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Green Synthesis of ZnO Nanoparticles and Evaluation of Its Effect on Cancer Cells

Nilgün Güler[a], Dilek Bahar[b], Mithat Güllü[c, *], Şerife Gürbüz[d], Muhammad Shahid Iqbal[e, #], Zeshan Hassan[f], Tahira Abbas[g], and Mushtaq Hussain[e]

[a] *Kayseri University Mustafa Cikrikcioglu Vocational School, Chemistry Technology Programme, Kayseri, Türkiye*
[b] *Erciyes University Genom and Stem Cell Centre (GENKOK), Kayseri, Türkiye*
[c] *Department of Biology, Faculty of Science, Erciyes University, Kayseri, Türkiye*
[d] *Department of Biology, Graduate School of Natural and Applied Sciences, Erciyes University, Kayseri, Türkiye*
[e] *Department of Botany, University of Layyah, Layyah, 31200 Pakistan*
[f] *Department of Plant Production and Biotechnology, 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*

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Abstract—Technological advances are moving away from syntheses using natural materials. Thus, synthetic materials used in industrial production and synthesis lead to environmental pollution. In this study, a green, sustainable, simple and low-cost synthesis method was used for the synthesis of ZnO NPs. For this, extracts of *Malus domestica* (Yahyali apple) (S1), *Rosa canina* L. (rosehip) (S2), *Viburnum opulus* L. (gilaburu) (S3) and *Tilia* L. (linden) (S4) plants were prepared. Everyone biomass sample separately was combined with A549, DLD-1 and HepG2 cancer cells and healthy L929 cells and its antiproliferative effects on the cells were examined by the MTT (3-(4.5-Dimethylthiazol-2-yl)-2.5-Diphenyltetrazolium Bromide) method. It was observed that the biomass samples obtained from gilaburu, linden, yayla apple and rosehip extracts contained point ZnO NPs in the wurtzite structure with a size 1–3 nm. All samples showed an antiproliferative effect on L929 healthy cells at a concentration of 12.5 μM and this effect continued even at decreasing concentrations. All samples showed an antiproliferative effect with an approximately 80% decrease in the number of A549 lung cancer cells compared to other cancer cells. If the effect of the samples on healthy fibroblast L929 cells is brought to a tolerable level or can be evaluated as a side effect on the connective tissue, all samples can be used as anticancer drug in the treatment of these cancers since they show cytotoxic effects on A549, HEPG2, DLD-1 cancer cells at 12.5 μM concentration. Further cancer research may lead to the use of nanoparticles at specified concentrations in the treatment of cancer in animals and humans.

Keywords: A549 cell line, cancer cells, gilaburu, green synthesis, ZnO NP's
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INTRODUCTION

Nanotechnology studies have become an interesting field for many researchers due to their multidisciplinary nature and have become one of the fastest developing scientific and technological fields. This technology covers the design, manufacturing, and analysis of nanostructural and physical properties of nanomaterials (Sedefoğlu, 2024; Waseem et al., 2024; Kumar and Yadav, 2009). The size of nanoparticles is between 1–100 nm, they have different shapes, and their morphology varies depending on the method of production (Horikoshi and Serpone, 2013). Nanoparticles, which can be obtained from a wide variety of metals, have attracted great attention due to their morphological properties and have begun to be studied in almost every field. However, many of the physical and chemical methods used in the production of nanoparticles require reducing agents and organic solvents that show high reactivity and toxicity (Umadevi and Krishna, 2024). However, nanoparticle synthesis by Green synthesis is a more cost-effective, environmentally friendly and biocompatible synthesis method than other methods. In this method, extracts obtained from various parts of plants are widely used for the synthesis of nanoparticles. These extracts contain various phytochemicals that act as coating and reducing agents. Plant materials are preferred more often than other biomaterials due to their easy availability and safe use. Additionally, its suitability for large-scale production is among its advantages (Hussain et al., 2016; Thakur and Yadav, 2024; Chandra et al., 2020;

[#] Nilgün Güler and Muhammad Shahid Iqbal are Co-first authors.

Iravani, 2011; Vijayaraghavan and Ashokkumar, 2017). Zinc oxide (ZnO) nanoparticles are among the nanoparticles frequently researched in scientific and industrial fields. It has found application in many different fields with its large surface area relative to its volume, superior catalytic efficiency, and special optical and electrical properties (Bhandari et al., 2023). It is used extensively in chemical sensors, Ultraviolet (UV) filters, cosmetics and sunscreen creams. It is widely researched as an antimicrobial preservative in the food industry and in the biomedical field for its antimicrobial and anticancer activity. In addition to traditional methods, the effects of ZnO nanoparticles produced through green synthesis are also widely investigated (Patidar et al., 2013; Diak et al., 2015; Smijs and Pavel, 2011; Espitia et al., 2025; Xie et al., 2011; Bisht and Rayamajhi, 2016; Gopala et al., 2017; Krishna et al., 2016).

