*, 2025, vol. 15, no. 2, pp. 2673–2684.
https://doi.org/10.1007/s13399-023-04827-0

Güzin Aslan, H., Karacan, N., and Aslan, E., Synthesis, characterization and antimicrobial activity of a new aromatic sulfonyl hydrazone derivative and its transition metal complexes, *J. Chin. Chem. Soc.* (Weinheim, Ger.), 2013, vol. 60, no. 2, pp. 212–217.
https://doi.org/10.1002/jccs.201100580

Jayachandran, A., Aswathy, T.R., and Nair, A.S., Green synthesis and characterization of zinc oxide nanoparticles using *Cayratia pedata* leaf extract, *Biochem. Biophys. Rep.*, 2021, vol. 26, 100995.
https://doi.org/10.1016/j.bbrep.2021.100995

Jianrong, Ch., Yuqing, M., Nongyue, H., Xiaohua, W., and Sijiao, L., Nanotechnology and biosensors, *Biotechnol. Adv.*, 2004, vol. 22, no. 7, pp. 505–518.
https://doi.org/10.1016/j.biotechadv.2004.03.004

Karam, Sh.T. and Abdulrahman, A.F., Green synthesis and characterization of ZnO nanoparticles by using thyme plant leaf extract, *Photonics*, 2022, vol. 9, no. 8, p. 594.
https://doi.org/10.3390/photonics9080594

Kundu, M., Mondal, B., Das, D., and Roy, U.K., Synthesis and reactivity of copper and copper containing magnetically separable catalysts, *ChemistrySelect*, 2022, vol. 7, no. 17, p. e202104543.
https://doi.org/10.1002/slct.202104543

Moodley, J.S., Krishna, S.B.N., Pillay, K., Sershen, F., and Govender, P., Green synthesis of silver nanoparticles from *Moringa oleifera* leaf extracts and its antimicrobial potential, *Adv. Nat. Sci.: Nanosci. Nanotechnol.*, 2018, vol. 9, no. 1, 15011.

Nadagouda, M.N. and Varma, R.S., Green synthesis of silver and palladium nanoparticles at room temperature using coffee and tea extract, *Green Chem.*, 2008, vol. 10, no. 8, pp. 859–862.
https://doi.org/10.1039/b804703k

Pavithra, S., Sudha, P., Kalaiselvi, V., Ramya, V., and Vidhya, N., Green synthesis and characterization of zno nanoparticles using *Hibiscus rosa-sinensis* leaf extract, *J. Environ. Nanotechnol.*, 2020, vol. 9, no. 3, pp. 7–12.
https://doi.org/10.13074/jent.2020.09.203419

Pelaz, B., Jaber, S., de Aberasturi, D.J., Wulf, V., Aida, T., de la Fuente, J.M., Feldmann, J., Gaub, H.E., Josephson, L., Kagan, Ch.R., Kotov, N.A., Liz-Marzán, L.M., Mattoussi, H., Mulvaney, P., Murray, Ch.B., Rogach, A.L., Weiss, P.S., Willner, I., and Parak, W.J., The state of nanoparticle-based nanoscience and biotechnology: progress, promises, and challenges, *Nano Focus*, 2012, vol. 6, no. 10, pp. 8468–8483.
https://doi.org/10.1021/nn303929a

Perez, C., Antibiotic assay by agar-well diffusion method, *Acta Biol. Med. Exp.*, 1990, vol. 15, pp. 113–115.

Rajiv, P., Rajeshwari, S., and Venckatesh, R., Bio-fabrication of zinc oxide nanoparticles using leaf extract of *Parthenium hysterophorus* L. and its size-dependent antifungal activity against plant fungal pathogens, *Spectrochim. Acta, Part A*, 2013, vol. 112, pp. 384–387.
https://doi.org/10.1016/j.saa.2013.04.072

Rani, N., Singh, P., Kumar, S., Kumar, P., Bhankar, V., and Kumar, K., Plant-mediated synthesis of nanoparticles and their applications: A review, *Mater. Res. Bull.*, 2023, vol. 163, p. 112233.
https://doi.org/10.1016/j.materresbull.2023.112233

Rigopoulos, N., Gkaliouri, Ch.M., Ioannou, Z., Giaouris, E., Sakavitsi, V., and Gournis, D., Green synthesis of silver nanoparticles using olive mill wastewater and olive stones extract and testing their antimicrobial activities against *Escherichia coli* and *Staphylococcus epidermidis, Nano Express*, 2024, vol. 5, no. 1, p. 015026.
https://doi.org/10.1088/2632-959x/ad2fd1

