Pharmacogn. Res., 2025; 17(1):108-114.
https://www.phcogres.com

Original Article

Green Synthesis of Gold Nanoparticles Using *Sphaeranthus amaranthoides*: Drug Loading and Anticancer Properties in Nanomedicine

Iram Shabbir Khan, Swarnalatha Yanamadala*, Senthilkumar Chinnaiyan, Narendran Chiterasu, Sidhika Kannan

Department of Nano Science and Technology, Sathyabama Institute of Science and Technology (Deemed to be University), Chennai, Tamil Nadu, INDIA.

ABSTRACT

Aim: This study introduces a sustainable method for synthesizing anisotropic *Sphaeranthus amaranthoides* leaf extract reduced gold nanoparticles (S-GNPs) by utilizing the phenolic compounds present in *Sphaeranthus amaranthoides* leaf extract. **Background:** Unlike conventional chemical methods, this eco-friendly approach leverages natural sunlight as a catalyst and hyaluronic acid for stabilization, providing a green, scalable solution. **Objectives:** The research aims to develop a biocompatible, stable nanoparticle system for targeted cancer drug delivery. **Materials and Methods:** The nanoparticles were synthesized and characterized using Surface Plasmon Resonance (SPR) and High-Resolution Transmission Electron Microscopy (HRTEM) to confirm size, morphology, and zeta potential. Stability was tested in saline solutions at physiological pH. *In vivo* toxicity studies were conducted using zebra fish larvae, demonstrating high biocompatibility at concentrations below 100 µg/mL. **Conclusion:** Dexamethasone-loaded S-GNPs exhibited significant cytotoxicity against THP-1 Acute Monocytic Leukemia cells, underscoring the potential of this eco-friendly synthesis method for cancer therapy applications. These findings highlight the viability of S-GNPs as effective, biocompatible vehicles for targeted drug delivery, presenting a sustainable alternative to conventional nanoparticle systems.

Keywords: Anticancer activity, Dexamethasone, Gold nanoparticles, Leaf extract, *Sphaeranthus amaranthoides*.

Correspondence:
Dr. Swarnalatha Yanamadala
Dean, Department of Nano Science and Technology, Sathyabama Institute of Science and Technology (Deemed to be University), Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai-600 119, Tamil Nadu, INDIA.
Email: lokiswarna@gmail.com.

Received: 20-09-2024;
Revised: 26-10-2024;
Accepted: 03-12-2024.

INTRODUCTION

Gold Nanoparticles (GNPs) have emerged as a focal point of interest across numerous fields due to their remarkable properties, particularly their unique electronic, optical, and thermal characteristics.[1] These attributes make GNPs vital in numerous applications, such as diagnostics, therapeutic interventions, and advanced sensing technologies.[2] A significant advantage of GNPs is their ability to be synthesized in a uniform, monodisperse form, meaning the nanoparticles maintain consistent size and shape, which is essential for applications requiring precise and reproducible results.[3] GNPs also exhibit low toxicity, a property that increases their suitability for biomedical uses, including *in vivo* applications.[4] Their strong plasmon resonance within the visible spectrum enhances their optical capabilities, making them highly effective in imaging technologies and therapeutic methods such as photothermal therapy. In photothermal therapy, GNPs absorb light and generate localized heat, which can be used to destroy cancer cells. Additionally, the surface of GNPs can be modified with thiol groups, enabling the attachment of drug molecules or targeting agents.[5] This modification of the surface enables the creation of drug delivery systems that provide precise drug release and targeted delivery, thus enhancing therapeutic results.

GNPs have shown significant potential in cancer therapy. Studies, for example, have demonstrated the efficacy of resveratrol-stabilized gold nanoparticles loaded with the anticancer drug doxorubicin, highlighting GNPs as promising platforms for targeted drug delivery.[6] The precision and ability to target specific cells are particularly crucial in cancer treatments, where selective action is paramount.[7] A notable trend in nanoparticle synthesis is the growing preference for eco-friendly, green synthesis methods. These approaches utilize plant extracts, which act as natural reducing agents to produce biocompatible GNPs.[8] These plant extracts, rich in antioxidants like flavonoids and tannins,[9] not only facilitate the reduction of metal ions but also stabilize the resulting nanoparticles.

