

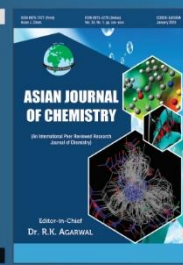


Asian Journal of Chemistry;

Vol. 38, No. 10 (2026), 2545-2552

ASIAN JOURNAL OF CHEMISTRY

<https://doi.org/10.14233/ajchem.2026.36719>



Phytochemical-Assisted Synthesis of GM-MgO NPs from *Garcinia mangostana* L. Leaf Derived Dye: Structural Insights and Biological Applications

C. ANJU*^{ORCID} and S. SUDHA KUMARI^{ORCID}

Department of Chemistry, S.T. Hindu College (Affiliated to Manonmaniam Sundaranar University, Tirunelveli), Nagercoil-629002, India

*Corresponding author: E-mail: anjuc1747@gmail.com

Received: 28 June 2026

Accepted: 17 August 2026

Published online: 9 October 2026

AJC-22484

This study reports an eco-friendly approach for the synthesis of *Garcinia mangostana* L. leaf dye-derived magnesium oxide nanoparticles (GM-MgO NPs) using a natural dye extracted from *G. mangostana* L. leaves. The synthesized GM-MgO NPs were characterized using SEM, EDX, XRD, UV-Vis and FTIR to evaluate their morphology and structural properties. Microscopic analysis revealed the rod-like nanostructures, while elemental and diffraction studies confirmed the formation of crystalline and phase-pure MgO nanorods with an average crystallite size of 52.2 nm. FTIR analysis indicated that the phytochemical constituents present in the *G. mangostana* leaf dye extract played a key role in the GM-MgO NPs formation by acting as reducing and stabilizing agents. The biological potential of the synthesized GM-MgO NPs was assessed. The GM-MgO NPs exhibited significant anti-inflammatory activity, moderate antioxidant capacity and measurable cytotoxicity effects, with IC₅₀ values of 56.44 µg/mL, 287.34 µg/mL and 99.06 µg/mL, respectively. The GM-MgO NPs showed stronger antifungal activity against *C. albicans* than antibacterial activity against *E. coli*, likely due to their nanoscale properties and surface-bound phytochemicals.

Keywords: Green synthesis, *Garcinia mangostana* L., Phytochemical-mediated synthesis, Biological applications.

INTRODUCTION

Green synthesis of nanomaterials using plant-derived phytochemicals offers an eco-friendly alternative to conventional methods, reducing toxic chemical use while incorporating bioactive constituents that may enhance their performance [1,2]. Among metal oxide nanomaterials, magnesium oxide nanoparticles (MgO NPs) have attracted attention due to their physico-chemical stability, biocompatibility, low toxicity and high surface area. These properties support their applications in antibacterial activity, wound healing, catalysis, environmental remediation and drug delivery. Their biological effects involve mechanisms such as oxidative stress, membrane disruption and modulation of cellular signaling pathways [3-6].

The biological activities of MgO NPs are strongly influenced by the particle size, morphology and surface chemistry [7]. In this context, green synthesis emerged as an effective strategy, particularly as plant-based extracts have gained notable interest. These extracts are rich in phytochemicals such as polyphenols, flavonoids and tannins, which can facilitate nanoparticle formation while simultaneously acting as capping

agents that stabilize the nanostructures and impart additional biological activity. These naturally derived compounds may also contribute to antioxidant, anti-inflammatory and antimicrobial effects [8-11].

Natural plant dyes are underexplored bioresources for nanoparticle synthesis, as their functional groups can coordinate metal ions and facilitate nanoparticle formation. They offer a greener approach while enabling control over nanoparticle properties through their chemical composition; however, their use in metal oxide nanostructure synthesis remains limited [12,13]. *Garcinia mangostana* L. commonly known as mangosteen, is a phytochemically rich plant known for its diverse bioactive constituents [14,15]. Different parts of the plant have been widely investigated for therapeutic applications, including antioxidant, anti-inflammatory and antimicrobial activities. Extracts of *G. mangostana* L. have been frequently employed in nanoparticle synthesis [16]; however, the use of leaf-derived natural dye as a precursor for MgO nanoparticle synthesis remains largely unexplored.