In this study, impure ZnO nanoparticles were synthesized from extracts of rosehip, linden, yahyali apple and gilaburu plants and their proliferative-antiproliferative effects on cells were tested by combining them with various cell lines.

MATERIALS AND METHODS

Collection of Plant Specimens

Plant material was collected in accordance with applicable national and international guidelines (International Union for Conservation of Nature). *International Union for Conservation of Nature Natural Resources IUCN Red List Categories and Criteria* (IUCN, 2001). Yahyali Apple was obtained from a garden established on an area of 300 decares located between Senirköy and Yeşilhisar Ovaçiftliği neighborhoods of Yahyali district of Kayseri province. Gilaburu, Linden and Rosehip were collected from Han Mah., Talas, Kayseri. Coordinates: 38.684300, 35.562577. $Zn(NO_3)_2{\cdot}6H_2O$ (from Sigma) was used as the Zinc source in the synthesis.

Preparation of Plant Specimens

Specimens were carefully washed using tap water then distilled water, to remove soil particles. Afterward, the specimens were dried at 60°C to constant weight then grounded to fine powder using a stainless-steel grinder Green Zech 850 W, China. Plant powder was preserved in airtight jars for subsequent use.

Preparation of Extracts from Plants

Plant powders of Yahyali apple, rosehip, gilaburu and linden were used to obtain their extracts. Plant powders were individually weighed 25 g. It was mixed with 100 mL of distilled H_2O at 95°C for 1 h with a magnetic stirrer. The resulting extract was cooled to 25°C and filtered twice with Whatman No. 1 filter paper to remove large particles. The extracts were stored in the refrigerator at 4°C for using green.

Green Synthesis of ZnO-NPs

The synthesis steps of ZnO-NPs are shown in Fig. 1. A small amount of solvent (H_2O) and 5 g of Zinc nitrate ($Zn(NO_3)_2{\cdot}6H_2O$) were separately added to 50 mL of extracts at 100°C and magnetically stirred until the ZnO structure was formed, then the mixture was annealed in the oven at 400°C for 120 min. Thus, Biomass powder samples containing ZnO-NPs were obtained. The resulting light yellow four powders were separately used in subsequent biological studies. SEM and X-RD analyzes were performed for the characterization of ZnO-NPs synthesized from four different plants (Abbasi et al., 2016). Different analyses were performed to detect the presence of inorganic nano ZnO in biomass containing phytochemicals and organic matter from different plant extracts.

SEM Analysis

The powder S1, S2, S3, S4 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 samples are separately 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.

X-RD 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 separately ground thoroughly in a mortar and further turned into powder. Powder four samples are separately 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 (Hossain and Islam, 2013).

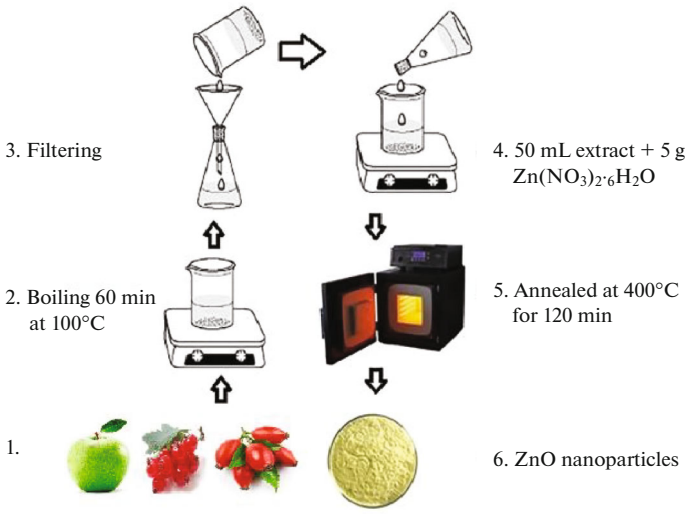


Fig. 1. Synthesis of ZnO-NPs by plants (Colak et al., 2017).

Cell Culture

To determine the antiproliferative effect of the synthesized S1, S2, S3 and S4 samples, human lung adenocarcinoma cell line (A549), human colon adenocarcinoma cell line (DLD-1), human hepatocellular carcinoma cell line (HepG2) and healthy mouse fibroblast cell line (L929) were used. Cell lines were cultured separately in F-12K (contains 2 mM L-glutamine and 1500 mg/L sodium bicarbonate), RPMI 1640 and Dulbecco's Modified Eagle's Medium (DMEM), 10% Fetal Bovine Serum (FBS), 1% L-Glutamine, 1% Penicillin-Streptomycin culture media, respectively, in T75 cell culture flasks, in a 37°C, 5% CO_2 incubator until they reached 75% confluency.

