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Research Article

Mycosynthesis of Zinc Oxide Nanoparticles Coated with Silver using *Ganoderma lucidum* (Curtis) P. Karst and Its Evaluation of *In Vitro* Antidiabetic and Anticancer Potential

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Nanotechnology is an evolving interdisciplinary field of research interspersing material science and nanobiotechnology. Nanoparticles are studied extensively for their specific catalytic, magnetic, electronic, optical, antimicrobial, theranostic, diagnosis, wound healing, and anti-inflammatory properties. ZnO nanoparticles (NPs) have many applications owing to their unique characteristics, which include low cost, nontoxicity, abundance in nature, and the ability to prepare compounds with varying morphologies having different properties. The main aim of the study is to biosynthesis of ZnO nanoparticles coated with silver from the aqueous extract of *Ganoderma lucidum* (Curtis) P. Karst and to evaluate its antidiabetic potential by performing alpha-glucosidase inhibition and alpha-amylase inhibition assays and to evaluate the anticancer potential by cytotoxicity (MTT) assay against human breast cancer MDA-MB 231 cell lines. The biosynthesis of ZnO nanoparticles coated with Ag was characterized by UV–vis spectroscopy, Fourier transform infrared spectroscopy, energy dispersive X-ray analysis, scanning electron microscope, and transmission electron microscopy. An increasing concentration in the biosynthesized ZnO nanoparticles coated with Ag produces strong antidiabetic activity through enzyme inhibition effect and anticancer activity through the reduction of cell viability. The present study recommended that the "Biological" method of biological nanoparticle production is a promising approach that allows synthesis in aqueous conditions, with low energy requirements and low costs. In the future, the mycosynthesized nanoparticles might be used in the medical arena to treat and prevent diseases.

1. Introduction

In the sphere of research, nanotechnology has become increasingly essential. Nanotechnology is a field of science and technology that works with tiny molecules and is commonly employed for therapeutic purposes in underdeveloped nations. Nanoparticles are defined as particles with a diameter of fewer than 100 nm [1].

ZnO, also known as zincite, is a versatile material with a wide range of applications in technology, including electromagnetic shielding, LEDs, and other light-emitting devices [2]. Many research investigations have focused on ZnO NPs,

and they have a wide range of industrial uses, including textiles, cosmetics, water treatment, and UV emitting devices; ZnO NPs play a vital role in therapeutic as well as pharmaceutical areas because of having fewer side effects. ZnO NPs have a huge surface area, which allows them to have an effective target action on cancer cells [3].

The coating is a process in which the metals such as gold, silver, chromium, etc., are doped with the main synthesized nanoparticles to stabilize the particles and also avoid agglomeration. The coating can be used to expand the advantages of any metal nanoparticles [4]. The three most common ways of creating nanoparticles are physical, chemical, and biological. Among all the methods of nanoparticle synthesis, we chose to proceed with the green synthesis because of its rapid, cost-effective, eco-friendly procedures, and avoiding the production of undesirable or harmful byproducts [5].

Ganoderma lucidum (Curtis) P. Karst is a medicinal mushroom belonging to the family of Ganodermataceae. *G. lucidum* is also known as Lingzhi in China, and it has been dubbed the "mushroom of immortality." In Asian countries, it was traditionally used to enhance the immune power and treat various diseases [6]. There is a huge number of bioactive components including triterpenes, polysaccharides, sterols, and peptides found in the *G. lucidum*. Those identified compounds have numerous health benefits and are also used to treat the diseases, such as cancer, diabetes, asthma, arthritis, etc. [7, 8].

There are no studies on the mycosynthesis of ZnO nanoparticles coated with Ag from *G. lucidum* that we are aware of. Therefore, we aimed to synthesize the silver-coated ZnO nanoparticles and evaluate their antidiabetic and anticancer potential through some respected assays [9].

2. Materials and Methods

2.1. Sample Collection. G. lucidum was gathered from the Maruthamalai foothills (11°2′46″ N, 76°51′7″ E) in the Western Ghats, Coimbatore, Tamil Nadu, India. The Mycology Division of the Indian Forest Genetics and Tree Breeding Institute, Coimbatore, validated *G. lucidum*, and the voucher specimen (RT-25406/9-1-2016) was kept in our laboratory for future reference.

2.2. Preparation of Aqueous Extract. Deionized water was used to completely clean the mushroom sample, removing dirt and other contaminants. It was then air-dried for 5 days in the shade at room temperature. The dried mushroom sample was crushed into a fine powder after being cut into small pieces. In an Erlenmeyer flask, 3 g of mushroom powder was mixed with 300 ml deionized water and heated in a mantle for 2 hr at 80°C, then cooled and filtered using Whatman no. 1 filter paper. As a reducing agent, the filtrate aqueous extract is employed [10].

2.3. Synthesis of Silver-Coated Zinc Oxide Nanoparticles. To make silver-coated zinc oxide nanoparticles (Ag–ZnO NPs), 450 ml of *G. lucidum* aqueous extract was mixed with 45 ml of 1 mM zinc nitrate solution in a 1,000 ml Erlenmeyer flask. The precipitate was separated from the reaction solution by centrifugation at 10,000 rpm for 15 min and the pellet was collected; the centrifugation process was then done twice more and the remaining pellet was collected. Pellets were dried in a hot air oven until all liquid ingredients were evaporated, then kept in airtight bottles for future research [11].