DOI: 10.5530/pres.20251946

Among the various plant sources, *Sphaeranthus amaranthoides*, a plant native to India and Burma, stands out due to its potent medicinal properties and antioxidant activity.[10] Its bioactive compounds, including tannins and polyphenols, make it particularly suitable for green synthesis approaches. In response to these developments, the present research emphasizes the swift, single-step production of gold nanoparticles by employing *Sphaeranthus amaranthoides* leaf extract as a reducing agent. The resulting gold nanoparticles were subsequently employed as a vehicle for the administration of the anticancer medication Dexamethasone. By loading Dexamethasone onto these *Sphaeranthus amaranthoides*-mediated Gold Nanoparticles (S-GNPs), we aimed to create a novel drug delivery system with potential applications in targeted cancer therapy. The cytotoxic activity of these drug-loaded nanoparticles was tested against the THP-1 Acute Monocytic Leukemia cell line, with promising results that suggest the potential efficacy of S-GNPs as a targeted anticancer therapy. The use of green synthesis techniques, combined with the well-established medicinal properties of *Sphaeranthus amaranthoides*, underscores the importance of eco-friendly approaches in developing next-generation nanomedicines.

MATERIALS AND METHODS

Chloroauric acid ($HAuCl_4$), Polyvinyl Alcohol (PVA), and Dexamethasone were procured from Sigma-Aldrich, USA. MTT assay cell viability was purchased from Sigma Aldrich. THP-1 cells were procured from National Centre for Cell Science (NCCS) Pune, India. These reagents were utilized as received, without undergoing any additional purification processes, ensuring that the materials maintained their original integrity and consistency for experimental use.

Preparation of aqueous *Sphaeranthus amaranthoides* leaf extract

A total of 8.0 g of dry leaves were ground and mixed with 100 mL of distilled sterile water to create an aqueous extract. The mixture was then heated gently at a temperature range of approximately 50-70°C for 10-15 min. This heating process helps to extract the bioactive compounds from the plant material without degrading them. After heating, the mixture was filtered to remove solid residues, yielding a clear crude extract. This filtrate, containing the plant's bioactive components, was then ready for further use in experimental procedures such as nanoparticle synthesis or biological assays. The careful preparation ensures the integrity and effectiveness of the extract for subsequent applications.

Synthesis of gold nanoparticles by aqueous leaf extracts

To synthesize gold nanoparticles, 2.0 mL of the prepared aqueous leaf extract was added to a solution containing 20 mL of chloroauric acid (4.0 mM) and 2.4 mL of polyvinyl alcohol (PVA, 1%), which acts as a stabilizing agent. The mixture was then exposed to direct sunlight for 2 hr, a green synthesis method that utilizes light energy to facilitate the reduction of gold ions into gold nanoparticles. After the reaction, the mixture was centrifuged at 14,000 RPM for 15 min to separate the nanoparticles from the supernatant. The resulting pellet, which contained the gold nanoparticles, was then resuspended in 1.0 mL of deionized water to ensure proper dispersion for further analysis or applications. This method ensures an eco-friendly and efficient approach to nanoparticle synthesis, using natural plant extracts and solar energy.

Characterization of S-GNPs

The UV-visible spectra of the synthesized *Sphaeranthus amaranthoides*-mediated Gold Nanoparticles (S-GNPs) were recorded using an Analytika Jena UV-vis Spectrophotometer. This analysis provides insight into the optical properties of the S-GNPs, as the characteristic Surface Plasmon Resonance (SPR) band is an indicator of successful nanoparticle synthesis. The mean particle size and zeta potential of the S-GNPs were measured using a Zetasizer (3000SH, Malvern Instruments Ltd., UK), which offers valuable data on the stability and dispersion quality of the nanoparticles. The zeta potential measurement is particularly important, as it reflects the surface charge of the nanoparticles and their potential for colloidal stability, where a higher zeta potential generally indicates better stability and less likelihood of aggregation.[11]

To investigate the surface morphology of the synthesized S-GNPs, High-Resolution Transmission Electron Microscopy (HRTEM) analysis was performed using the Hitachi SU6600 Scanning Electron Microscope, coupled with Energy-Dispersive Spectroscopy (EDS) (Horiba, 8121-H, Japan). HRTEM provided detailed images of the nanoparticles at the nanoscale, allowing for precise visualization of their size, shape, and structural uniformity. EDS analysis further confirmed the elemental composition of the S-GNPs, ensuring the successful reduction of gold ions into metallic gold and verifying the presence of gold in the nanoparticles.[12]