MTT Test

Cells were seeded in 96-well plates at 5×10^3 cells/well and incubated for one day. ZnO samples were sterilized by passing through filters with 0.22 μm micrometers pores. Then, the samples containing ZnO nanoparticles were added to the wells by serial dilution with PBS in volumes of 12.5, 6.25, 3.125, 1.56 and 0.78 μM and incubated for 24 h. For the MTT solution, 5 mg MTT powder was dissolved in 1 mL dPBS, and after incubation, 20 μL of MTT solution was added to the wells, each with a volume of 200 μL to a final concentration of 5 mg/mL and incubated for 3 h. Following the observation of formazan crystals, the culture medium was aspirated and formazan crystals were dissolved with Dimethyl sulfoxide (DMSO). The colour formed was read on the Enzyme Linked Immuno-Sorbent Assay (ELISA) reader at 560 nm (Saha et al., 2023; Hussein and Mohammed, 2021; Rani et al., 2022; Nilavukkarasi et al., 2020; Rajeshkumar et al., 2018).

RESULTS

Characterization of Samples

SEM images of ZnO nanoparticles from four plants. The hollow-wurtzite structure (in Fig. 3) is observed in Figs. 2a–2d and dot ZnO particles with dimensions of 1–3 nm attract attention in (Fig. 2).

X-ray (X-RD) analysis results. Figure 4 is the XRD analysis results of ZnO NP's produced from plant extracts and belongs to four different 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), (11 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. 4 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.

Cell study results. A549, DLD-1 and HEPG2 cancer cells and healthy L929 cells were used in this study. ZnO nanoparticles obtained from 4 different sources were combined with these cells and the MTT test was applied. When results compared with the control, it was observed that all samples caused a decrease in the number of cells in the cancerous and healthy cell lines at high concentrations. It was even determined that A549 lung cancer cells were destroyed more than all

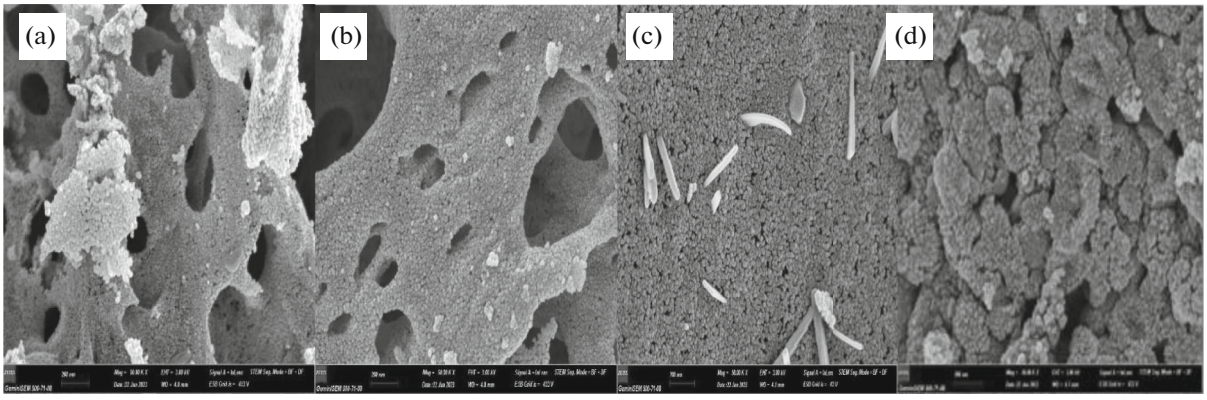


Fig. 2. SEM images of ZnO NP's produced from extracts (a) Yahyali apple; S1 (b) Rosehip; S2 (c) Gilaburu; S3 (d) Linden; S4. (Photographs at 50000 times magnification).

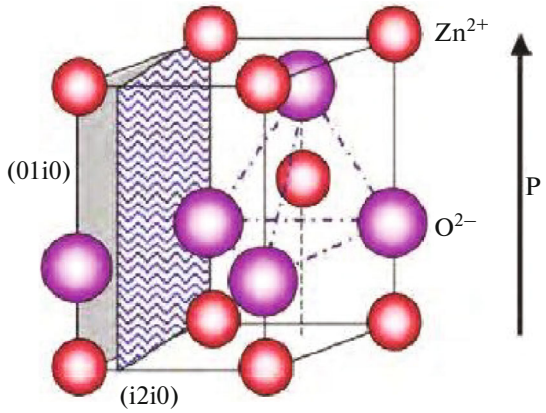


Fig. 3. The Wurtzite structure model of ZnO (Uthirakumar, 2011).

samples and had an active antiproliferative, cytotoxic effect. This situation is seen in the graphs in Fig. 5.

