"A Comparative Investigation into the Biocompatibility and Cytotoxicity of Phytofabricated Gold and Titanium Dioxide Nanoparticles for Biomedical Applications"

Dr. Karle Chhaya Sharadchandra
Arts, Commerce and Science College, satral, Maharashtra

Abstract:

Titanium Nanoparticles from peltophoprum petrocarpum and Gold Nanoparticles from M. elengi fabricated via eco-friendly ("green") chemical pathways have attracted considerable interest because their distinctive physicochemical features and inherent biocompatibility enable a broad spectrum of applications from biomedicine to food-packaging technologies and environmental remediation. In this study, Gold (Au) and titanium dioxide (TiO_2) nanoparticles were synthesized using plant-mediated green chemistry and subsequently characterized by Fourier-transform infrared spectroscopy (FTIR) and high-resolution transmission electron microscopy (HRTEM). Biocompatibility was assessed on a liver cancer cell (HEPG2) cell line employing the MTT assay. Both Au and TiO_2 nanoparticles demonstrated pronounced, dose-dependent compatibility with the cells, exhibiting minimal cytotoxic effects across the tested concentration range. These encouraging in-vitro findings lay the groundwork for extended biological evaluations and potential translational applications of the green-synthesized Au and TiO_2 nanomaterial.

1.Introduction

Nanotechnology has made significant advancement in the field of functional nanomaterial development due to their unique physical and chemical properties including size dependent properties [1]–[4], which make them several applications including sensors, cancer cell diagnostics and energy storage [5]–[8]. Among them Au and TiO_2nanoparticles (NPs) have attracted great attention for their potential applications.

Au nanoparticles have been extensively used in various fields due to their unique properties such as size, shape, high stability, non-toxicity, biocompatibility and target cells [9]. Au Nps are easy to synthesis and functionalize with targeting moieties [10], [11]. Method of selection is crucial to prepare Au NPs with reproducibility, stability, size and shapes. Top down and bottom up approach are the method for preparation of Au nanoparticles with high quality.

Numerous research articles have been reported on synthesis of gold NPs as well as functionalized Au NPs [12]–[15]. One of the challenging aspects while preparation of Au NPs is to prepare Au NPs free from aggregation, to avoid this, capping agent such as citrate, polymers, surfactants, chelating ligands have been added during synthesis. However, the synthesis of gold NPs involves lot of chemicals and requires harsh environmental conditions. Alternatively, ecofriendly green chemical route has been developed to prepare Au NPs with improved physicochemical properties. For instance, OM El-Borady et al. prepared Au NPs by green chemical route using common reed leaf extracts. The prepared NPs exhibited notable anticancer, anti-oxidant, and photocatalytic activities [16]. Au NPs prepared through bio-inspired pathway using thyme plant extract was examined for catalytic properties on reduction of 4-nitorphenol [17]. Au NPs prepared using vitex negundo plant extract has shown significant antibacterial activity where the plant extract acts as capping and stabilizing agent. It was reported that the polyphenols, flavonoids, terpenoids, biological active compounds present in plant extracts were responsible for reduction of Au NPs [18]. Another research article authored by Scholastica O. Anadozie et al. highlights the size of Au NPs produced was about 2-17 nm and exhibit anti-cancer activity in dose dependent manner [19].