2.4. Silver Coating. Five milliliters of 10 mM silver nitrate was added drop wisely with the mixture of aqueous extract of *G. lucidum* and 1 mM zinc nitrate solution under constant stirring. The mixture was stirred for 2–3 hr with the use of a magnetic stirrer. Then the mixture of the aqueous solution was placed in the open shaker to improve the synthesis of Ag–ZnO NPs [12, 13].

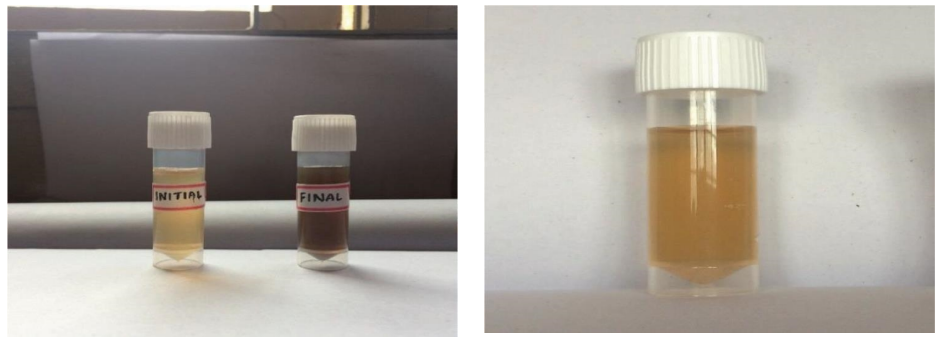
2.5. Characterization of Biosynthesized Ag-Coated ZnO NPs. The obtained Ag–ZnO NPs from *G. lucidum* were characterized by using UV–vis spectrometry, FTIR analysis, EDX, SEM, and TEM analysis.

UV/VIS 3000+ double beam UV visible ratio–recording scanning spectrophotometer from Lab India (SKU : 174-0020) with dimensions of (WDH)/weight = 540440390 mm/36 kg was used to study the optical absorption spectra of Ag–ZnO NPs. FTIR is a qualitative analysis and it shows the presence of different functional groups, which give rise to the well-known signatures in the IR region of the electromagnetic spectrum. The presence of Ag-coated ZnO nanoparticles was confirmed by an energy-dispersive analysis X-ray (EDX) spectrum using an X-ray microanalyzer (Oxford Instruments, UK). The structural characterization of the ZnO nanoparticles coated with Ag was carried out by SEM (JEOL JEM 2100) and TEM (JEOL JEM 2100). The sample was prepared by air-drying drops of diluted solutions of the preparations on carbon films supported by copper grids.

2.6. Antidiabetic Activity of Silver-Coated Zinc Nanoparticles

2.6.1. In Vitro Alpha-Glucosidase Inhibition Assay. Matsui et al. [14] used an adapted approach to investigate the effect of ZnO NPs coated with Ag on alpha-glucosidase inhibition. The stock solution of alpha-glucosidase (0.5 U/ml) was also prepared in 20 mmol/l sodium phosphate buffer (pH 6.9) in 96 well plates. Alpha-glucosidase has been prepared by varying concentrations of Ag–ZnO NPs and acarbose standard drug (1–5 μg/ml), respectively. The mixture was incubated at 37°C for 15 min, and 100 μl of 4-nitrophenyl-β-D-glucopyranoside (PNPG) was added further. The reaction mixture was incubated for 10 min at 37°C. To stop the reaction, 750 ml of Na_2CO_3 (0.1 M) was added, and the OD values of spectrophotometer (UV-100 Cyber Lab, USA) readings were taken at 405 nm in triplicate. Acarbose alone was used as reference and controls for assay contain only 4-nitrophenyl-β-D-glucopyranoside (PNPG). The percentage of alpha-glucosidase inhibition was measured as follows:

$$\% \text{ Activity of sample} = \frac{A405 \text{ of sample} - A405 \text{ of controls}}{A405 \text{ of control}} \times 100, \quad (1)$$



(a) (b)

Figure 1: Mycosynthesis of Ag-coated ZnO NPs from *G. lucidum*: (a) initial and final color of Ag-coated ZnO NPs; (b) Ag coated with the mixture of *G. lucidum* extract and zinc nitrate solution.

To prevent the action of the alpha-glucosidase by 50% (IC50), the inhibitory concentration of the gold nanoparticles was calculated graphically [10, 14].

2.6.2. In Vitro Alpha-Amylase Enzyme Inhibition Assay. The approach was used to determine the activity of alpha-amylase (Hansawasdi et al. [15]). In each tube, 2 mg of starch azure was suspended in 0.2 ml of 0.5 M Tris–HCl buffer (pH 6.9) and 0.01 M $CaCl_2$. The tubes holding the substrate solution were boiled for 5 min before being incubated for 5 min at 37°C. Ag–ZnO NPs were taken in each tube containing different concentrations of dimethyl sulfoxide (10, 20, 40, 60, 80, and 100 g/ml) [15].