Additionally, the crystalline structure of the S-GNPs was characterized by Powder X-ray Diffraction (XRD) using a SEIFERT JSO-Debye flex 2002 model X-ray diffractometer with CuKα radiation (λ= 1.54 Å). XRD analysis enabled the determination of the crystalline phase and provided data on the lattice parameters of the nanoparticles, confirming the formation of crystalline gold in the S-GNPs. The XRD patterns typically exhibit characteristic peaks corresponding to the Face-Centered Cubic (FCC) structure of gold, thus verifying the nanoparticle's structural integrity. Together, these advanced characterization techniques ensured a comprehensive understanding of the physical, chemical, and structural properties of the synthesized

S-GNPs, contributing to their potential application in targeted therapeutic interventions.[13]

Drug loading

The anticancer drug Dexamethasone (250 µg, 0.086 µmole) was combined with gold nanoparticles synthesized using *Sphaeranthus amaranthoides* (S-GNPs) to evaluate their potential in cancer treatment. Specifically, 1400 µg of S-GNPs were dispersed in 200 µL of Millipore water, and the drug was added to the solution. This mixture was stirred for 30 min to ensure proper interaction between the drug and nanoparticles. After stirring, the solution was incubated at room temperature for 6 hr, allowing sufficient time for the Dexamethasone to adsorb onto the surface of the gold nanoparticles. To remove any unbound drug, the solution was centrifuged at 14,000 rpm, leaving behind only the drug-loaded S-GNPs. The use of *Sphaeranthus amaranthoides* in the synthesis of these gold nanoparticles is crucial due to the plant's bioactive properties, which may enhance the therapeutic efficacy and targeting ability of the nanoparticles, particularly in the delivery of anticancer agents like Dexamethasone.[14]

Evaluation of Anticancer activity

The anticancer efficacy of *Sphaeranthus amaranthoides*-mediated Gold Nanoparticles (S-GNPs), Dexamethasone-loaded S-GNPs, and free Dexamethasone was evaluated against human lymphocytic leukemia cell lines (K-562) using the MTT assay. The MTT assay, a widely used colorimetric technique, assesses cell viability by measuring the reduction of MTT (3-(4, 5-dimethylthiazol-2-yl)-2, 5-diphenyl tetrazolium bromide) to formazan crystals by mitochondrial dehydrogenases in living cells. This reduction only occurs in viable cells, making it a reliable indicator of cell survival. In the experiment, THP-1 acute monocytic leukemia cells were cultured in 96-well plates in Modified Eagle Medium (MEM) supplemented with 10% Fetal Bovine Serum (FBS) to provide essential nutrients for cell growth.[15]

To test the cytotoxicity of the drug-loaded nanoparticles, the cells were treated with various concentrations of Dexamethasone-loaded S-GNPs, with the final concentration of Dexamethasone ranging from 0.5 to 10.5 µM. Each experimental condition was performed in triplicate to ensure the reliability of the data. Following the addition of the nanoparticles, the plates were incubated at 37°C in a humidified atmosphere containing 5% CO_2 for 48 hr to allow the nanoparticles to interact with the cells and exert their anticancer effects.

After the incubation period, cell viability was assessed by adding MTT stock solution (5 mg/mL) to each well at one-tenth of the

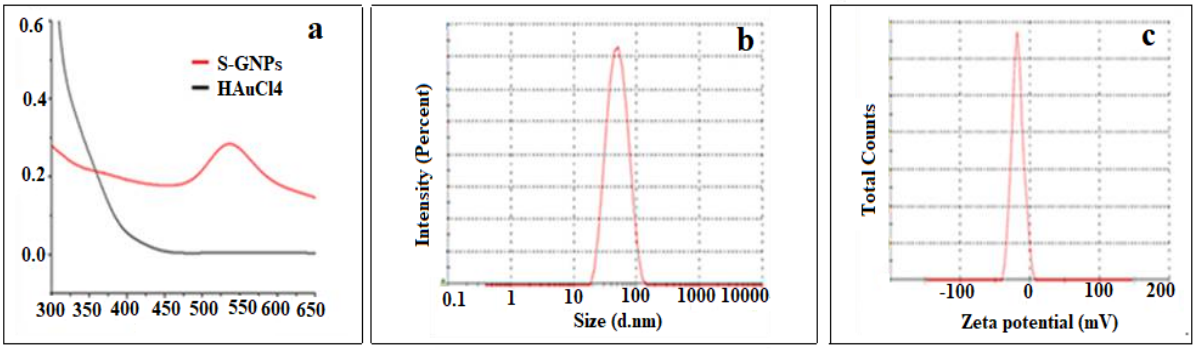

Figure 1: (a) UV–visible spectra showing the absorption peak of $HAuCl_4$ and the surface Plasmon resonance (SPR) peak of synthesized S-GNPs; (b) Particle size distribution of S-GNPs, demonstrating their uniformity and average size; (c) Zeta potential distribution of S-GNPs in an aqueous medium, indicating their surface charge and colloidal stability.