Similarly, TiO_2 has also been used for several applications including drug delivery, sensors, energy storage and photocatalytic applications [20]–[23]. TiO_2 NPs have been synthesized through various chemical routes such as hydrothermal, sol-gel, solvothermal, and precipitation technique. Synthesis of TiO_2 NPs through chemical routes produced larger particles and consumes high energy; moreover, the chemical synthesis route is not ecofriendly and produce secondary waste. Like gold NPs, TiO_2 has also been prepared through green chemical approach. Medicinal plants such as Trigonell foenum-graecum, Aloe Vera, Jatropa, Acorus Calamus leaf, Moringa oleifera, Hibiscus, and Azadirechta indica have been utilized for the preparation of TiO_2 NPs [24]–[31]. Jyoti Fulekar et al. prepared TiO_2 nanoparticles using rhizospheric microorganisms and roots as natural source for methyl orange dye degradation [32]. Syzygium cumini extract has been used for preparation of TiO_2 NPs [33]. The TiO_2 has been used to remove Pb^{2+} (82.53%) from industrial waste water. TiO_2 NPs has been prepared using phyllanthus niruri extract exhibited significant methyl orange dye adsorption (273.37mg g^{-1}) capacity [34]. Citrus lemon is well known source of vitamin-C, which is used to prepare TiO_2 NPs and successfully applied for dye-sensitized solar cells [35]. Biological fouling caused due to undesired accumulation of microorganisms, bio waste, and diatoms on submerged artificial surface. Green synthesized TiO_2 using algal extracts showed excellent antifouling characteristics [36]. TiO_2 NPs has been prepared by both conventional chemical route as well as green chemical approach and compared the efficacy against methylene blue dye degradation [37]. The results showed that 89% dye degradation efficacy was achieved by biomediated synthesis of TiO_2 which is high when compared to chemically prepared TiO_2. Bixa orellana seed extract is possessing excellent health benefits which is also used for the preparation of TiO_2 NPs and applied to dye sensitized solar cells. The results showed that current conversion efficiency was found to be 3%, Bixa orellana seed extracts acts as stabilizing and capping agent. Significant antibacterial and antioxidant properties were achieved by TiO_2 NPs prepared via psidium guajava mediated biosynthesis. The authors suggested that psidium guajava mediated biosynthesis can satisfy TiO_2 production in large-scale [38]. Plant extracts such as ranunculus muricatus, cinnamomum tamala leaves, averrhoa bilimbi fruit and pandanus amaryllifolius leaves extracts have been used for the preparation of Au/TiO_2 nanocomposite [39]–[41]. The composite consist of Au-TiO_2 improves the photocatalytic performance.

Literatures evidenced that Au and TiO_2 NPs have emerged as promising tool for various biomedical applications, their widespread use is depends on their biocompatibility. Biocompatibility is described the material should be compatible with living organism/tissue when administered. Green synthesis of gold as well as TiO_2 nanoparticles was prepared using plant extracts. The plant extracts acts as both stabilizing and reducing agent. However, limited number of research articles has been reported on the biocompatibility of green synthesized Au and TiO_2. The biocompatibility assay needs to be documented in order use the NPs for various applications. This research article report the preparation of Au and TiO_2 NPs and comparative study of biocompatibility [45]- [46].

2. Materials and Methods

Gold chloride ($HAuCl_4$), Glycerin and Sodium citrate, Titanium Nitrate, Ethyl alcohol, All chemicals and solvents used were of analytical grade are used.

2.1 Preparation of Au NPs using M. Elengi fruit extracts

Aliquots of Au (III) chloride solution (15mM) was added drop wise to 50 ml of freshly prepared M. Elengi fruits extracts. The reaction mixture was stirred to 10 minutes and the appearance of wine red colour was observed. The color change was due to Au NPs formation. The UV-Vis spectrophotometric measurement of the prepared NPs was carried out in different time period to confirm the stability.

2.2 Preparation of TiO_2 NPs using Peltophorum pterocarpum extract

Freshly picked Peltophorum Pterocarpum flowers were cleaned with distilled water and then dried in the dark to preserve their delicate scent. Distilled water and 5 grams of desiccated Peltophorum Pterocarpum flowers were mixed then heated to 80 ºC for 30 minutes. Before being stored at 4°C for the experiment, this extracts were filtered. Known quantity of the freshly prepared Peltophorum Pterocarpum flower extracts were gently added to a titanium trichloride ($TiCl_3$) solution was stirred continually to produce the TiO_2 NPs. As TiO_2 nanoparticles formed, the fluid's colour changed from pink to brown. Further, the obtained TiO_2 was dried at 50°C and sintered at 600 °C.

2.3 Characterization

The green synthesized nanoparticles were characterized using FTIR, SEM, and HR-TEM (200 KV acceleration voltages). FTIR spectroscopy was performed to identify the functional groups NPs.