PPA from the porcine pancreas was dissolved in Tris–HCl buffer to a concentration of 2 units/ml, and 0.1 ml of this enzyme solution was added to each of the tubes stated above. The absorbance of the resulting supernatant was measured at 595 nm using a spectrophotometer (UV–vis spectrophotometer UV-2450, Shimadzu). The alpha-amylase inhibitory activity was calculated as follows:

$$\frac{[(\mathrm{Ac}+)-(\mathrm{Ac}-)]-[(\mathrm{As}-\mathrm{Ab})]}{[(\mathrm{Ac}+)-(\mathrm{Ac}-)]}\times 100, \quad (2)$$

where Ac+, Ac−, As, and Ab are defined as the absorbance of 100% enzyme activity (only solvent with enzyme), 0% enzyme activity (only solvent without enzyme activity), a test sample (with enzyme), and a blank (a test sample without enzyme), respectively.

2.7. Anticancer Activity of Silver-Coated Zinc Nanoparticles

2.7.1. MTT Assay. The cytotoxic effects of Ag–ZnO NPs against MDA-MB 231 cell lines were determined using the MTT test. The cell lines were seeded in 96-well microtiter plates, which were then filled with the appropriate amounts of Ag–ZnO NPs stock solutions and cultured at 37°C for 48 hr. As a control, cells that had not been treated were utilized. The MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide, tetrazole) colorimetric assay was used to test the cultivated cell. MTT (5 mg/ml, 20l) was added to each group of cells, and the plates were incubated for another 4 hr. The medium was then withdrawn, and DMSO (200L, Sigma–Aldrich, USA) was added to dissolve the formazan crystals formed by metabolically active cells reducing the tetrazolium salt [16].

MTT is reduced into metabolically active cells to yield an insoluble purple formazan product. The cell suspensions were dispensed (100 μl) in triplicate into 96-well culture plates at optimized concentrations of 1×105 cells/well for each cell line, after a 24 hr recovery period. Assay plates were read using a spectrophotometer at 560 nm. The absorbance of the samples was measured using a microplate (ELISA) reader [17].

Trypan blue assay was performed to quantify the dead cells following the treatment of cytotoxic stimuli using trypan blue dye.

3. Results and Discussion

3.1. Visual Observation. Analysis of ZnO nanoparticles was made by coating Ag particles, the aqueous solution of *G. lucidum* was then mixed with the solution of zinc nitrate. Later, the silver nitrate slowly started to change its nature which resulted in the color change. This color transition served as evidence for the synthesis completion [18]. The final brownish color change is shown in Figure 1, which exhibited the reduction of zinc nitrate to zinc oxide and it occurs due to the excitation of the surface plasmon resonance effect [11]. The observation was alike to the green synthesis of silver nanoparticles from an aqueous extract of brown seaweed of *Padina boergesenii*, which was completed by Chikkanna et al. [19].

3.2. UV–Visible Spectral Analysis. UV–vis spectroscopy was used to confirm the formation of synthesized nanoparticles in the initial stage. The dark brownish sample of ZnO NPs was coated with Ag nanoparticles, which were synthesized from the extract of *G. lucidum*. The synthesized ZnO NPs were scanned by using UV–vis spectroscopy under the range between 300 and 600 nm [20]. The result obtained from UV–vis spectral analysis showed (Figure 2) a high-absorption peak at 370 nm, which corresponds to synthesized ZnO NPs. Also, this intense response of ZnO NPs could be due to the surface plasmon resonance effect. The synthesized product is

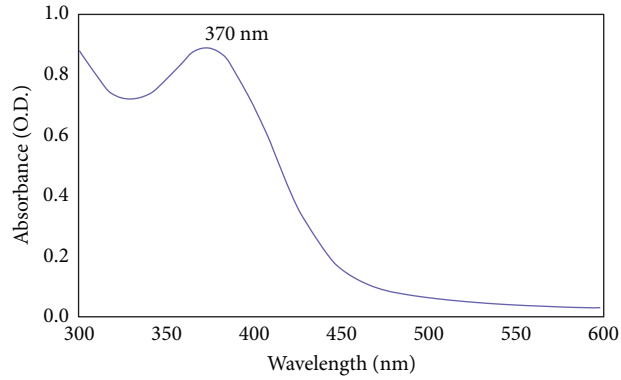


Figure 2: UV–vis absorption spectra of Ag-coated ZnO NPs synthesized from *G. lucidum*.

Table 1: FTIR analysis of Ag-coated ZnO NPs.

Sr. No.	Wavenumber (cm^{-1})	Stretch	Functional groups
1	1,991	NH_2	Primary amides
2	1,644	N=O	Nitrogen group
3	1,515	CO_2	Carbonyl group
4	1,392	C=C	Alkenes
5	958	C–S	Alkyl sulfides

confirmed to claim ZnO NPs coated with Ag because no other peaks were observed in the UV spectrum region [21]. A similar observation was also reported earlier by Siva Vijayakumar et al. [22] in the green synthesis of zinc oxide nanoparticles from the extracts of leaf, stem, and *in vitro* grown callus of *Mussaenda frondosa L.*: characterization and their applications.