In this study, the green synthesis approach for the preparation of GM-MgO NPs using a natural dye derived from *G.*

mangostana leaves is reported. The synthesized GM-MgO NPs were characterized using spectroscopic and microscopic techniques to assess their structural and morphological properties. Their antioxidant, anti-inflammatory, cytotoxic and antimicrobial activities were evaluated for potential biomedical applications. This study explores a novel plant-based precursor for MgO nanostructure synthesis and supports the development of sustainable nanotechnology.

EXPERIMENTAL

All chemicals and solvents including magnesium acetate, *n*-hexane and methanol were purchased from Sigma-Aldrich, India. Deionized distilled water was used for all solutions, with a methanol-water mixture as the hydro-methanolic solvent system. Fresh leaves of *Garcinia mangostana* L. were collected from Thirupparappu, Kanyakumari District, India. The leaves were washed thoroughly with running tap water, shade-dried, powdered and stored in airtight containers until dye extraction.

Preparation of dye extraction: Dye extraction was performed using a Soxhlet apparatus. The powdered sample was placed in a thimble and defatted with *n*-hexane for 6 h at 68 °C. The defatted material was sun-dried to remove residual solvent and extracted with methanol at 65 °C. The resulting yellowish-brown extract was oven-dried at 40 °C for 3 h to obtain powdered dye, which was used for GM-MgO NPs synthesis [17,18].

Green synthesis of MgO nanoparticles: For GM-MgO NPs synthesis, 5 g of dye was dissolved in 50 mL methanol and filtered. The filtrate (25 mL) was mixed with 50 mL of 0.5 M Mg(II) acetate solution and allowed to stand for 2 h at room temperature. A colour change from light brown to deep brown confirmed the formation of GM-MgO NPs. The mixture was stirred for 1 h, centrifuged for 30 min and washed with deionized water and methanol. The purified GM-MgO NPs were oven-dried at 80 °C for 6 h and calcined at 500 °C [18].

Characterization: FTIR spectra were recorded from 4000-500 cm⁻¹ using a Shimadzu FTIR-84005, while UV-Vis spectra were obtained from 200-800 nm using a Shimadzu UV-1800 spectrophotometer. XRD analysis was performed using a Bruker D8 Advance diffractometer with CuK α radiation (λ = 1.5406 Å) over a 2 θ range of 10-80°. The crystalline size was estimated using the Scherrer's equation [$D = K\lambda/\beta\cos\theta$], where K = 0.9, λ is the X-ray wavelength, β is the FWHM of the diffraction peak and θ is the Bragg angle. The morphology and elemental composition of the GM-MgO NPs were examined using a ZEISS SEM equipped with a Smart EDX detector. SEM analysis was performed at an accelerating voltage of 10.00 kV with magnifications ranging from 10 KX to 100 KX, corresponding to particle dimensions of approximately 10 μ m-50 nm.

Cytotoxicity studies (MTT assay)

MCF-7: Human breast cancer cell line (line used in this study was procured from National Centre for Cell Science (NCCS), Pune, India. Cells were maintained in Dulbecco's modified eagle medium (DMEM), supplemented with 10% heat-inactivated fetal bovine serum (FBS) and 1% mixture of antibiotics containing penicillin (100 U/mL), streptomycin

(0.1 mg/mL) and amphotericin B (0.25 μ g/mL). The cell-containing tissue culture flask (25 cm²) was incubated for 24 h at 37 °C in a humidified atmosphere with 5% CO₂ to allow cell adherence.

For the MTT assay, cells were seeded at a density of 10,000 cells/well in 96-well plates in 100 μ L of DMEM and allowed to acclimatize under the same culture conditions for 24 h under standard conditions (37 °C, 5% CO₂). After incubation, the old medium was carefully aspirated and replaced with fresh DMEM (100 μ L) containing the test samples at final concentrations of 6.25, 12.5, 25, 50 and 100 μ g/mL in the wells. Untreated cells containing 100 μ L of DMEM served as the negative control. All treatments were performed in triplicate (n = 3) and results were expressed as the mean $\pm$ standard deviation. After 24 h of treatment, the culture media was aspirated and 100 μ L of 0.5 mg/mL MTT solution in PBS was added to each well. The plates were incubated for 2 h to allow for formazan crystal formation. After incubation, supernatant (MTT solution) was removed and 100 μ L of 100 % DMSO was added to solubilize the formazan crystals. Absorbance was measured at the appropriate wavelength to determine cell viability. The cell viability was calculated using the following formula [19,20].