3. Biocompatibility and Cytotoxicity Assessment

Cytotoxicity of Titanium and Gold Nanoparticals in HEPG2 (Liver Cancer Cell) using MTT Assay.

3.1 Preparation of Test Material

All Test Samples were filter sterilized using 0.22µ filters and diluted by double dilutionmethod in MEM with FBS.

3.2 Chemicals and Materials-

Sr No.	Chemicals	Materials
1.	Cell Culture Plates	96 well microtiter plates (Himedia)
2.	Cell culture flasks	T25 Flasks (Himedia)
3.	Trypsin/EDTA	0.25% Trypsin and 0.02% EDTA in Dulbecco's Phosphate Buffered Saline (Himedia)
4.	DMSO	Dimethyl sulfoxide (Himedia)
5.	Cell culture Medium	Eagle's Minimum Essential Medium (EMEM)10% (v/v) Fetal Bovine Serum
6.	Cell Line	(Human embryo kidney Cancer Cell)
7.	Culture Conditions	37ºC with 5% CO2

3.3 Preparation of Cells

HEK293 (Human embryo kidney Cancer Cell) were cultured in MEM with NEAA media supplemented with 10% (v/v) fetal bovine serum. Cells were cultured at 37ºC and 5% CO_2; complete medium was changed every 2 to 3 days.

3.4 MTT Assay Procedure

- Cells were seeded in 96 well plates at a concentration of 1,00,000 cells per well (100ul). The plates were incubated at 37^0C at 5% CO_2 for 24hrs.
- After the incubation period cells were observed for half confluence monolayer.
- Culture medium was removed and the cells were treated with 7 different concentration of test item. Cisplatin used as standard.
- Cells in cell culture medium without any test item incubated and under the same conditions served as control.
- Plates were incubated 37^0C and 5% CO_2 for 2**4** hrs.
- After 24hrs, cells were observed under inverted microdscope for changes in morphology or death if any.
- After observation, culture medium were removied and 100 ul fresh medium added with 10 ul mg/ml MTT reagent in each well.

- Plated were incubated for 4hrs at 37^0C in 5% CO_2 incubator.
- 100ul solibilization(DMSO) added into each well.
- 10. Plates were allowed to stand for 1hr at 37^0C in 5% CO_2.
- 11. After checking for complete solubilization of the purple formazan crystal absorbance was measured at 570nm using microplate reader.
- IC50 values were calculated by plotting a log graph for the concentration of the test items vs %cell survival.
- Percentage of cell survival was calculated using the formula:

$$\text{Percentage cell survival(\%)} = \frac{\text{Absorbance of test}}{\text{Absorbance of control}} \times 100$$

3.5 Comparative **IC50 values of MTT Assay of Standard with Titanium and Gold Nps.**

Sr. No.	Test Item	Log IC50 Value	IC50 Value
1.	Standard Cisplatin	0.756	2.1309
2.	TiNps	1.313	3.721
3.	AuNps	0.545	1.7204

The biocompatibility and cytotoxicity of the synthesized Au NPs and TiO_2 NPs were evaluated using cell viability assays (e.g., MTT assay)