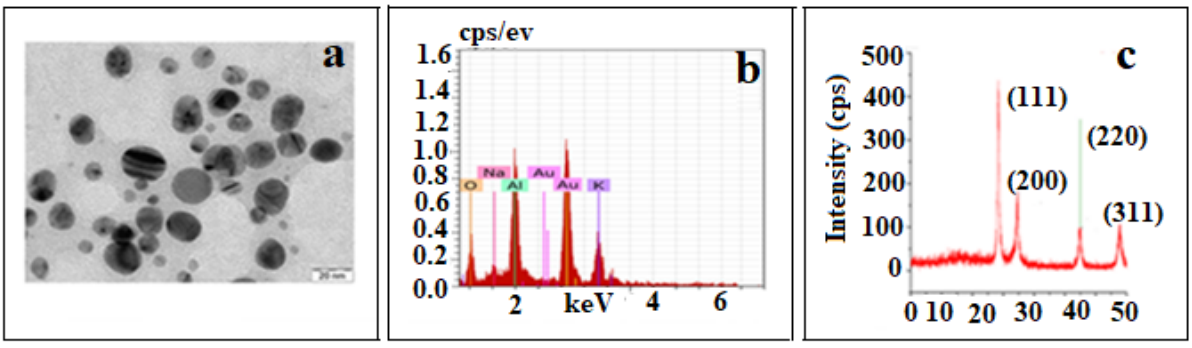

Figure 2: (a) High-Resolution Transmission Electron Microscopy (HRTEM) image of S-GNPs, showing their size and morphology; (b) Energy-Dispersive X-ray (EDX) spectrum confirming the elemental composition of gold in the nanoparticles; (c) Powder X-Ray Diffraction (XRD) pattern of S-GNPs, indicating their crystalline nature and characteristic peaks of gold nanoparticles.

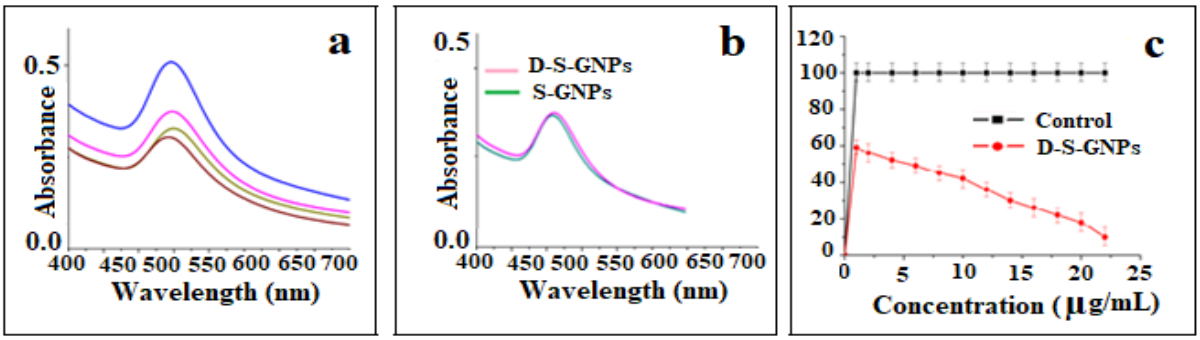

Figure 3: (a) The UV-visible spectra of Dexamethasone solutions before adding S-GNPs and the supernatant after harvesting Dexamethasone loaded S-GNPs. (b) The UV-visible spectra of S-GNPs and Dexamethasone loaded S-GNPs and (c) Anti-cancer activity on THP-1 Acute Monocytic Leukemia cancer cells. Data represented as mean ± SD. ($n = 3$) analyzed by Student's t test; $p < 0$.

original culture volume. The cells were then incubated for an additional 3-4 hr at 37°C, allowing the mitochondrial enzymes of the viable cells to reduce the MTT into purple formazan crystals. Once the incubation was complete, the culture medium was carefully removed, and the insoluble formazan crystals were dissolved in Dimethyl Sulfoxide (DMSO). The absorbance of the resulting solution was measured at 570 nm using a multi-plate reader (Bio-Rad Laboratories). The intensity of the color generated by the formazan dye correlates with the number of viable cells, allowing for a quantitative assessment of the cytotoxic effect of the S-GNPs, drug-loaded S-GNPs, and free Dexamethasone on the THP-1 acute monocytic leukemia cells. This method provided valuable insights into the potential of Dexamethasone-loaded S-GNPs as a targeted anticancer therapy.