3.3. Fourier-Transformed Infrared (FTIR) Spectral Analysis. The FTIR absorption spectra of the water-soluble extract before and after reduction of Ag-coated ZnO NPs showed the capping ligand of the silver-coated zinc oxide nanoparticles which may be due to the linkage of an alkenes, alkyl sulfides groups, carboxyl groups, primary amides, and nitro groups as described in Table 1 and Figure 3. FTIR analysis of the synthesized Ag–ZnO NPs exposes strong bands at 1,991, 1,644, 1,515, 1,392, and 958 cm^{-1}. We confirmed that the strong peak was focused at 1,515 cm^{-1}, which corresponds to the carboxyl groups from amino acid residues, and that proteins had the highest ability to bind metals, based on the FTIR results. This intercalation might explain why proteins create metal oxide nanoparticles (i.e., capping of silver-coated zinc nanoparticles) to avoid agglomeration and maintain the medium. It has already been reported in the green synthesis of ZnO nanoparticles using *Solanum nigrum* leaf extract, that the same functional groups of phytochemicals induce the nanoparticles were synthesized using amines, alkanes, and carboxyl ions that are widely seen in secondary metabolites such as terpenoids, flavonoids, and alkaloids.

3.4. Scanning Electron Microscope Analysis. The silver-coated zinc nanoparticles synthesized with the aid of *G. lucidum* extract were scanned using SEM in order to determine the morphology, polydispersed shape, and size of the synthesized nanoparticle. SEM images (Figure 4) showed that the particles formed were spherical, hexagonal, and triangular. The nanoparticles formed were in the range of 20–100 nm in size. The obtained SEM results were similar to the synthesis of ZnO NPs from the leaves of *Passiflora caerulea L. (Passifloraceae)*, which was reported earlier by Santhoshkumar et al. [23].

3.5. Energy Dispersive Diffraction Analysis. The elemental composition of mycosynthesized ZnO NPs coated with Ag from *G. lucidum* was investigated using EDX to confirm the presence of Zn in the nanoparticle solution that was purified using the ultracentrifugation process. The EDX findings (Figure 5) revealed a significant peak of zinc and silver in the suspension, confirming its existence [24]. The presence of silver alongside zinc shows that biomolecules were involved in the creation of ZnO nanoparticles coated with Ag and that they may have also functioned as stabilizing molecules to ensure the nanoparticles' stability. The obtained result from EDX was similar to the study of Santhoshkumar et al. [23]. In his study, the synthesis of zinc oxide nanoparticles was using the plant leaf extract of *Passiflora caerulea L. (Passifloraceae)*, in which *Zn* was elevated in the nanoparticles suspension which was visible in the result of EDX analysis.

3.6. Transmission Electron Microscopy (TEM) Analysis. TEM analysis was carried out for further confirmation of the synthesized ZnO NPs coated with Ag from *G. lucidum*. The findings of the TEM are shown in Figure 6, which showed that the produced particles were mostly polydistributed and were spherical, hexagonal, and triangular. The selected area electron diffraction (SAED) pattern also reveals the crystalline structure of the ZnO nanoparticles coated with Ag. The particle sizes varied from 10 to 20 nm [25, 26]. In previous kinds of literature, it was observed that nanoparticles ranging from 2 to 20 nm are assumed to be good characteristics of a nanoparticle. So, the resultant product also has the same mentioned range in size, which was enough to conclude the good formation of synthesized ZnO NPs coated with Ag. A similar observation has been reported in the green synthesis of zinc oxide nanoparticles using flower extract of *Nyctanthes arbor-tristis* by Jamdagni et al. [27].

3.7. Alpha-Amylase Inhibition Assay and Alpha-Glycosidase Assay. Antidiabetic activity of synthesized ZnO NPs coated with Ag was evaluated by the inhibition assays of alpha-glucosidase and alpha-amylase enzymes. The results obtained from both enzyme inhibition assays shown in Tables 2 and 3 exhibited the concentration of both Ag–ZnO NPs and standard drug (acarbose) on their respective enzymes. It reveals the carbohydrate digestive enzyme inhibition effect of synthesized Ag–ZnO NPs from *G. lucidum*. So, the results exhibited the significant antidiabetic potential of Ag–ZnO NPs. With an increasing concentration of Ag–ZnO NPs, the enzyme inhibition level was automatically elevated remarkably, so it might be used to prepare effective antidiabetic drugs without any harmful actions. Thus, the Ag–ZnO NPs seem to be a promising and effective antidiabetic agent that can induce a significant reduction of enzymes. A similar