$$\text{Viability (\%)} = \frac{\text{Average absorbance of treated}}{\text{Average absorbance of control}} \times 100$$

Anti-inflammatory activity (protein denaturation assay): A mixture of total volume of 0.5 mL was prepared by combining 3 % bovine serum albumin and 0.1 mL of the test samples of varying concentrations (6.25 to 100 μ g/mL) in various test tubes and incubated at 37 °C for 20 min. After incubation, 2.5 mL of phosphate-buffered saline (pH 6.3) was added to each tube and then heated at 80 °C for 10 min. The absorbance of each sample was measured at 660 nm using the spectrophotometer. All experiments were performed in triplicate (n = 3) and results were expressed as mean $\pm$ standard deviation. The percentage inhibition of protein denaturation was subsequently calculated using the formula [21,22].

$$\text{Inhibition (\%)} = \frac{\text{Abs}_{\text{control}} - \text{Abs}_{\text{test}}}{\text{Abs}_{\text{control}}} \times 100$$

Antioxidative activity (DPPH radical scavenging assay): For the DPPH assay, a stock solution of ascorbic acid was prepared using distilled water (1 mg/mL, w/v). The 60 μ M solution of DPPH in methanol was freshly prepared and 200 μ L of this solution was mixed with 50 μ L of the test sample at various concentrations (1.56, 3.12, 6.25, 12.5, 25, 50, 100, 200, 400, 800 and 1000 μ g/mL) across multiple test tubes. These test tubes were kept in the dark for 15 min at room temperature and the decrease in absorbance was measured at 515 nm. All experiments were performed in triplicate (n = 3) and results were expressed as mean $\pm$ standard deviation. The control was prepared using the DPPH solution, without any extract or ascorbic acid. A 95% methanol solution was used as a blank and the radical scavenging was calculated using the formula [23,24]:

$$\text{Inhibition (\%)} = \frac{\text{Abs}_{\text{control}} - \text{Abs}_{\text{test}}}{\text{Abs}_{\text{control}}} \times 100$$

Antimicrobial activity: The antimicrobial activity was evaluated by the agar well diffusion method. For antibacterial testing, Mueller-Hinton agar (HIMEDIA-M173) was sterilized and poured into Petri plates. A standardized inoculum of *Escherichia coli* (MTCC 443) was spread onto the agar and four 8 mm wells were prepared. Test samples (50 and 100 μ L; 10 mg/mL) were added to wells T1 and T2. Gentamicin (40 μ L; 4 mg/mL) and chloroform served as positive and negative controls, respectively. Plates were incubated at 37 °C for 24 h and inhibition zones were measured. Antifungal activity was assessed using a 1:1 mixture of Mueller-Hinton agar and potato dextrose agar (HIMEDIA-MH096) against *Candida albicans* (MTCC 227) under similar conditions. Clotrimazole (40 μ L; 300 μ L/mL) and chloroform were used as positive and negative controls, respectively. Plates were incubated at 27 °C for 48 h [25,26]. All assays were performed in triplicate ($n = 3$), and results were expressed as mean $\pm$ standard deviation.

The MIC of GM-MgO NPs was determined by broth microdilution using 96-well microtiter plates. Two-fold serial dilutions of the NPs (15.625–1000 μ g/mL) were prepared in Mueller-Hinton broth for bacteria and fungal broth for *C. albicans*, using DMSO as the solvent. Standardized inocula were added and the plates were incubated at 37 °C for 24–48 h. The MIC was recorded as the lowest concentration showing no visible microbial growth. For MBC determination, 10 μ L from wells without visible growth was plated onto Mueller-Hinton agar and incubated at 37 °C for 24 h. The MBC was defined as the lowest concentration producing no visible colony growth. MFC was determined using the same procedure under appropriate fungal culture conditions [26].

RESULTS AND DISCUSSION

The distinct phytochemical profile of *G. mangostana* (GM) leaf dye compared with the previously reported conventional leaf extracts supports the novelty of this study [27,28]. The phytochemical screening, HPLC and GC-MS analyses identified substituted phenols, fatty acid esters and related derivatives. The phenolic hydroxyl and ester groups may interact with Mg^{2+} ions, forming intermediate complexes that facilitate nucleation and $Mg(OH)_2$ formation. Subsequent anisotropic growth and thermal transformation of these nuclei may yield GM-MgO NPs with the observed nanorod morphology [29,30].