4. Results and Discussion:

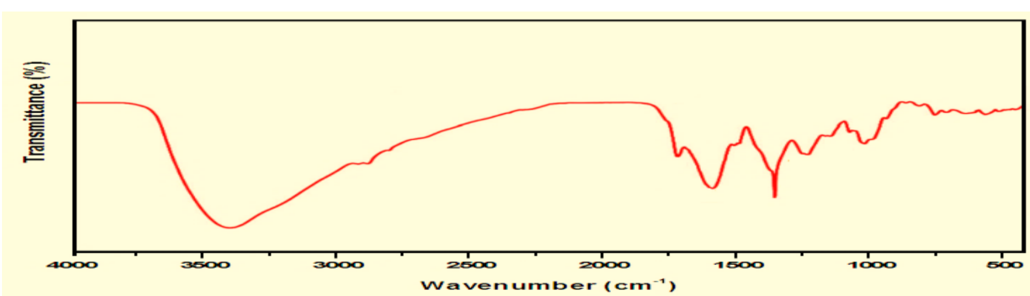

Figure 1: FTIR spectra of (a) Au NPs prepared by M.Elengi

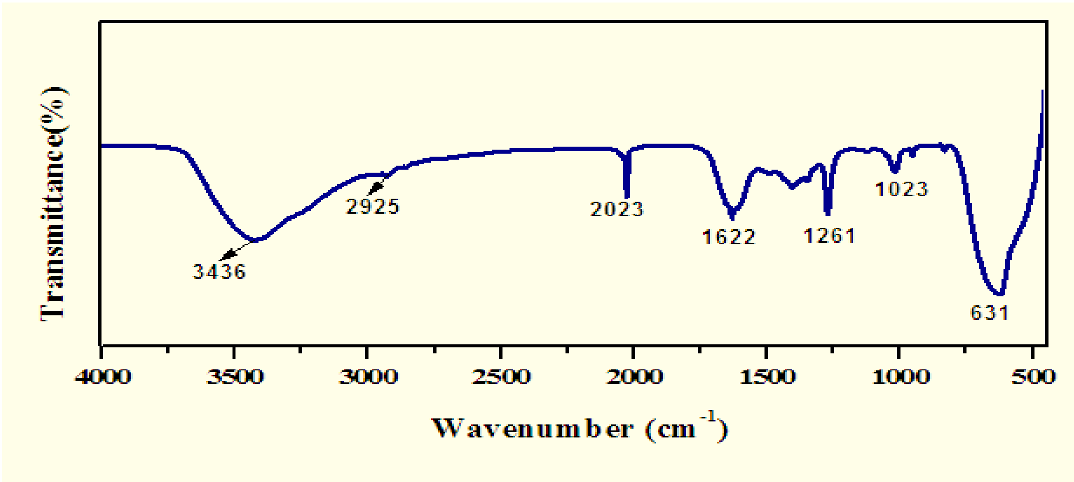

Figure 1: (b) FTIR obtained for TiO_2 NPs prepared by Peltophorum Pterocarpum Flower extracts

The presence of biomolecules on Au NPs was assessed by FTIR spectroscopy. As shown in figure 1(a), the peak at 1065 cm^{-1}, due to C–O bond derived from protein of fruit extract. The peaks appeared at 1233 cm^{-1} and 1384 cm^{-1} are attributed to the following functional groups like ester, amine and carboxylic group. The peak observed at 3422 cm^{-1} is due to stretching of N-H and O-H molecules. The absorption band at 1381 cm^{-1} is due to flavonoids present in fruit extract. The observed FTIR characteristic bands confirmed that biomolecules such as flavonoids behind the reason for reducing Au^{3+} ions to form Au NPs.

FTIR was performed to confirm the functional groups of green synthesized TiO_2 nanoparticles. Figure 1(b) shows the FTIR spectra of TiO_2 NPs. The peak appeared at 631 cm^{-1} indicates the O-Ti-O lattice vibration of rutile TiO_2. The peaks at 1023 cm^{-1}, 1261 cm^{-1}, 1622 cm^{-1} and 2023 cm^{-1} are corresponds to -C-O-C stretching vibrations of alcoholic group, C=C stretching vibration, C-H stretching vibration, –C=O bond in Quinone structure respectively. The peaks at 2925 cm^{-1} and 3436 cm-1 are attributed to the C-H extended vibration for CH_3 and –OH stretching vibration of weakly bound water molecules respectively.