In vivo toxicity of S-GNPs towards zebra fish embryo

Healthy adult zebrafish were chosen for fertilization in aerated water medium. Fertilized eggs or embryos were collected and stored in E3 medium. Ten healthy embryos were transferred into each well in a 24-well plate along with 3 mL E3 medium, and different concentrations (20-100 µg/mL) of S-GNPs were added and incubated for 4 days at room temperature. The percentage of survival and changes in the morphology during the development of the embryos of zebrafish were observed. The tests were performed in triplicate along with control embryos not treated with S-GNPs.

RESULTS

The study successfully synthesized Gold Nanoparticles (S-GNPs) using a green synthesis method involving *Sphaeranthus amaranthoides* extract. The synthesis was confirmed by the appearance of a Surface Plasmon Resonance (SPR) (Figure 1) band at 538 nm, characteristic of gold nanoparticles. Photon Correlation Spectroscopy (PCS) revealed that the average particle size of the synthesized nanoparticles was approximately 85.92 nm, indicating a narrow size distribution and monodispersity. The zeta potential of the S-GNPs was measured at −25.3 mV, suggesting good electrostatic stability, which is important for preventing particle aggregation in suspension. The High-Resolution Transmission Electron Microscopy (HRTEM) images (Figure 2) showed that the synthesized S-GNPs were spherical and well-dispersed, with no visible aggregation. The Energy-Dispersive X-ray (EDX) analysis confirmed the presence of gold, validating the successful reduction of chloroauric acid into metallic gold nanoparticles. Further structural analysis using X-ray Diffraction (XRD) revealed distinct. The peaks related to the (111), (200), (220), and (311) planes of the Face-Centered Cubic (FCC) lattice of gold, confirming the crystalline nature of the synthesized nanoparticles. The successful loading of Dexamethasone onto the S-GNPs was evidenced by a shift in the SPR band from 538 nm to 557 nm (Figure 3), indicating interaction between the drug and the nanoparticles. *In vitro* studies on drug release showed a well-regulated release pattern over 12 hr. About 16% of the medication was discharged during the initial 2 hr, succeeded by a phase of continuous release, with 48% of the drug released over the 12-hr period. Stability studies conducted in various pH buffers that mimic physiological conditions showed that the SPR band remained stable, suggesting the nanoparticles maintained their structural integrity across different pH environments, which is essential for potential therapeutic applications. *In vivo* toxicity studies using zebrafish embryos revealed that the S-GNPs were biocompatible at concentrations up to 60 µg/mL, with survival rates remaining high. At 100 µg/mL, a slight reduction in survival was observed, indicating the potential for mild toxicity at higher concentrations. However, no significant morphological abnormalities were observed in zebrafish embryos exposed to S-GNPs, further confirming their biocompatibility. The cytotoxic effects of Dexamethasone-loaded S-GNPs were tested against the THP-1 Acute Monocytic Leukemia cell line using the MTT assay. The results indicated that the drug-loaded nanoparticles had a significantly lower IC_{50} value (2.5 µM) compared to free Dexamethasone (5 µM), suggesting that the S-GNPs enhance the anticancer efficacy of the drug by improving its cellular uptake and bioavailability (Figure 4).