FTIR spectra analysis: The comparison between the FTIR spectrum of the GM-MgO and the *G. mangostana* leaf dye extract revealed the prominent shifts in the bands. The FTIR spectrum of the GM leaf dye extract showed bands at 3398 cm^{-1} (O–H str.), 2949 and 2835 cm^{-1} (C–H str.), 1411 cm^{-1} (C–H bend.), 1658 cm^{-1} (C=O str.) and 1020 cm^{-1} (C–O–C str.). In GM-MgO NPs, these bands shifted to 3466, 2919–2918, 1425, 1645 and 1064 cm^{-1} , respectively (Fig. 1). The shifts in O–H, C=O and C–O–C bands suggest the involvement of hydroxyl, carbonyl and ester-containing phytochemicals in Mg^{2+} complexation and nanoparticle stabilization. New bands appear at 534 and 881 cm^{-1} were assigned to Mg–O vibrations, supporting the formation of GM-MgO NPs and their interaction with plant-derived functional groups

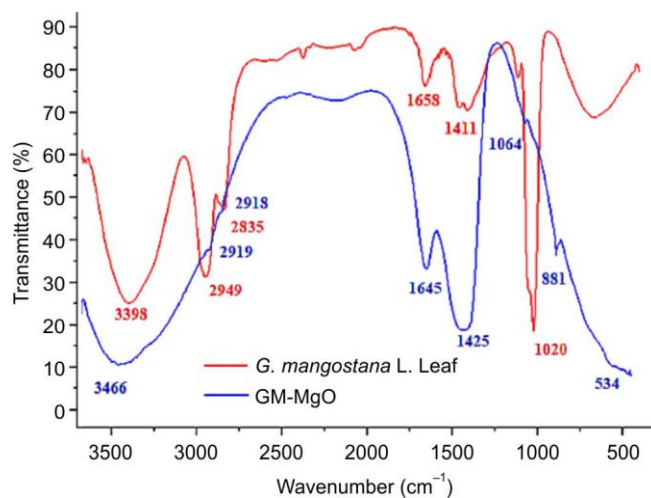


Fig. 1. FT-IR spectra of GM MgO NPs

[27–31]. Similar FTIR features have been reported for GM-MgO NPs synthesized using banana peel extract, with O–H stretching near 3348 cm^{-1} , C–H stretching around 2923 cm^{-1} and Mg–O vibrations in the 655–594 cm^{-1} region [32]. The slight differences in band positions may be associated with the distinct phytochemical composition of the *G. mangostana* leaf dye extract.

UV-Visible spectra analysis: The UV-Vis spectrum of GM-MgO NPs (Fig. 2b) exhibited an absorption peak at 250 nm, which falls within the reported nanoscale absorption region and may be attributed to the increased band gap and associated blue shift, supporting the formation of GM-MgO NPs. In comparison, the *G. mangostana* leaf dye extract showed an absorption peak at 276 nm (Fig. 2a), with the shift from 276 to 250 nm further supporting nanoparticle formation. Similar blue shifts have been reported for the plant-mediated MgO NPs synthesis [33]. Green-synthesized GM-MgO NPs generally exhibit absorption peaks in the 230–330 nm range, with reported values of 271–276 nm [34], 267 and ~270 nm [35] and 290–324 nm [36], depending on the particle size, morphology and synthesis conditions. The absorption peak at 250 nm observed for GM-MgO NPs is consistent with these reports and supports their nanoscale nature.

SEM with EDX analysis: The SEM images (Fig. 3a–c) of the synthesized GM-MgO NPs revealed predominantly nanorod-like morphology with relatively uniform distribution and slight variations in size and shape. Histogram analysis showed a mean nanorod length of 176.5 ± 77 nm (Fig. 3d). The observed morphology, together with the XRD results, supports the crystalline nature of the nanoparticles. The formation of nanorod-like structures may be influenced by bioactive compounds in the GM leaf dye extract, which can act as capping and stabilizing agents during synthesis.