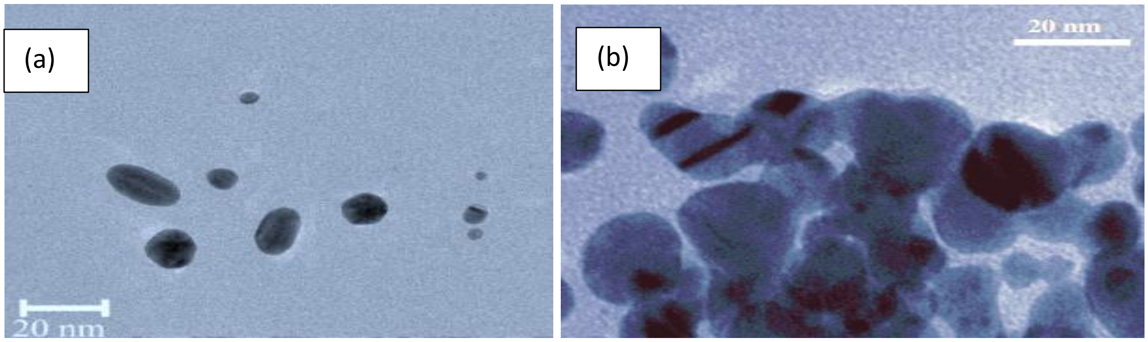

Figure 2: (a) HRTEM images of Gold nanoparticles synthesized using M. Elengi extract and (b) TiO_2 nanoparticles synthesized by Peltophorum Pterocarpum flower extracts

High resolution transmission electron microscope (HRTEM) was done to elucidate the structure and morphology of prepared samples. Figure 2 shows the HRTEM images of Gold nanoparticles obtained by M. Elengi extract with different magnification. As observed from figure 2(a), the mean particles size of Au NPs was observed as 14.5nm. Figure 2 (b) shows the HRTEM image of TiO_2 NPs, in which the particles size is observed as ranging from 18nm to 50 nm, also the spherical morphology is observed for both the samples.

5. **Conclusion**

The green synthesis of gold and titanium dioxide nanoparticles offers a sustainable and environmentally friendly approach to nanoparticle production. This study highlights the importance of biocompatibility and cytotoxicity in determining the potential applications of nanoparticles in biomedicine and other fields. The IC50 values, which represent the concentration of the sample required to inhibit cancer cell growth by 50%, were calculated for Cisplatin and both the samples. The IC50 value for cisplatin was found to be 2.1309 µg/ml, for Green synthesized TiNps was 3.721 µg/ml while for Green synthesized AuNps was 1.7204 µg/ml.

1. The results of this study demonstrate that both Green synthesized TiNps and Green synthesized AuNps exhibit significant inhibitory effects on cancer cell growth, with Green synthesized AuNps showing a higher percentage inhibition (93.64%) compared Green synthesized TiNps (87.26%).

2. The IC50 values further support these findings, with AuNps requiring a lower concentration (1.7204µg/ml) to achieve 50% inhibition compared to TiNps (3.721 µg/ml).
3. Thus the result indicates that AuNps is more effective in inhibiting the cancer cell growth compared to TiNps, with higher percentage inhibition and lower IC50 value.

References

[1] P. O. Andersson et al., "Polymorphand sizedependent uptake and toxicity of TiO2 nanoparticles in living lung epithelial cells," Small, vol. 7, no. 4, pp. 514–523, 2011.

[2] D. Li et al., "Morphology-dependent evolutions of sizes, structures, and catalytic activity of Au nanoparticles on anatase TiO2 nanocrystals," J. Phys. Chem. C, vol. 123, no. 16, pp. 10367–10376, 2019.

[3] R. Kaur and B. Pal, "Size and shape dependent attachments of Au nanostructures to TiO2 for optimum reactivity of Au–TiO2 photocatalysis," J. Mol. Catal. A Chem., vol. 355, pp. 39–43, 2012.

[4] T. Špringer, M. L. Ermini, B. Spacková, J. Jablonku, and J. Homola, "Enhancing sensitivity of surface plasmon resonance biosensors by functionalized gold nanoparticles: size matters," Anal. Chem., vol. 86, no. 20, pp. 10350–10356, 2014.

[5] M. Hegde et al., "Nanoparticles in the diagnosis and treatment of cancer metastases: current and future perspectives," Cancer Lett., vol. 556, p. 216066, 2023.