DISCUSSION

There are anticancer studies in the literature on nano ZnO by green synthesis from different plants (Bisht and Rayamajhi, 2016; Shobhaa et al., 2017; Al-Hraishawi et al., 2023). However, no green synthesis study has been found with the plants used in this study. For example, in the study conducted by Çigdem Acar, it was determined that nano ZnO obtained by green synthesis from Achiella Millefeuille L. plant had a cytotoxic effect on A549 and HT29 cancer cells at 42.82 µg/Ml (Acar, 2021). The synthesis of ZnO particles from an extract obtained from the pomegranate flower, namely *Hibiscus* leaves (Bala et al., 2015). Studies in the literature mostly involve the preparation of nanoparticles containing silver and gold metals via green synthesis and their determination of biological activity (Zahir and Rahuman, 2012; Gudikandula and Charya, 2016; Kunjiappan et al., 2014). There are also studies on the synthesis of nanoparticles containing copper, palladium, and platinum elements from extracts obtained via green synthesis (Nazar et al., 2018; Nasrollahzadeh and Sajadi, 2016). There are publications investigating the antioxidant, antifungal, antibacterial, photodegradative, and cytotoxic properties of ZnO nanoparticles obtained via green synthesis (Suresh et al., 2015; Nagajyothi et al., 2014).

In this study, ZnO nanoparticles obtained by green synthesis method from linden, rose hip, yahyal apple and gilaburu plant extracts were tested on A549, DLD-1, HepG2 and L929 cell lines and their antiproliferative effects were revealed. It was determined that nanoparticles showed antiproliferative, cytotoxic activity in all cell lines compared to the control group. However, this effect showed an opposite correlation

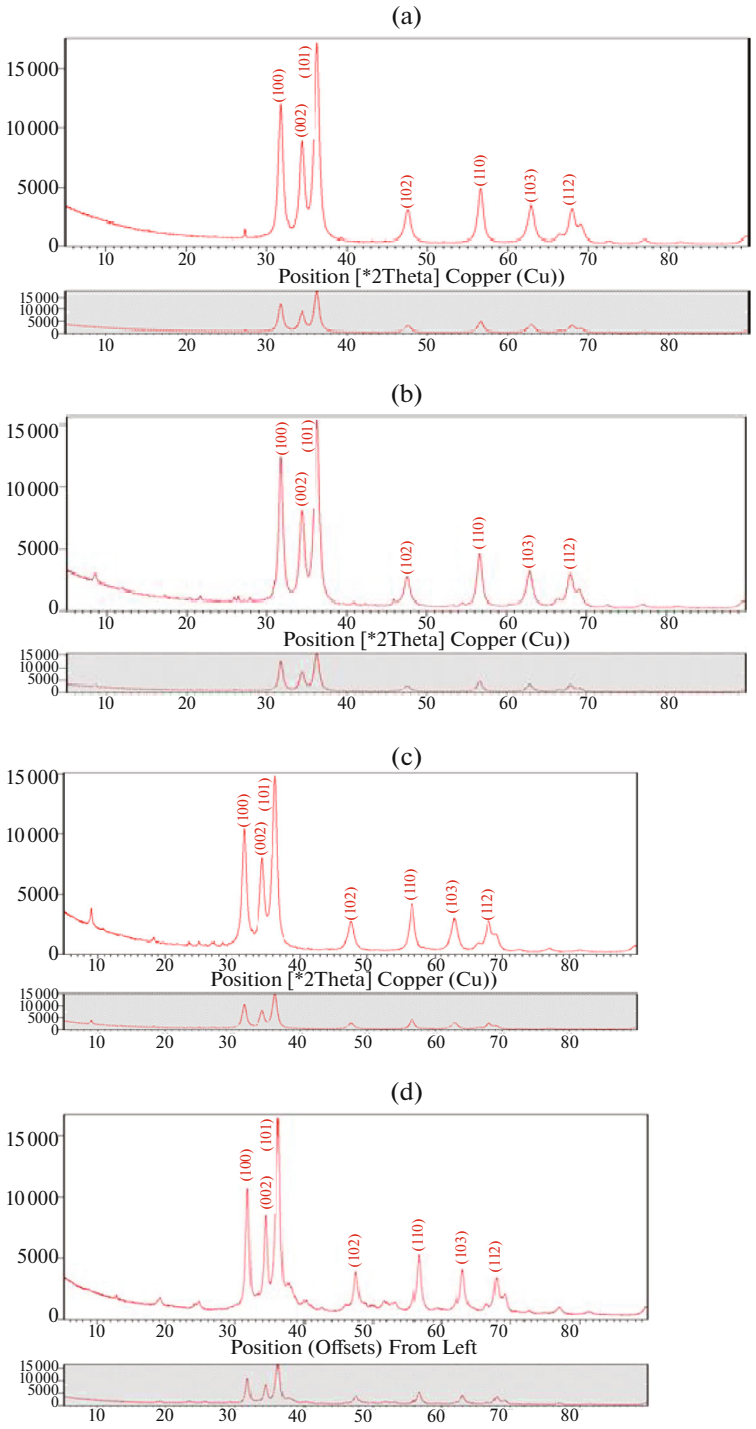


Fig. 4. X-ray analysis results of Samples (S1, S2, S3, S4) produced plant extracts from (a) Rosehip, (b) Gilaburu, (c) Yahyali apple, (d) Linden.