The elemental composition of GM-MgO NPs was determined by EDX (Fig. 3e), which showed characteristic peaks corresponding to Mg and O, confirming MgO formation. A minor C peak may be attributed to residual organic compounds from the GM leaf extract. SEM–EDX analysis supports the successful formation and high elemental purity of the GM-MgO NPs [37,38].

X-ray diffraction analysis: The XRD spectrum of GM-MgO (Fig. 4) displayed five distinct, significant, intense,

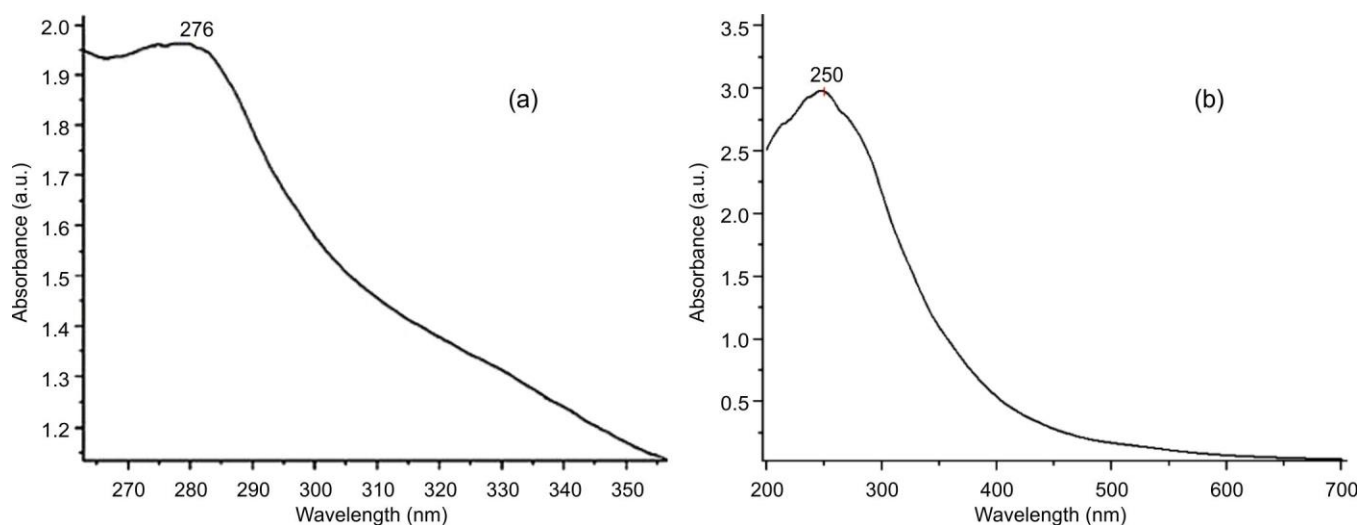


Fig. 2. UV-Vis spectrum of (a) GM leaf dye extract [27] and (b) GM MgO NPs

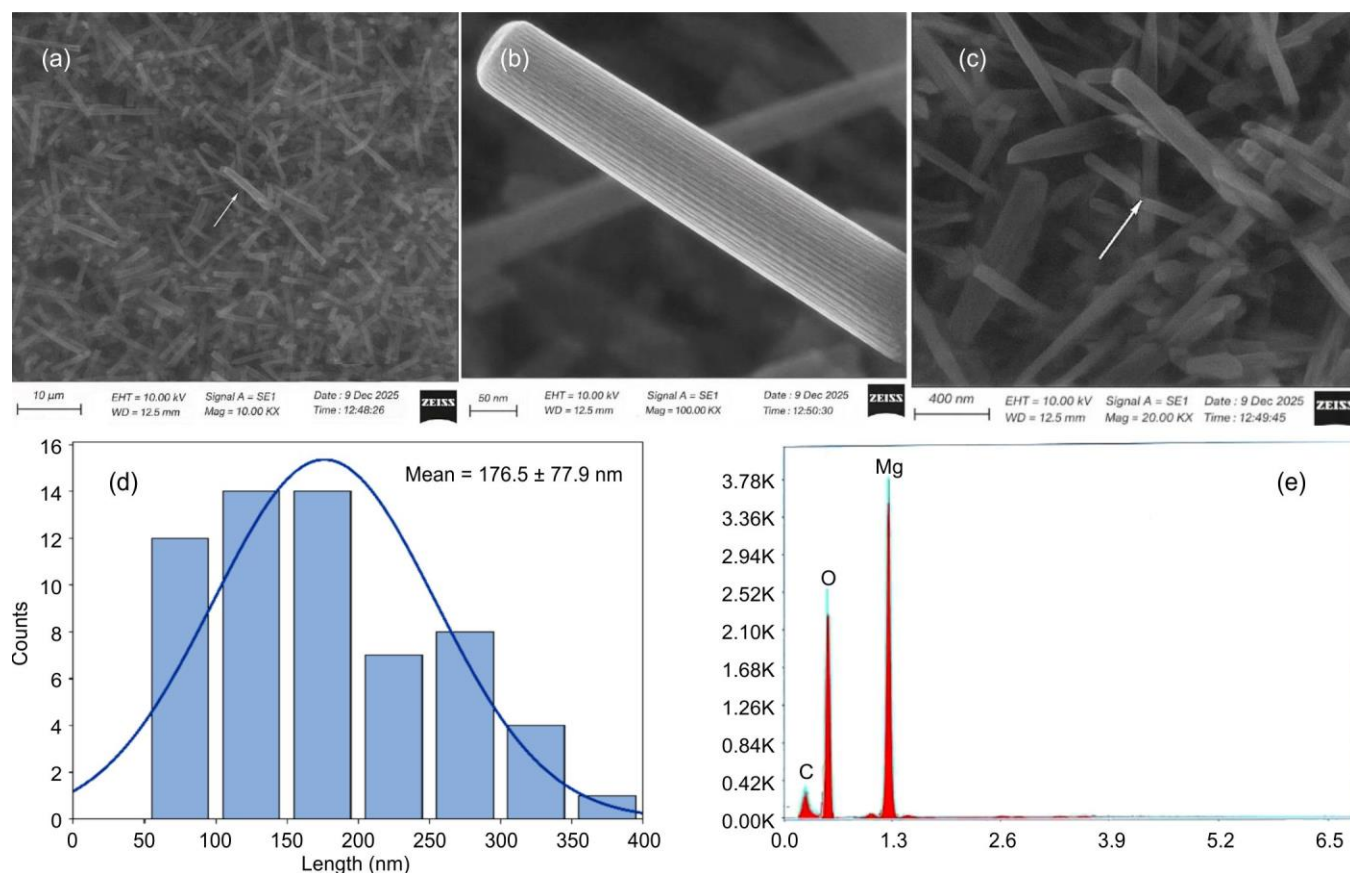


Fig. 3. (a-c) SEM images of GM-MgO NPs at 10 μm, 50 nm and 400 nm, (d) histogram and (e) EDX image of GM-MgO NPs

sharp and well-defined diffraction peaks at 2θ values of 37.93° , 42.95° , 62.4° , 75.61° and 78.63° (Table-1), which corresponded to the (111), (200), (220), (311) and (222) crystallographic planes, respectively. These patterns corresponded well with the face-centred cubic (FCC) periclase structure of GM-MgO NPs (JCPDS card no. 4-829 & 45-0946) [39-41]. The absence of additional impurity peaks confirmed the phase purity of the GM-MgO NPs [42]. The sharp, well-defined diffraction peaks confirmed the high crystallinity of GM-MgO NPs and

TABLE-1
POWDER XRD DATA OF GM-MGO NPS

2θ	θ	FWHM	β	D (nm)
37.93°	18.9°	0.189	0.003298	44.43
42.95°	21.4°	0.226	0.003944	37.75
62.40°	31.2°	0.200	0.003490	46.44
75.61°	37.8°	0.137	0.002391	73.39
78.63°	39.3°	0.174	0.003036	59.00