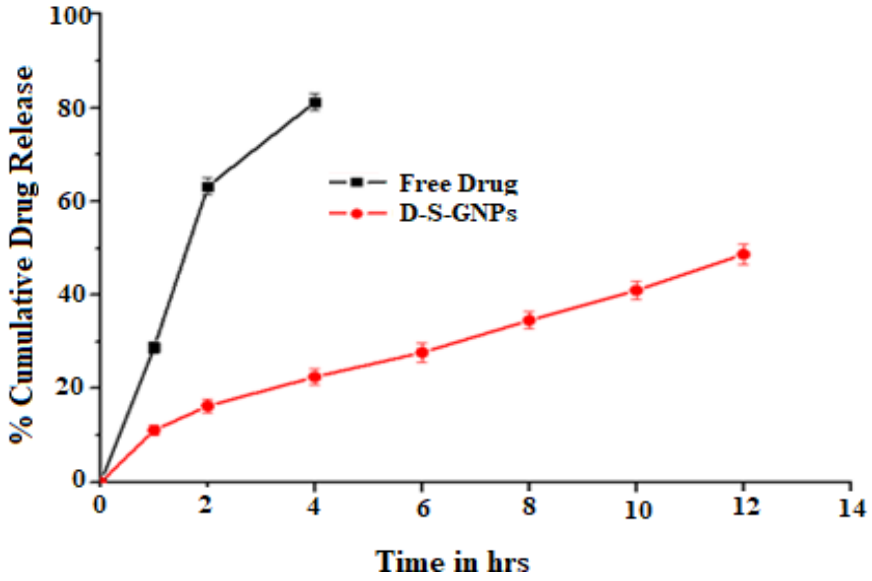

Figure 4: *In vitro* release profiles of dexamethasone-loaded S-GNPs compared to free dexamethasone in phosphate buffer solution (pH 7.4) at 37°C, presented as mean ± SD ($n = 3$), highlighting the sustained release behavior of the nanoparticle formulation.

DISCUSSION

The eco-friendly synthesis of Gold Nano Particles (S-GNPs) using *Sphaeranthus amaranthoides* extract harnesses the plant's rich natural compounds such as tannins and polyphenols, which serve as effective reducing agents for the transformation of chloroauric acid into gold nanoparticles. The color shift from pale yellow to ruby red, combined with the Surface Plasmon Resonance (SPR) peak at 538 nm, confirms the formation of nanoparticles. The consistent SPR peak suggests that the nanoparticles are of uniform size, essential for biomedical consistency. This synthesis mechanism is comparable to the reduction of ferric ions by polyphenols observed in previous studies.[16] Photon Correlation Spectroscopy (PCS) showed that the nanoparticles had an average diameter of around 50.93 nm, confirming the control over size distribution, which is vital for ensuring repeatable biological effects. The nanoparticles demonstrated a zeta potential of -21.7 mV, indicating good stability against aggregation. High-Resolution Transmission Electron Microscopy (HRTEM) provided images showing well-defined spherical nanoparticles, further supporting their stability. Energy Dispersive X-ray (EDX) analysis confirmed the successful reduction of chloroauric acid into gold, while X-ray Diffraction (XRD) patterns identified the characteristic Face-Centered Cubic (FCC) structure of gold, aligned with bulk gold data.[16] The successful binding of the anticancer drug Dexamethasone onto the nanoparticles was confirmed by a shift in the SPR band to 557 nm, indicating an interaction between the drug and the nanoparticle surface. Drug loading reached approximately 45 µg, and the anticancer efficacy of the drug-loaded S-GNPs against THP-1 Acute Monocytic Leukemia cells was significantly improved compared to free Dexamethasone, with an IC_{50} value of 3 µM compared to 5.5 µM. This improved efficacy is attributed to the enhanced permeability of the drug-loaded nanoparticles.[17] The drug release profile of Dexamethasone from the S-GNPs exhibited a sustained release pattern, with only 48% of the drug released after 12 hr, following an initial burst release of 16%. This controlled release is crucial for maintaining therapeutic levels over an extended period, thus minimizing dosing frequency.[18] The redshift of the SPR band from 538 nm to 557 nm upon loading dexamethasone onto the Gold Nanoparticles (S-GNPs) indicates a significant interaction between the drug molecules and the nanoparticle surface. This shift is attributed to changes in the local refractive index and the plasmon resonance of the nanoparticles, which occur due to the adsorption of dexamethasone. The interactions are likely driven by a combination of electrostatic forces, where the negatively charged nanoparticles attract the partially positive regions of the dexamethasone molecule, and hydrophobic interactions, given the amphiphilic nature of dexamethasone. These interactions not only ensure robust drug loading but may also influence the release kinetics, as the drug is gradually desorbed from the nanoparticle surface under biological conditions. Such sustained release behavior is crucial for maintaining therapeutic drug levels over extended periods and minimizing side effects, especially in cancer treatment. The integration of dexamethasone with S-GNPs thus represents a promising approach for controlled drug delivery, as supported by the observed redshift and its implications on drug-nanoparticle interactions.