with concentration, and as the concentration decreased, the antiproliferative effect increased. Because all extracts contained different phytochemicals, they showed the same antiproliferative effect on all cancer cells because their nano ZnO content was the same. This suggests that this is due to the energetic nanoparticles they contain. Nano ZnO synthesized from extracts obtained from different plants is considered a mixture of biomass with the same chemical structure but different. Therefore, each contains the

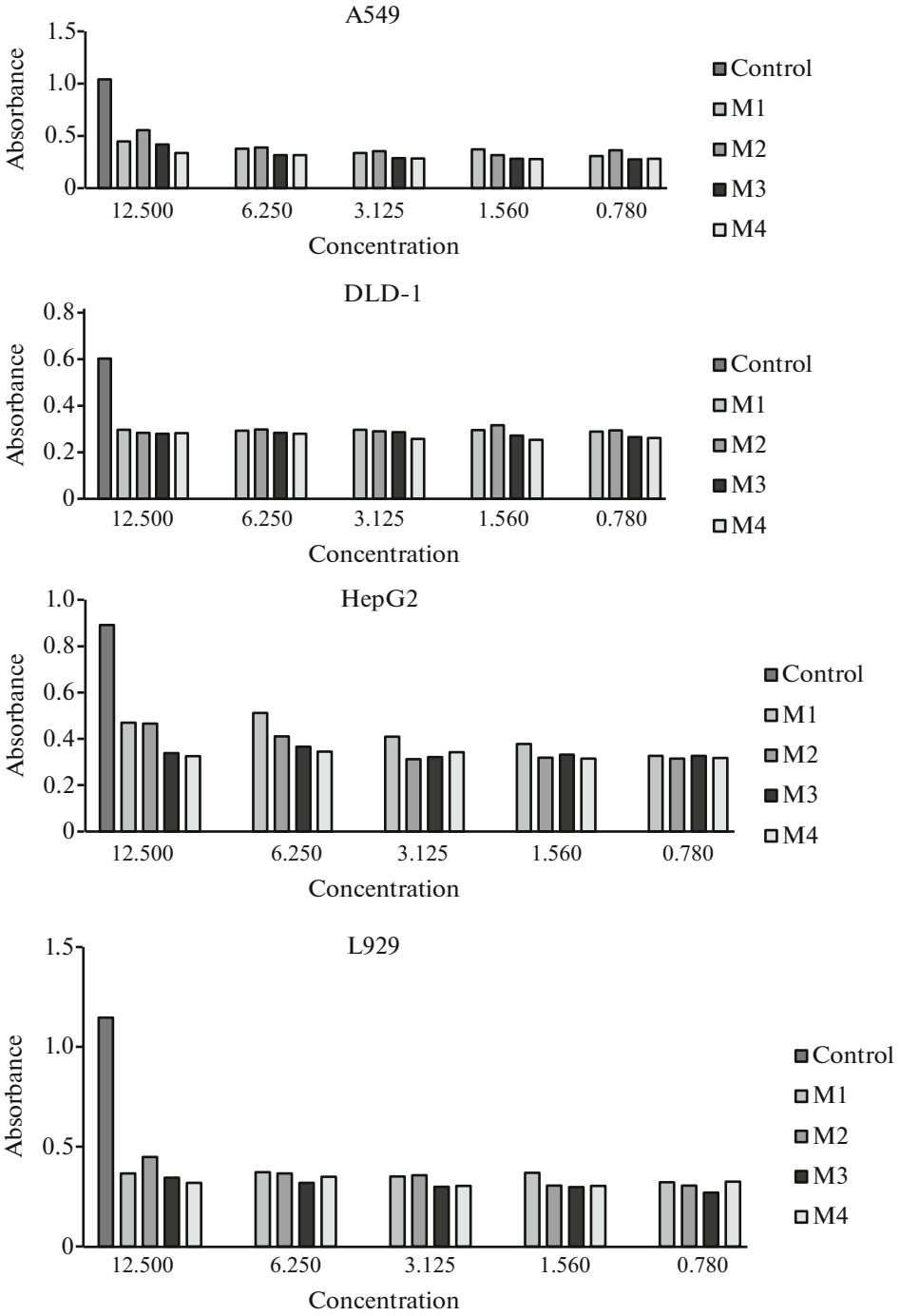


Fig. 5. Graphical Results of MTT Tests on Four Different Cell Lines (A549; DLD-1; HepG2; L929) for M1 (=S1), M2 (=S2), M3 (=S3), M4 (=S4) samples.

same nano ZnO but has a different environment, so the biomass will interact differently with cancer cells.