[6] A. Manohar, V. Vijayakanth, S. V. P. Vattikuti, and K. H. Kim, "Electrochemical energy storage and photoelectrochemical performance of Ni1-XZnXFe2O4 nanoparticles," Mater. Sci. Semicond. Process., vol. 157, p. 107338, 2023.

[7] J. Xu, J. Ma, Y. Peng, S. Cao, S. Zhang, and H. Pang, "Applications of metal nanoparticles/metal-organic frameworks composites in sensing field," Chinese Chem. Lett., vol. 34, no. 4, p. 107527, 2023.

[8] R. Baretta, A. Raucci, S. Cinti, and M. Frasconi, "Porous hydrogel scaffolds integrating Prussian Blue nanoparticles: A versatile strategy for electrochemical (bio) sensing," Sensors Actuators B Chem., vol. 376, p. 132985, 2023.

[9] S. B. Yaqoob, R. Adnan, R. M. Rameez Khan, and M. Rashid, "Gold, silver, and palladium nanoparticles: a chemical tool for biomedical applications," Front. Chem., vol. 8, p. 376, 2020.

[10] A. A. Selim, T. M. Sakr, and B. M. Essa, "Gold Nanoparticles: Synthesis, Functionalization and Biomedical Applications Especially in Cardiovascular Therapy," Pharm. Chem. J., vol. 57, no. 1, pp. 29–39, 2023.

[11] T. Patil, R. Gambhir, A. Vibhute, and A. P. Tiwari, "Gold nanoparticles: synthesis methods, functionalization and biological applications," J. Clust. Sci., vol. 34, no. 2, pp. 705–725, 2023.

[12] P. Zhao, N. Li, and D. Astruc, "State of the art in gold nanoparticle synthesis," Coord. Chem. Rev., vol. 257, no. 3–4, pp. 638–665, 2013.

[13] A. Majdalawieh, M. C. Kanan, O. El-Kadri, and S. M. Kanan, "Recent advances in gold and silver nanoparticles: synthesis and applications," J. Nanosci. Nanotechnol., vol. 14, no. 7, pp. 4757–4780, 2014.

[14] D. T. Nguyen, D.-J. Kim, and K.-S. Kim, "Controlled synthesis and biomolecular probe application of gold nanoparticles," Micron, vol. 42, no. 3, pp. 207–227, 2011.

[15] M. Grzelczak, J. Pérez-Juste, P. Mulvaney, and L. M. Liz-Marzán, "Shape control in gold nanoparticle synthesis," Colloid. Synth. Plasmonic Nanometals, pp. 197–220, 2020.

[16] O. M. El-Borady, M. Fawzy, and M. Hosny, "Antioxidant, anticancer and enhanced photocatalytic potentials of gold nanoparticles biosynthesized by common reed leaf extract," Appl. Nanosci., vol. 13, no. 5, pp. 3149–3160, 2023, doi: 10.1007/s13204-021-01776-w.

[17] M. Hamelian, K. Varmira, B. Karmakar, and H. Veisi, "Catalytic Reduction of 4-Nitrophenol Using Green Synthesized Silver and Gold Nanoparticles over Thyme Plant

Extract," Catal. Letters, vol. 153, no. 8, pp. 2341–2351, 2023, doi: 10.1007/s10562-022-04164-3.

[18] M. M. Shanwaz and P. Shyam, "Anti-bacterial Effect and Characteristics of Gold Nanoparticles (AuNps) Formed with Vitex negundo Plant Extract," Appl. Biochem. Biotechnol., vol. 195, no. 3, pp. 1630–1643, 2023, doi: 10.1007/s12010-022-04217-8.

[19] S. O. Anadozie et al., "One-pot synthesis, characterisation and biological activities of gold nanoparticles prepared using aqueous seed extract of Garcinia kola," Process Biochem., vol. 128, pp. 49–57, 2023, doi: https://doi.org/10.1016/j.procbio.2023.02.010.

[20] S. Khan, J.-S. Park, and T. Ishihara, "A review of the single-step flame synthesis of defective and heterostructured TiO2 nanoparticles for photocatalytic applications," Catalysts, vol. 13, no. 1, p. 196, 2023.