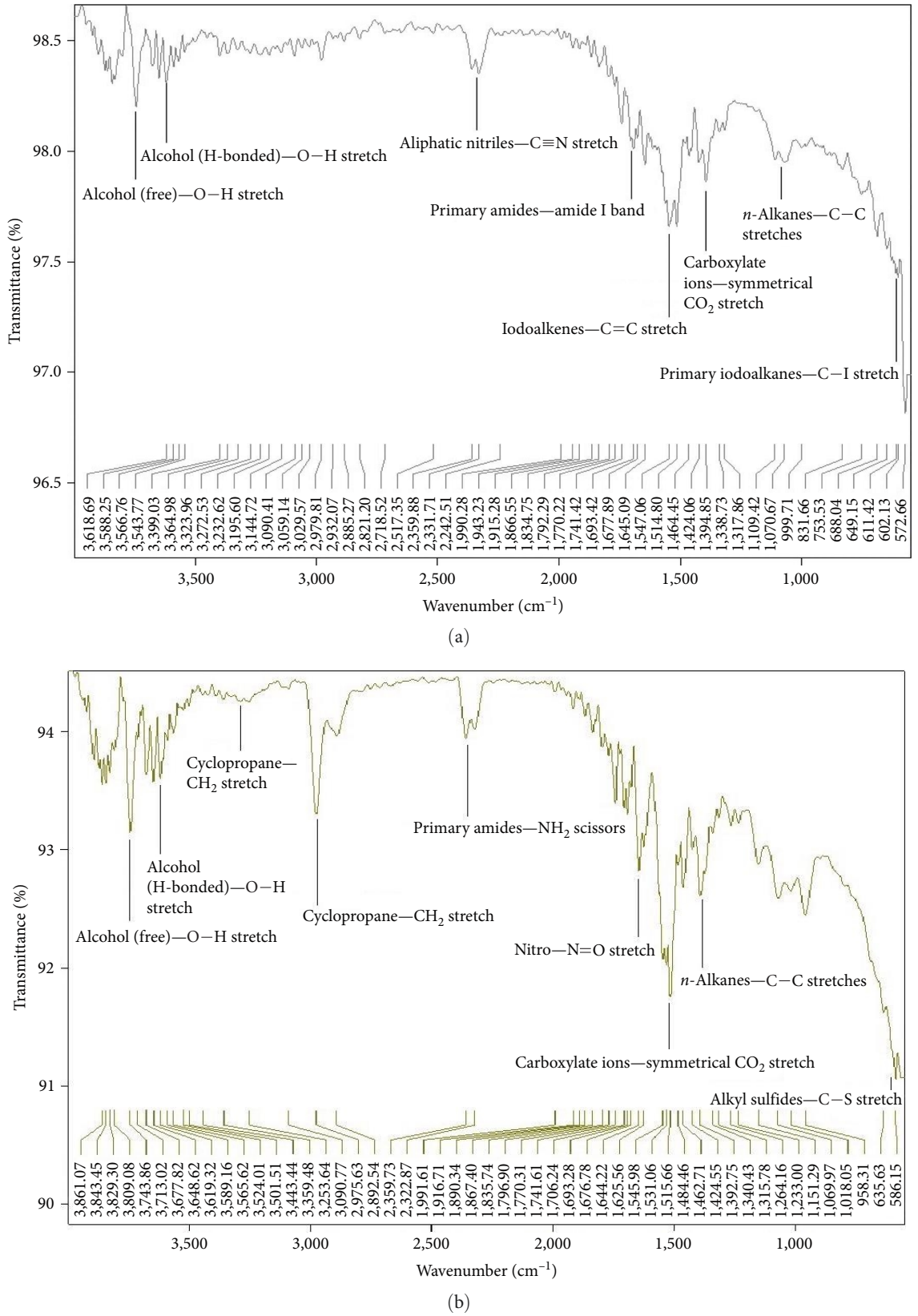
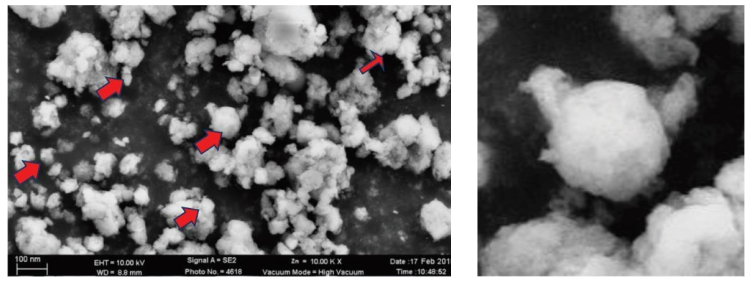


Figure 3: FTIR spectrum of Ag-coated ZnO NPs synthesized from *G. lucidum*: (a) control water-soluble extract (*G. lucidum*); (b) Ag-coated ZnO NPs with water-soluble extract of *G. lucidum*.



(a) (b)

Figure 4: SEM analysis of Ag-coated ZnO NPs synthesized from *G. lucidum*: (a) synthesized nanoparticles; (b) enlarged portion of Ag-coated ZnO NPs.

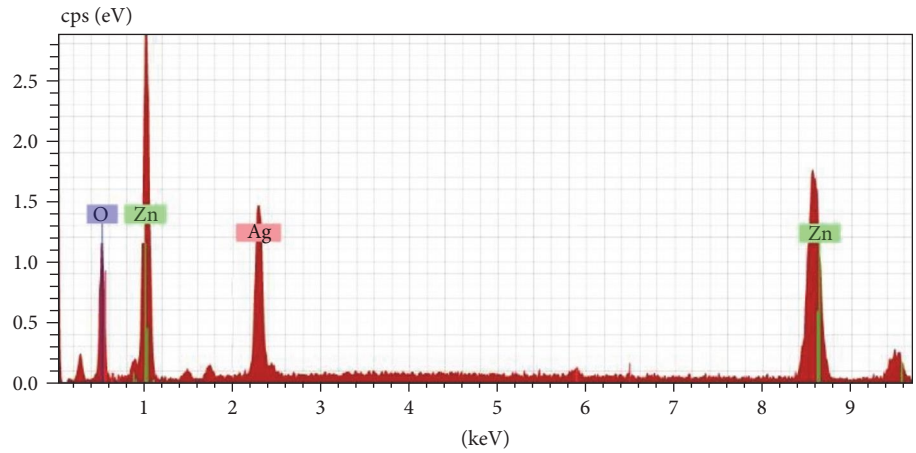


Figure 5: EDAX spectrum of Ag-coated ZnO NPs synthesized from *G. lucidum*.