CONCLUSIONS

In this study, the same behaviors of common nano ZnO found in different samples obtained by green synthesis on cells reveal the potential of all samples to be used as anticancer agents. Because the resulting nano ZnO is not pure, the biomass mixture and its environment will vary depending on the plant used for synthesis. Therefore, whether the nano ZnO size is small or large, it will not affect the results of the study. The other problem is that if the cytotoxic effect on healthy

fibroblast cells is considered as a tolerable side effect, the obstacle to the samples being anticancer agents, drugs will be eliminated. Because every cancer drug has tolerable side effects, clinical and phase studies and evaluations should be done on this subject.

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AUTHOR CONTRIBUTION

Concept-NG; Design-NG; Resources-NG, DB; ŞG; Materails—NG, MG, MSI, ZA, TA, MH; Data Collection and/or Processing—NG, MG, MSI, ZA, TA, MH, DB, ŞĞ; Analysis and/or Interpretation—NG, DB, ŞĞ; Literature Search—NG, DB, ŞG; Writing Manuscript—NG, DB.; MG, MSI, ZA, TA, MH.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

No human or animal subjects were used in this study. Therefore, there was no need to comply with the principles of the Declaration of Helsinki.

CONFLICT OF INTEREST

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

REFERENCES

Abbasi, E., Milani, M., Fekri Aval, S., Kouhi, M., Akbarzadeh, A., Tayefi Nasrabadi, H., Nikasa, P., Joo, S.W., Hanifehpour, Yo., Nejati-Koshki, K., and Samiei, M., Silver nanoparticles: synthesis methods, bio-applications and properties, *Crit. Rev. Microbiol.*, 2016, vol. 42, no. 2, pp. 173–180.
https://doi.org/10.3109/1040841x.2014.912200

Acar, Ç.A., Green synthesis of zinc oxide nanoparticles using aqueous extract of *Achiella millefolium* L. in vitro anticancer potential on lung and colon cancer cells, *Turk. J. Health Sci. Life*, 2021, vol. 4, no. 1, pp. 40–45. https://izlik.org/JA58FH85AF.

Al-Hraishawi, H., Al-Saadi, N., and Jabbar, S., In vitro analysis: the anticancer activity of zinc oxide nanoparticles from *Cinnamomum verum, J. Nanostruct.*, 2023, vol. 13, no. 1, pp. 146–150.
https://doi.org/10.22052/JNS.2023.01.016

Bala, N., Saha, S., Chakraborty, M., Maiti, M., Das, S., Basu, R., and Nandy, P., Green synthesis of zinc oxide nanoparticles using *Hibiscus subdariffa* leaf extract: effect of temperature on synthesis, anti-bacterial activity and anti-diabetic activity, *RSC Adv.*, 2015, vol. 5, no. 7, pp. 4993–5003.
https://doi.org/10.1039/c4ra12784f

Bhandari, Kh.P., Sapkota, D.R., Jamarkattel, M.K., Stillion, Q., and Collins, R.W., Zinc oxide nanoparticles—solution-based synthesis and characterizations, *Nanomaterials*, 2023, vol. 13, no. 11, p. 1795.
https://doi.org/10.3390/nano13111795

Bisht, G. and Rayamajhi, S., ZnO nanoparticles: a promising anticancer agent, *Nanobiomedicine*, 2016, vol. 3, p. 9.
https://doi.org/10.5772/63437

Chandra, H., Kumari, P., Bontempi, E., and Yadav, S., Medicinal plants: treasure trove for green synthesis of metallic nanoparticles and their biomedical applications, *Biocatal. Agric. Biotechnol.*, 2020, vol. 24, p. 101518.
https://doi.org/10.1016/j.bcab.2020.101518

Çolak, H., Karaköse, E., and Duman, F., High optoelectronic and antimicrobial performances of green synthesized ZnO nanoparticles using *Aesculus hippocastanum, Environ. Chem. Lett.*, 2017, vol. 15, no. 3, pp. 547–552.
https://doi.org/10.1007/s10311-017-0629-z

Diak, M., Grabowska, E., and Zaleska, A., Synthesis, characterization and photocatalytic activity of noble metal-modified TiO_2 nanosheets with exposed {0 0 1} facets, *Appl. Surf. Sci.*, 2015, vol. 347, pp. 275–285.
https://doi.org/10.1016/j.apsusc.2015.04.103

Espitia, P.J.P., Batista, R.A., Otoni, C.G., and Soares, N.F.F., Antimicrobial food packaging incorporated with triclosan: potential uses and restrictions, *Antimicrobial Food Packaging*, Elsevier, 2025, pp. 595–602.
https://doi.org/10.1016/b978-0-323-90747-7.00037-5