[21] H. Khan and M. U. H. Shah, "Modification strategies of TiO2 based photocatalysts for enhanced visible light activity and energy storage ability: A review," J. Environ. Chem. Eng., p. 111532, 2023.

[22] R. Prammitha, A. R. Jeice, and K. Jayakumar, "Review of multifaceted application based green synthesized Tio2 nanoparticles," Surfaces and Interfaces, p. 102912, 2023.

[23] F. M. P. Tonelli, F. C. P. Tonelli, and H. G. Cordeiro, "TiO2 nanoparticles in cancer therapy as nanocarriers in paclitaxel's delivery and nanosensitizers in phototherapies and/or sonodynamic therapy," Curr. Pharm. Biotechnol., vol. 25, no. 2, pp. 133–143, 2024.

[24] K. G. Rao, C. H. Ashok, K. V. Rao, C. S. Chakra, and P. Tambur, "Green synthesis of TiO2 nanoparticles using Aloe vera extract," Int. J. Adv. Res. Phys. Sci, vol. 2, no. 1A, pp. 28–34, 2015.

[25] T. Pushpamalini, M. Keerthana, R. Sangavi, A. Nagaraj, and P. Kamaraj, "Comparative analysis of green synthesis of TiO2 nanoparticles using four different leaf extract," Mater. Today Proc., vol. 40, pp. S180–S184, 2021.

[26] V. Patidar and P. Jain, "Green synthesis of TiO2 nanoparticle using Moringa oleifera leaf

extract," Int. Res. J. Eng. Technol, vol. 4, no. 3, pp. 1–4, 2017.

[27] K. G. Rao, C. H. Ashok, K. V. Rao, C. S. Chakra, and V. Rajendar, "Green synthesis of tio2 nanoparticles using hibiscus flower extract," in Proceedings of the International Conference on Emerging Technologies in Mechanical Sciences, 2014, pp. 79–82.

[28] B. K. Thakur, A. Kumar, and D. Kumar, "Green synthesis of titanium dioxide nanoparticles using Azadirachta indica leaf extract and evaluation of their antibacterial activity," South African J. Bot., vol. 124, pp. 223–227, 2019.

[29] A. Ansari et al., "Green Synthesis of TiO2 Nanoparticles Using Acorus calamus Leaf Extract and Evaluating Its Photocatalytic and In Vitro Antimicrobial Activity," Catalysts, vol. 12, no. 2. 2022. doi: 10.3390/catal12020181.

[30] S. Subhapriya and P. Gomathipriya, "Green synthesis of titanium dioxide (TiO2) nanoparticles by Trigonella foenum-graecum extract and its antimicrobial properties," Microb. Pathog., vol. 116, pp. 215–220, 2018, doi: https://doi.org/10.1016/j.micpath.2018.01.027.

[31] S. P. Goutam, G. Saxena, V. Singh, A. K. Yadav, R. N. Bharagava, and K. B. Thapa, "Green synthesis of TiO2 nanoparticles using leaf extract of Jatropha curcas L. for photocatalytic degradation of tannery wastewater," Chem. Eng. J., vol. 336, pp. 386–396, 2018, doi: https://doi.org/10.1016/j.cej.2017.12.029.

[32] J. Fulekar, D. P. Dutta, B. Pathak, and M. H. Fulekar, "Novel microbial and root mediated green synthesis of TiO2 nanoparticles and its application in wastewater remediation," J. Chem. Technol. Biotechnol., vol. 93, no. 3, pp. 736–743, 2018.

[33] N. K. Sethy, Z. Arif, P. K. Mishra, and P. Kumar, "Green synthesis of TiO2 nanoparticles from Syzygium cumini extract for photo-catalytic removal of lead (Pb) in explosive industrial wastewater," vol. 9, no. 1, pp. 171–181, 2020, doi: doi:10.1515/gps-2020-0018.