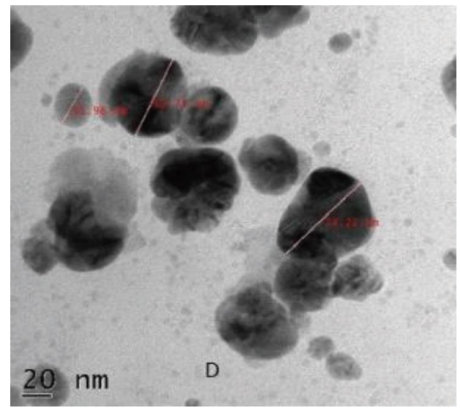


Figure 6: TEM analysis of Ag-coated ZnO NPs synthesized from *G. lucidum*.

carbohydrate digestive enzyme inhibition effect was reported earlier in the antidiabetic activity of Ag NPs from green synthesis using *Lonica japonica* leaf extract by Balan et al. [28].

3.8. Cytotoxicity–MTT Assay. MTT assay was performed on chemoresistance breast cancer MDA-MB 231 cell lines to investigate the anticancer activity of Ag–ZnO NPs synthesized from *G. lucidum*. The attained results shown in Figure 7 exhibits that the cell viability was significantly decreased when increasing the concentration of both ZnO NPs coated with Ag synthesized from *G. lucidum* and crude extract of *G. lucidum* on cell lines. Trypan blue assay resulted in maximum quantity of more than 90% of dead cells stained by trypan blue assay counted using a hemocytometer on a basic upright microscope. Nanoparticles are a good therapeutic agent in anticancer therapy. *G. lucidum* is a good anticancer medicine since ancient days [29]; so, nanoparticle and *G. lucidum* will be a good combination in treating breast

Table 2: Alpha amylase inhibition assay effect of Ag-coated ZnO NPs synthesized from *G. lucidum*.

Sr. No.	Concentration (μg/ml)	Percent (%) inhibition of alpha-glucosidase activity	Standard (acarbose)
1.	10	32.33 ± 0.01	13.06 ± 0.01
2.	20	46.52 ± 0.10	20.09 ± 0.01
3.	40	58.90 ± 0.01	39.30 ± 0.01
4.	60	75.32 ± 0.01	53.59 ± 0.03
5.	80	82.21 ± 0.06	70.78 ± 0.01
6.	100	94.37 ± 0.06	85.34 ± 0.02
7.	IC 50 (μg/ml)	24	39

Values are mean $\pm$ SD ($n = 6$), values not sharing a common letter differ significantly at <0.05 by DMRT.

Table 3: Alpha-glucosidase inhibition effect of Ag-coated ZnO NPs synthesized from *G. lucidum*.

Sr. No.	Concentration (μg/ml)	Percent (%) inhibition of alpha-amylase activity	Standard (acarbose)
1.	10	14.01 ± 0.01	18.17 ± 0.01
2.	20	28.67 ± 0.01	21.34 ± 0.01
3.	40	37.25 ± 0.01	31.21 ± 0.02
4.	60	45.34 ± 0.02	42.78 ± 0.01
5.	80	68.12 ± 0.01	60.34 ± 0.03
6.	100	79.24 ± 0.01	74.71 ± 0.01
7.	IC 50 (μg/ml)	47	50

Values are mean $\pm$ SD ($n = 6$), values not sharing a common letter differ significantly at <0.05 by DMRT.

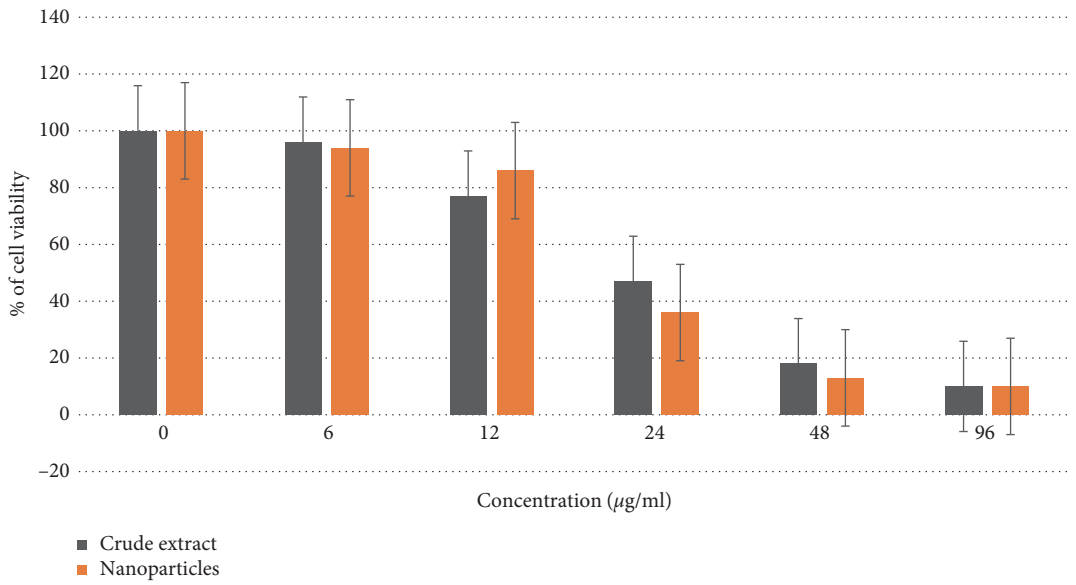


Figure 7: Percentage of cell viability for crude extract and synthesized ZnO NPs coated with Ag based on the MTT assay.