Gopala Krishna, P., Paduvarahalli Ananthaswamy, P., Gadewar, M., Bora, U., and Bhangi Mutta, N., In vitro antibacterial and anticancer studies of ZnO nanoparticles prepared by sugar fueled combustion synthesis, *Adv. Mater. Lett.*, 2017, vol. 8, no. 1, pp. 24–29.
https://doi.org/10.5185/amlett.2017.6424

Gudikandula, K. and Charya Maringanti, S., Synthesis of silver nanoparticles by chemical and biological methods and their antimicrobial properties, *J. Exp. Nanosci.*, 2016, vol. 11, no. 9, pp. 714–721.
https://doi.org/10.1080/17458080.2016.1139196

Bisht, G. and Rayamajhi, S., ZnO nanoparticles: a promising anticancer agent, *Nanobiomedicine*, 2016, vol. 3, p. 9.
https://doi.org/10.5772/634

Hossain, M.A. and Islam, S., Synthesis of carbon nanoparticles from kerosene and their characterization by SEM/EDX, XRD and FTIR, *Am. J. Nanosci. Nanotechnol.*, 2013, vol. 1, no. 2, pp. 52–56.
https://doi.org/10.11648/j.nano.20130102.12

Hussain, I., Singh, N.B., Singh, A., Singh, H., and Singh, S.C., Green synthesis of nanoparticles and its potential application, *Biotechnol. Lett.*, 2016, vol. 38, no. 4, pp. 545–560.
https://doi.org/10.1007/s10529-015-2026-7

Hussein, B.Y. and Mohammed, A.M., Green synthesis of ZnO nanoparticles in grape extract: Their application as anti-cancer and anti-bacterial, *Mater. Today Proc.*, 2021, vol. 42, pp. a18–a26.
https://doi.org/10.1016/j.matpr.2021.03.729

Iravani, S., Green synthesis of metal nanoparticles using plants, *Green Chem.*, 2011, vol. 13, no. 10, p. 2638.
https://doi.org/10.1039/c1gc15386b

Krishna, P.G., Ananthaswamy, P.P., Yadavalli, T., Mutta, N.B., Sannaiah, A., and Shivanna, Y., ZnO nanopellets have selective anticancer activity, *Mat. Sci. Eng.*, 2016, vol. 62, pp. 919–926.
https://doi.org/10.1016/j.msec.2016.02.039

Kumar, V. and Yadav, S.K., Plant-mediated synthesis of silver and gold nanoparticles and their applications, *J. Chem. Technol. Biotechnol.*, 2009, vol. 84, no. 2, pp. 151–157.
https://doi.org/10.1002/jctb.2023

Kunjiappan, S., Chowdhury, R., and Bhattacharjee, C., A green chemistry approach for the synthesis and characterization of bioactive gold nanoparticles using *Azolla microphylla* methanol extract, *Front. Mater. Sci.*, 2014, vol. 8, no. 2, pp. 123–135.
https://doi.org/10.1007/s11706-014-0246-8

Microwaves in Nanoparticle Synthesis: Fundamentals and Applications, Horikoshi, S. and Serpone, N., Eds., Wiley, 2013.

Nagajyothi, P.C., Sreekanth, T.V.M., Tettey, C.O., Jun, Ya.I., and Mook, Sh.H., Characterization, antibacterial, antioxidant, and cytotoxic activities of ZnO nanoparticles using *Coptidis rhizoma, Bioorg. Med. Chem. Lett.*, 2014, vol. 24, no. 17, pp. 4298–4303.
https://doi.org/10.1016/j.bmcl.2014.07.023

Nasrollahzadeh, M. and Mohammad Sajadi, S., Pd nanoparticles synthesized in situ with the use of *Euphorbia granulate* leaf extract: catalytic properties of the resulting particles, *J. Colloid Interface Sci.*, 2016, vol. 462, pp. 243–251.
https://doi.org/10.1016/j.jcis.2015.09.065

Natural Resources, Species Survival Commission, *IUCN Red List Categories and Criteria*, IUCN, 2001.

Nazar, N., Bibi, I., Kamal, Sh., Iqbal, M., Nouren, Sh., Jilani, K., Umair, M., and Ata, S., Cu nanoparticles synthesis using biological molecule of *P. granatum* seeds extract as reducing and capping agent: growth mechanism and photo-catalytic activity, *Int. J. Biol. Macromol.*, 2018, vol. 106, pp. 1203–1210.
https://doi.org/10.1016/j.ijbiomac.2017.08.126

Nilavukkarasi, M., Vijayakumar, S., and Prathipkumar, S., Capparis zeylanica mediated bio-synthesized ZnO nanoparticles as antimicrobial, photocatalytic and anticancer applications, *Mater. Sci. Energy Technol.*, 2020, vol. 3, pp. 335–343.
https://doi.org/10.1016/j.mset.2019.12.004

Patidar, D., Kaswan, A., Saxena, N.S., and Sharma, K., Monodispersed ZnO nanoparticles and their use in heterojunction solar cell, *Sci. World J.*, 2013, vol. 2013, no. 1, p. 260521.
https://doi.org/10.1155/2013/260521

Uthirakumar, A.P., Fabrication of ZnO based dye sensitized solar cells, *Solar Cells-Dye Sensitized Devices*, 2011.