[34] A. Panneerselvam, J. Velayutham, and S. Ramasamy, "Green synthesis of TiO2 nanoparticles prepared from Phyllanthus niruri leaf extract for dye adsorption and their isotherm and kinetic studies," IET Nanobiotechnology, vol. 15, no. 2, pp. 164–172, Apr.

2021, doi: https://doi.org/10.1049/nbt2.12033.

[35] S. Singh, I. C. Maurya, A. Tiwari, P. Srivastava, and L. Bahadur, “Green synthesis of TiO2 nanoparticles using Citrus limon juice extract as a bio-capping agent for enhanced performance of dye-sensitized solar cells,” Surfaces and Interfaces, vol. 28, p. 101652, 2022, doi: https://doi.org/10.1016/j.surfin.2021.101652.

[36] W. M. Alarif et al., “Green Synthesis of TiO2 Nanoparticles Using Natural Marine Extracts for Antifouling Activity,” Marine Drugs, vol. 21, no. 2. 2023. doi: 10.3390/md21020062.

[37] M. Aravind, M. Amalanathan, and M. S. M. Mary, “Synthesis of TiO2 nanoparticles by chemical and green synthesis methods and their multifaceted properties,” SN Appl. Sci., vol. 3, no. 4, p. 409, 2021, doi: 10.1007/s42452-021-04281-5.

[38] T. Santhoshkumar et al., “Green synthesis of titanium dioxide nanoparticles using Psidium guajava extract and its antibacterial and antioxidant properties,” Asian Pac. J. Trop. Med., vol. 7, no. 12, pp. 968–976, 2014.

[39] G. K. Naik, P. M. Mishra, and K. Parida, “Green synthesis of Au/TiO2 for effective dye degradation in aqueous system,” Chem. Eng. J., vol. 229, pp. 492–497, 2013, doi: https://doi.org/10.1016/j.cej.2013.06.053.

[40] K. Tahir et al., “Preparation, characterization and an efficient photocatalytic activity of Au/TiO2 nanocomposite prepared by green deposition method,” Mater. Lett., vol. 178, pp. 56–59, 2016, doi: https://doi.org/10.1016/j.matlet.2016.04.176.

[41] Y. Yulizar, Sudirman, D. O. B. Apriandanu, and A. P. Wibowo, “Plant extract mediated synthesis of Au/TiO2 nanocomposite and its photocatalytic activity under sodium light irradiation,” Compos. Commun., vol. 16, pp. 50–56, 2019, doi: https://doi.org/10.1016/j.coco.2019.08.006.

[42] T. Mosmann, “Rapid colorimetric assay for cellular growth and survival: Application to proliferation and cytotoxicity assays,” J. Immunol. Methods, vol. 65, no. 1, pp. 55–63, 1983, doi: https://doi.org/10.1016/0022-1759(83)90303-4.

[43] M. J. Akhtar et al., "Nanotoxicity of pure silica mediated through oxidant generation rather than glutathione depletion in human lung epithelial cells," Toxicology, vol. 276, no. 2, pp. 95–102, 2010.

[44] M. Ahamed, M. A. Siddiqui, M. J. Akhtar, I. Ahmad, A. B. Pant, and H. A. Alhadlaq, "Genotoxic potential of copper oxide nanoparticles in human lung epithelial cells," Biochem. Biophys. Res. Commun., vol. 396, no. 2, pp. 578–583, 2010.

[45] Chhaya V. Wagh , Dr. Praveen Kumar "M. Elengi fruit Extract Assisted Green Synthesis of Gold NPs and its Photocatalytic, Antimicrobial, and Anti-Oxidant Activity"International Journal of Science, Mathematics and Technology Learning Volume 31 no. pp.480-491 2, 2023.

[46] Chhaya V. Wagh , Dr. Praveen Kumar " Green Synthesis of Titanium Dioxide Nanoparticles using Peltophorum Pterocarpum Flower Extracts and its Photocatalytic, Antimicrobial, and Anti-oxidant Activity" International Journal of Interdisciplinary Organizational Studies Volume 19 no. 1,pp.18-29, 2024