The nanoparticles demonstrated stability in various pH environments simulating physiological conditions, indicating their robustness for biomedical applications.[19] Biocompatibility studies using zebrafish embryos revealed that the nanoparticles were well-tolerated at concentrations up to 60 µg/mL, with a slight reduction in survival observed at 100 µg/mL, which could suggest a concentration threshold for toxicity. Importantly, no significant morphological changes were observed in the zebrafish embryos, further supporting the safety profile of S-GNPs at therapeutic doses.[20]

CONCLUSION

This study successfully demonstrated the green Synthesis of Gold Nanoparticles (S-GNPs) using *Sphaeranthus amaranthoides* leaf extract as a natural reducing agent. The resulting nanoparticles exhibited excellent biocompatibility, as shown by the high survival rate of zebrafish embryos, particularly at concentrations up to 60 µg/mL. Furthermore, no significant morphological changes were observed in the embryos, confirming the safety of the nanoparticles. When loaded with the steroid drug Dexamethasone, the S-GNPs showed substantial anticancer activity against THP-1 Acute Monocytic Leukemia cells, highlighting their potential as an effective system for targeted cancer drug delivery. The environmentally friendly synthesis process and the efficient drug-loading capacity of these nanoparticles make them a promising tool in the development of advanced cancer treatments.

ACKNOWLEDGEMENT

The authors acknowledge DST-SEED for supporting this work through a grant to DR. Y. Swarnalatha (DST sanction letter No- DST/SEED/TSP/STI/2021/466).

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ABBREVIATIONS

GNPs: Gold Nanoparticles; **SPR:** Surface Plasmon Resonance; **HRTEM:** High-Resolution Transmission Electron Microscopy; **EDS:** Energy-Dispersive Spectroscopy; **XRD:** X-ray Diffraction; **FCC:** Face-Centered Cubic; **MTT:** 3-(4,5-dimethylthiazol-2-yl)-2, 5-diphenyl tetrazolium bromide; **DMSO:** Dimethyl Sulfoxide; **S-GNPs:** *Sphaeranthus amaranthoides*-mediated Gold Nanoparticles; **PCS:** Photon Correlation Spectroscopy; **EDX:** Energy-Dispersive X-ray; **FBS:** Fetal Bovine Serum; **MEM:** Modified Eagle Medium; **IC_{50}:** Half-maximal Inhibitory Concentration.

SUMMARY

The study presents a novel, sustainable method for synthesizing anisotropic Gold Nanoparticles (S-GNPs) using *Sphaeranthus amaranthoides* leaf extract. This green synthesis approach employs natural sunlight as a catalyst and hyaluronic acid for nanoparticle stabilization. The phenolic compounds in the leaf extract play a crucial role in reducing gold ions to form nanoparticles, providing an eco-friendly and scalable alternative to conventional chemical methods. S-GNPs were thoroughly characterized using techniques such as Surface Plasmon Resonance (SPR) and High-Resolution Transmission Electron Microscopy (HRTEM), confirming their size, morphology, and stability. Toxicity testing in zebrafish larvae indicated biocompatibility at concentrations below 100 µg/mL, and Dexamethasone-loaded S-GNPs demonstrated significant cytotoxic effects against THP-1 Acute Monocytic Leukemia cells. This highlights the potential of S-GNPs as a biocompatible and effective vehicle for targeted cancer drug delivery, offering a greener alternative to traditional nanoparticle systems for therapeutic applications.