cancer. Our synthesized Ag–ZnO NPs might be an alternative treatment and therapeutic approach against cancer because other treatments include chemotherapy, radiotherapy, and drugs are potentially cause severe side effects like pain, strain, etc. In the future, the production of drugs by using natural sources instead of toxic chemicals will play a major role in pharmaceutical industries [30]. Currently, several studies are going on with the combination of nanoparticles and other therapeutic techniques like infrared laser light for treating the various types of cancers. In those researches, the positive results are appearing in the animal models which were proved by many researchers. Hence, more clinical trials are needed to successfully approve nanoparticle-related treatments for testing on humans [31]. In this study, Ag–ZnO NPs and crude extract of mushroom were treated on human chemoresistance breast cancer MDA-MB 231 cell lines.

4. Conclusion

The biosynthesis method used in this study exhibited a simple, eco-friendly meanwhile budget-friendly process when compared to other methods. Thus, the results of the present study successfully proved the antidiabetic and anticancer potential of our mycosynthesized Ag–ZnO NPs. The effect of Ag–ZnO NPs on chemoresistance breast cancer MDA-MB 231 cell lines revealed promising cytotoxicity. Due to nontoxic and less usage of chemicals, these kinds of biosynthesized Ag–ZnO NPs will predominantly take their place in the pharmaceutical field.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] A. Arya, K. Gupta, T. S. Chundawat, and D. Vaya, "Biogenic synthesis of copper and silver nanoparticles using green alga *Botryococcus braunii* and its antimicrobial activity," *Bioinorganic Chemistry and Applications*, vol. 2018, Article ID 7879403, 9 pages, 2018.

[2] N. A. Martynova, V. N. Svishchev, L. S. Lepnev et al., "Electrochemical coprecipitation of zinc and aluminum in aqueous electrolytes for ZnO and AZO coverage deposition," *International Journal of Photoenergy*, vol. 2019, Article ID 6808347, 10 pages, 2019.

[3] A. Hussain, M. Oves, M. F. Alajmi et al., "Biogenesis of ZnO nanoparticles using *Pandanus odorifer* leaf extract: anticancer and antimicrobial activities," *RSC Advances*, vol. 9, no. 27, pp. 15357–15369, 2019.

[4] H. M. Fahmy, A. M. Mosleh, A. A. Elghany et al., "Coated silver nanoparticles: synthesis, cytotoxicity, and optical properties," *RSC Advances*, vol. 9, no. 35, pp. 20118–20136, 2019.

[5] J. Singh, T. Dutta, K. H. Kim, M. Rawat, P. Samddar, and P. Kumar, "Green synthesis of metals and their oxide nanoparticles: applications for environmental remediation," *Journal of Nanobiotechnology*, vol. 16, Article ID 84, 2018.

[6] P. D. Babu and R. S. Subhasree, "The sacred mushroom "Reishi"-a review," *American-Eurasian Journal of Botany*, vol. 1, no. 3, pp. 107–110, 2008.

[7] C. Kao, A. C. Jesuthasan, K. S. Bishop, M. P. Glucina, and L. R. Ferguson, "Anti-cancer activities of *Ganoderma lucidum*: active ingredients and pathways," *Functional Foods in Health and Disease*, vol. 3, no. 2, pp. 48–65, 2013.

[8] P. Batra, A. K. Sharma, and R. Khajuria, "Probing lingzhi or reishi medicinal mushroom *Ganoderma lucidum* (higher Basidiomycetes): a bitter mushroom with amazing health benefits," *International Journal of Medicinal Mushrooms*, vol. 15, no. 2, pp. 127–143, 2013.

[9] H. M. Abdelmigid, M. M. Morsi, N. A. Hussien, A. A. Alyamani, and N. M. Al Sufyani, "Comparative analysis of nanosilver particles synthesized by different approaches and their antimicrobial efficacy," *Journal of Nanomaterials*, vol. 2021, Article ID 2204776, 12 pages, 2021.

[10] P. Senthilkumar, R. S. Kumar, L. Surendran et al., "Potent antidiabetic activity of aqueous extract of brown seaweed *Padina boergesenii* in streptozotocin-induced diabetic rats," *World Journal of Pharmaceutical Research*, vol. 6, no. 8, pp. 2022–2035, 2017.

[11] D. S. Ranjith Santhosh Kumar, P. Senthilkumar, L. Surendran, and B. Sudhagar, "*Ganoderma lucidum*-oriental mushroom mediated synthesis of gold nanoparticles conjugated with doxorubicin and evaluation of its anticancer potential on human breast cancer mcf-7/dox cells," *International Journal of Pharmacy and Pharmaceutical Sciences*, vol. 9, no. 9, pp. 267–274, 2017.

[12] S. Abel, J. L. Tesfaye, N. Nagaprasad, R. Shanmugam, L. P. Dwarampudi, and R. Krishnaraj, "Synthesis and characterization of zinc oxide nanoparticles using moringa leaf extract," *Journal of Nanomaterials*, vol. 2021, Article ID 4525770, 6 pages, 2021.

[13] S. Vinodhini, B. S. M. Vithiya, and T. A. A. Prasad, "Green synthesis of palladium nanoparticles using aqueous plant extracts and its biomedical applications," *Journal of King Saud University-Science*, vol. 34, no. 4, Article ID 102017, 2022.