Selim, Ya.A., Azb, M.A., Ragab, I., and Abd El-Azim, M.H.M., Green synthesis of zinc oxide nanoparticles using aqueous extract of *Deverra tortuosa* and their cytotoxic activities, *Sci. Rep.*, 2020, vol. 10, no. 1, p. 3445.
https://doi.org/10.1038/s41598-020-60541-1

Shaban, A.S., Owda, M.E., Basuoni, M.M., Mousa, M.A., Radwan, A.A., and Saleh, A.K., *Punica granatum* peel extract mediated green synthesis of zinc oxide nanoparticles: structure and evaluation of their biological applications, *Biomass Convers. Biorefin.*, 2024, vol. 14, no. 11, pp. 12265–12281.
https://doi.org/10.1007/s13399-022-03185-7

Shinde, S.S., Antimicrobial activity of ZnO nanoparticles against pathogenic bacteria and fungi, *Sci. Med. Central*, 2015, vol. 3, p. 1033.

Singh, M., Singh, S., Prasad, S., and Gambhir, I.S., Nanotechnology in medicine and antibacterial effect of silver nanoparticles, *Dig. J. Nanomater. Biostruct.*, 2008, vol. 3, no. 3, pp. 115–122.

Singh, N., Singh, R., Shah, K., Pramanik, B.K., and Sachin, J., Green synthesis of zinc oxide nanoparticles using lychee peel and its application in anti-bacterial properties and CR dye removal from wastewater, *Chemosphere*, 2023, vol. 327, p. 138497.
https://doi.org/10.1016/j.chemosphere.2023.138497

Suresh, J., Pradheesh, G., Alexramani, V., Sundrarajan, M., and Hong, S.I., Green synthesis and characterization of zinc oxide nanoparticle using insulin plant (*Costus pictus* D. Don) and investigation of its antimicrobial as well as anticancer activities, *Adv. Nat. Sci.: Nanosci. Nanotechnol.*, 2018, vol. 9, no. 1, 015008.
https://doi.org/10.1088/2043-6254/aaa6f1

Ultee, A., Slump, R.A., Steging, G., and Smid, E.J., Antimicrobial activity of carvacrol toward bacillus cereus on rice, *J. Food Prot.*, 2000, vol. 63, no. 5, pp. 620–624.
https://doi.org/10.4315/0362-028x-63.5.620

Veeranna, R., Shivamurthy, P., Chandrashekaraiah, M., Kundachira Subramanni, N., Madanahalli Ankanathappa, S., Ara Khanum, S., and Venkataravanappa, L.R., Metal nanoparticles as emerging catalysts: A mini review, *Int. J. Nano Dimension*, 2021, vol. 12, no. 2, pp. 90–97.

Vidya, C., Hiremath, S., Chandraprabha, M.N., Antonyraj, M.L., Gopal, I.V., Jain, A., and Bansal, K., Green synthesis of ZnO nanoparticles by *Calotropis gigantea, Int. J. Curr. Eng. Technol.*, 2013, vol. 1, no. 1, pp. 118–120.

Virkutyte, J. and Varma, R.S., Green synthesis of metal nanoparticles: Biodegradable polymers and enzymes in stabilization and surface functionalization, *Chem. Sci.*, 2011, vol. 2, no. 5, pp. 837–846.
https://doi.org/10.1039/c0sc00338g

Whitesides, G.M., Nanoscience, nanotechnology, and chemistry, *Small*, 2005, vol. 1, no. 2, pp. 172–179. https://doi.org/10.1002/smll.200400130

Yan, X., He, Q., Geng, B., and Yang, S., Microbial cell factories in the bioeconomy era: from discovery to creation, *BioDesign Res.*, 2024, vol. 6, p. 0052. https://doi.org/10.34133/bdr.0052

Yao, B.D., Chan, Y.F., and Wang, N., Formation of ZnO nanostructures by a simple way of thermal evaporation, *Appl. Phys. Lett.*, 2002, vol. 81, no. 4, pp. 757–759. https://doi.org/10.1063/1.1495878

Yin, Y., Rioux, R.M., Erdonmez, C.K., Hughes, S., Somorjai, G.A., and Alivisatos, A.P., Formation of hollow nanocrystals through the nanoscale Kirkendall effect, *Science*, 2004, vol. 304, no. 5671, pp. 711–714. https://doi.org/10.1126/science.1096566

Zhang, X., Guo, Q., and Cui, D., Recent advances in nanotechnology applied to biosensors, *Sensors*, 2009, vol. 9, no. 2, pp. 1033–1053. https://doi.org/10.3390/s90201033

Publisher's Note. Pleiades Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

AI tools may have been used in the translation or editing of this article.