REFERENCES

1. Shankar SS, Rai A, Ahmad A, Sastry M. Controlling the optical properties of lemongrass extract synthesized gold nanotriangles and potential application in infrared-absorbing optical coatings. Chem Mater. 2005;17(3):566-72. doi: 10.1021/cm048292g.
2. Brust M, Walker M, Bethell D, Schiffrin DJ, Whyman R. Synthesis of thiol-derivatised gold nanoparticles in a two-phase liquid-liquid system. J Chem Soc Chem Commun. 1994;(7):801-2. doi: 10.1039/C39940000801.
3. Clogston JD, Patri AK. Zeta potential measurement. Methods Mol Biol. 2011;697:63-70. doi: 10.1007/978-1-60327-198-1_6, PMID 21116954.
4. Gayatri S, Reddy C, Chitra K, Parthasarathy V. *Sphaeranthus amaranthoides*: A review. Int J Pharm Pharm Sci. 2013;5(3):123-5.
5. Elizondo N, Segovia P, Coello V. Green chemistry-Environmentally benign approaches. In: Kidwai M, Mishra N, editors. Tech. 2012;8:139-56.
6. Ghosh P, Han G, De M, Kim CK, Rotello VM. Gold nanoparticles in delivery applications. Adv Drug Deliv Rev. 2008;60(11):1307-15. doi: 10.1016/j.addr.2008.03.016, PMID 18555555.
7. Guo S, Wang E. Synthesis and electrochemical applications of gold nanoparticles. Anal Chim Acta. 2007;598(2):181-92. doi: 10.1016/j.aca.2007.07.054, PMID 17719891.
8. Parker JF, Fields-Zinna CA, Murray RW. The story of a monodisperse gold nanoparticle: Au25L18. Acc Chem Res. 2010;43(9):1289-96. doi: 10.1021/ar100048c, PMID 20597498.
9. Huang X, Jain PK, El-Sayed IH, El-Sayed MA. Plasmonic photothermal therapy (PPTT) using gold nanoparticles. Lasers Med Sci. 2008;23(3):217-28. doi: 10.1007/s10103-007-0470-x, PMID 17674122.
10. Huo S, Ma H, Huang K. Superior penetration and retention behavior of 50 nm gold nanoparticles in tumors. Cancer Res. 2012;73:319-30.
11. Inbakandan D, Venkatesan R, Ajmal Khan SA. Biosynthesis of gold nanoparticles utilizing marine sponge Acanthella elongata (Dendy, 1905). Colloids Surf B Biointerfaces. 2010;81(2):634-9. doi: 10.1016/j.colsurfb.2010.08.016, PMID 20828999.
12. Jain KK. Applications of nanobiotechnology in clinical diagnostics. Clin Chem. 2007;53(11):2002-9. doi: 10.1373/clinchem.2007.090795, PMID 17890442.
13. Jain S, Hirst DG, O'Sullivan JM. Gold nanoparticles as novel agents for cancer therapy. Br J Radiol. 2012;85(1010):101-13. doi: 10.1259/bjr/59448833, PMID 22010024.
14. Kawasaki ES, Player A. Nanotechnology, nanomedicine, and the development of new, effective therapies for cancer. Nanomedicine. 2005;1(2):101-9. doi: 10.1016/j.nano.2005.03.002, PMID 17292064.
15. Kevadiya BD, Chettiar SS, Rajkumar S, Bajaj HC, Gosai KA, Brahmbhatt H. Evaluation of clay/poly(L-lactide) microcomposites as anticancer drug, dexamethasone-reservoir through *in vitro* cytotoxicity, oxidative stress markers, and *in vivo* pharmacokinetics. Colloids Surf B Biointerfaces. 2013;112:400-7. doi: 10.1016/j.colsurfb.2013.07.008, PMID 24036475.

16. Kumar KP, Paul W, Sharma CP. Green synthesis of gold nanoparticles with *Zingiber officinale* extract: characterization and blood compatibility. Process Biochem. 2011;46(10):2007-13. doi: 10.1016/j.procbio.2011.07.011.
17. Lal SS, Nayak PL. Green synthesis of gold nanoparticles using various extracts of plants and spices. Int J Sci Innov Discov. 2012;2:325-50.
18. Maeda H. The enhanced permeability and retention (EPR) effect in tumor vasculature: the key role of tumor selective macromolecular drug targeting. Adv Enzyme Regul. 2001;41:189-207. doi: 10.1016/s0065-2571(00)00013-3, PMID 11384745.
19. Sharma P, Brown S, Walter G, Santra S, Moudgil B. Nanoparticles for bioimaging. Adv Colloid Interface Sci. 2006; 123-126: 471-85. doi: 10.1016/j.cis.2006.05.026, PMID 16890182.
20. Perron NR, Brumaghim JL. A review of the antioxidant mechanisms of polyphenol compounds related to iron binding. Cell Biochem Biophys. 2009;53(2):75-100. doi: 10 .1007/s12013-009-9043-x, PMID 19184542.

Cite this article: Khan E, Yanamadala S, Chinnaiyan S, Chiterasu N, Kannan S. Green Synthesis of Gold Nanoparticles Using *Sphaeranthus amaranthoides*: Drug Loading and Anticancer Properties in Nanomedicine. Pharmacog Res. 2025;17(1):108-14.