[14] T. Matsui, S. Ebuchi, K. Fukui, K. Matsugano, N. Terahara, and K. Matsumoto, "Caffeoylsophorose, a new natural α-glucosidase inhibitor, from red vinegar by fermented purple-fleshed sweet potato," *Bioscience, Biotechnology, and Biochemistry*, vol. 68, no. 11, pp. 2239–2246, 2004.

[15] C. Hansawasdi, J. Kawabata, and T. Kasai, "α-Amylase inhibitors from roselle (*Hibiscus sabdariffa Linn.*) tea," *Bioscience, Biotechnology, and Biochemistry*, vol. 64, no. 5, pp. 1041–1043, 2000.

[16] L. Thangavelu, A. H. Adil, S. Arshad et al., "Antimicrobial properties of silver nitrate nanoparticle and its application in endodontics and dentistry: a review of literature," *Journal of Nanomaterials*, vol. 2021, Article ID 9132714, 12 pages, 2021.

[17] M. Ehsan, A. Waheed, A. Ullah et al., "Plant-based bimetallic silver-zinc oxide nanoparticles: a comprehensive perspective of synthesis biomedical applications, and future trends," *BioMed Research International*, vol. 2022, Article ID 1215183, 20 pages2022.

[18] P. Mulvaney, "Surface plasmon spectroscopy of nanosized metal particles," *Langmuir*, vol. 12, no. 3, pp. 788–800, 1996.

[19] M. M. Chikkanna, S. E. Neelagund, and K. K. Rajashekarappa, "Green synthesis of zinc oxide nanoparticles (ZnO NPs) and their biological activity," *SN Applied Sciences*, vol. 1, Article ID 117, 2019.

[20] J. Estrada-Urbina, A. Cruz-Alonso, M. Santander-González, A. Méndez-Albores, and A. Vázquez-Durán, "Nanoscale zinc oxide particles for improving the physiological and sanitary quality of a Mexican landrace of red maize," *Nanomaterials*, vol. 8, no. 4, Article ID 247, 2018.

[21] M. D. Jayappa, C. K. Ramaiah, M. A. P. Kumar et al., "Green synthesis of zinc oxide nanoparticles from the leaf, stem and in vitro grown callus of *Mussaenda frondosa L.*: characterization and their applications," *Applied Nanoscience*, vol. 10, pp. 3057–3074, 2020.

[22] T. Siva Vijayakumar, S. Karthikeyeni, S. Vasanth et al., "Synthesis of silver-doped zinc oxide nanocomposite by pulse mode ultrasonication and its characterization studies," *Journal of Nanoscience*, vol. 2013, Article ID 785064, 7 pages, 2013.

[23] J. Santhoshkumar, S. V. Kumar, and S. R. Kumar, "Synthesis of zinc oxide nanoparticles using plant leaf extract against urinary tract infection pathogen," *Resource-Efficient Technologies*, vol. 3, no. 4, pp. 459–465, 2017.

[24] R. Dobrucka and J. Długaszewska, "Biosynthesis and antibacterial activity of ZnO nanoparticles using *Trifolium pratense* flower extract," *Saudi Journal of Biological Sciences*, vol. 23, no. 4, pp. 517–523, 2016.

[25] K. B. Narayanan and N. Sakthivel, "Green synthesis of biogenic metal nanoparticles by terrestrial and aquatic phototrophic and heterotrophic eukaryotes and biocompatible agents," *Advances in Colloid and Interface Science*, vol. 169, no. 2, pp. 59–79, 2011.

[26] M. Ramesh, M. Anbuvannan, and G. Viruthagiri, "Green synthesis of ZnO nanoparticles using *Solanum nigrum* leaf extract and their antibacterial activity," *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, vol. 136, Part B, pp. 864–870, 2015.

[27] P. Jamdagni, P. Khatri, and J. S. Rana, "Green synthesis of zinc oxide nanoparticles using flower extract of *Nyctanthes arbortristis* and their antifungal activity," *Journal of King Saud University-Science*, vol. 30, no. 2, pp. 168–175, 2018.

[28] K. Balan, W. Qing, Y. Wang et al., "Antidiabetic activity of silver nanoparticles from green synthesis using *Lonicera japonica* leaf extract," *RSC Advances*, vol. 6, no. 46, pp. 40162–40168, 2016.

[29] S. D. Mankar, S. Thombare, T. Todmal, R. Waghe, and A. Borde, "Medicinal mushroom: an ancient culture towards new lifestyle," *Research Journal of Pharmacognosy and Phytochemistry*, vol. 14, no. 1, pp. 50–54, 2022.

[30] S. Rajeshkumar, S. Menon, S. V. Kumar, M. Ponnanikajamideen, D. Ali, and K. Arunachalam, "Anti-inflammatory and antimicrobial potential of *Cissus quadrangularis*-assisted copper oxide nanoparticles," *Journal of Nanomaterials*, vol. 2021, Article ID 5742981, 11 pages, 2021.

[31] P. Senthilkumar, G. Yaswant, S. Kavitha et al., "Preparation and characterization of hybrid chitosan-silver nanoparticles (Chi-Ag NPs): a potential antibacterial agent," *International Journal of Biological Macromolecules*, vol. 141, pp. 290–298, 2019.