Rajeshkumar, S., Kumar, S.V., Ramaiah, A., Agarwal, H., Lakshmi, T., and Roopan, S.M., Biosynthesis of zinc oxide nanoparticles using *Mangifera indica* leaves and evaluation of their antioxidant and cytotoxic properties in lung cancer (A549) cells, *Enzyme Microb. Technol.*, 2018, vol. 117, pp. 91–95.
https://doi.org/10.1016/j.enzmictec.2018.06.009

Rani, N., Rawat, K., Shrivastava, A., Ekta, Yadav, S., Gupta, K., and Saini, K., In vitro study of green synthesized ZnO nanoparticles on human lung cancer cell lines, *Mater. Today Proc.*, 2022, vol. 49, pp. 1436–1442.
https://doi.org/10.1016/j.matpr.2021.07.203

Saha, R., Subramani, K., Dey, S., Sikdar, S., and Incharoensakdi, A., Physicochemical properties of green synthesised ZnO nanoparticles and utilisation for treatment of breast cancer, *Process Biochem.*, 2023, vol. 129, pp. 170–184.
https://doi.org/10.1016/j.procbio.2023.03.016

Sedefoglu, N., Green synthesis of ZnO nanoparticles by *Myrtus communis* plant extract with investigation of effect of precursor, calcination temperature and study of photocatalytic performance, *Ceram. Int.*, 2024, vol. 50, no. 6, pp. 9884–9895.
https://doi.org/10.1016/j.ceramint.2024.01.387

Shobhaa, N., Nandab, N., and Nagabhushana, B.M., Nano ZnO and its perspective in anti-cancer activities, *Mapana J. Sci.*, 2017, vol. 16, no. 2, pp. 41–52.
https://doi.org/10.12723/mjs.41.5

Smijs, T.G. and Pavel, S., Titanium dioxide and zinc oxide nanoparticles in sunscreens: focus on their safety and effectiveness, *Nanotechnol., Sci. Appl.*, 2011, pp. 95–112.
https://doi.org/10.2147/nsa.s19419

Suresh, D., Nethravathi, P.C., Udayabhanu, Rajanaika, H., Nagabhushana, H., and Sharma, S.C., Green synthesis of multifunctional zinc oxide (ZnO) nanoparticles using *Cassia fistula* plant extract and their photodegradative, antioxidant and antibacterial activities, *Mater. Sci. Semicond. Process.*, 2015, vol. 31, pp. 446–454.
https://doi.org/10.1016/j.mssp.2014.12.023

Thakur, R. and Yadav, S., Smart multifaceted potential microbial inoculant isolated from rhizospheric soils of *Bergenia ciliata* and possible role in developing green biosynthesized nanoparticles, *Biocatal. Agric. Biotechnol.*, 2024, vol. 57, p. 103087.
https://doi.org/10.1016/j.bcab.2024.103087

Umadevi, G. and Krishna, K.G., *Camellia sinensis*-mediated green synthesis of ZnO nanoparticles: an eco-friendly approach for high-performance gas sensing, *Sens. Actuators, A*, 2024, vol. 374, p. 115479.
https://doi.org/10.1016/j.sna.2024.115479

Vijayaraghavan, K. and Ashokkumar, T., Plant-mediated biosynthesis of metallic nanoparticles: a review of literature, factors affecting synthesis, characterization techniques and applications, *J. Environ. Chem. Eng.*, 2017, vol. 5, no. 5, pp. 4866–4883.
https://doi.org/10.1016/j.jece.2017.09.026

Waseem, S., Nisa, Z.U., Zeeshan, T., Ali, M.D., Begum, T., Kayani, Z.N., and Ayub, A., Green synthesis of ZnO nanoparticles using *Nigella sativa* seed extract for antibacterial activities, *Nano-Struc. Nano-Objects*, 2024, vol. 38, p. 101212.
https://doi.org/10.1016/j.nanoso.2024.101212

Xie, Ya., He, Yi., Irwin, P.L., Jin, T., and Shi, X., Antibacterial activity and mechanism of action of zinc oxide nanoparticles against *Campylobacter jejuni, Appl. Environ. Microbiol.*, 2011, vol. 77, no. 7, pp. 2325–2331.
https://doi.org/10.1128/aem.02149-10

Zahir, A.A. and Rahuman, A.A., Evaluation of different extracts and synthesised silver nanoparticles from leaves of *Euphorbia prostrata* against *Haemaphysalis bispinosa* and *Hippobosca maculata, Vet. Parasitol.*, 2012, vol. 187, nos. 3–4, pp. 511–520.
https://doi.org/10.1016/j.vetpar.2012.02.001

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