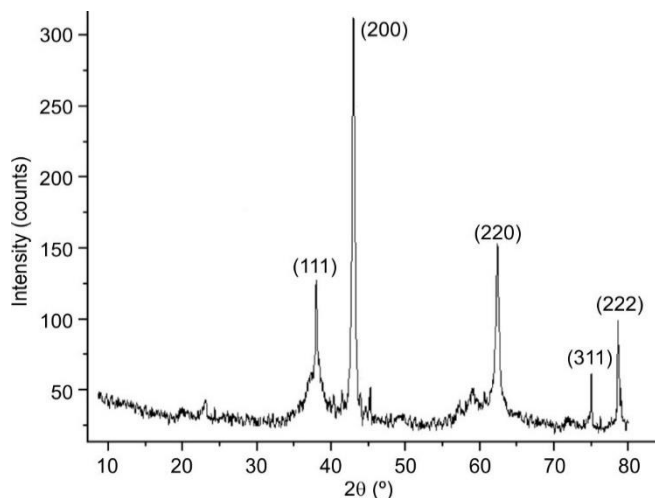


Fig. 4. XRD spectrum of GM-MgO NPs

well-developed crystal structure. The crystallite size calculated using Scherrer's equation ranged from 37.7 to 73.3 nm, with an average size of 52.2 nm. The nanoscale crystallite size and high crystallinity may contribute to consistent reactivity in biomedical and catalytic applications [43,44].

Biological studies

Antioxidant activity: The antioxidant activity of GM-MgO NPs was evaluated using the DPPH assay, with ascorbic acid as the standard ($IC_{50} = 28.19 \mu\text{g/mL}$) (Fig. 5a; Table-2). DPPH radical scavenging increased with the concentration, reaching nearly 25% at 25 $\mu\text{g/mL}$ and 50% between 200 and 400 $\mu\text{g/mL}$. The IC_{50} value of GM-MgO NPs was 287.34 $\mu\text{g/mL}$, with 58% inhibition at 1000 $\mu\text{g/mL}$, which indicate the moderate antioxidant activity. Compared with the *G. mangostana* leaf dye extract ($IC_{50} = 337.55 \mu\text{g/mL}$) [27], the GM-MgO NPs showed improved scavenging activity. This activity may be associated with surface reactivity and phytochemicals retained on the nanoparticle surface. Although lower than ascorbic acid, the antioxidant activity of GM-MgO NPs, coupled with their plant-mediated synthesis, supports their potential for biomedical applications [45-48].

TABLE-2
ANTIOXIDANT ACTIVITY, ANTI-INFLAMMATORY
ACTIVITY AND CYTOTOXICITY DATA OF GM-MgO NPs

Conc. ($\mu\text{g/mL}$)	Inhibition (%)		
	Antioxidant activity $\pm$ SD	Anti- inflammatory activity $\pm$ SD	Cytotoxicity $\pm$ SD
0	0	0	0
1.56	7.78 ± 0.12	—	—
3.12	9.77 ± 0.10	—	—
6.25	11.75 ± 0.14	6.53 ± 0.20	98.17 ± 0.12
12.5	18.69 ± 0.11	18.94 ± 0.25	89.17 ± 0.09
25	25.67 ± 0.15	25.86 ± 0.18	79.17 ± 0.09
50	34.62 ± 0.09	48.97 ± 0.30	62.34 ± 0.11
100	41.57 ± 0.12	55.02 ± 0.35	51.11 ± 0.21
200	47.54 ± 0.16	—	—
400	51.46 ± 0.11	—	—
800	54.36 ± 0.18	—	—
1000	58.05 ± 0.19	—	—
IC_{50} ($\mu\text{g/mL}$)	287.34	56.44	99.06

Anti-inflammatory activity: The synthesized GM-MgO NPs were evaluated for anti-inflammatory activity using a protein denaturation inhibition assay with diclofenac ($IC_{50} = 49.68 \mu\text{g/mL}$) as the reference standard (Fig. 5b). The results showed that as the concentration increases from 6.25 to 100 $\mu\text{g/mL}$, the inhibition of protein denaturation increases steadily from 6.53% to 55.01% (Table-2). The calculated IC_{50} value of 56.44 $\mu\text{g/mL}$ indicates significant inhibition efficacy, closely approaching that of the standard drug diclofenac. In comparison to *G. mangostana* leaf dye extract ($IC_{50} = 68.50 \mu\text{g/mL}$), GM-MgO NPs exhibited enhanced anti-inflammatory activity, potentially arising from the combined effects of MgO and phytochemical capping agents that may reduce protein denaturation under thermal stress [49-51].

Cytotoxicity effect: The cytotoxicity effect of GM-MgO NPs was evaluated using an MTT assay against MCF-7 (human breast cancer cell line) at concentrations of 6.25, 12.5, 25, 50 and 100 $\mu\text{g/mL}$ (Table-2). The results revealed that GM-MgO NPs exhibited a dose-dependent cytotoxic

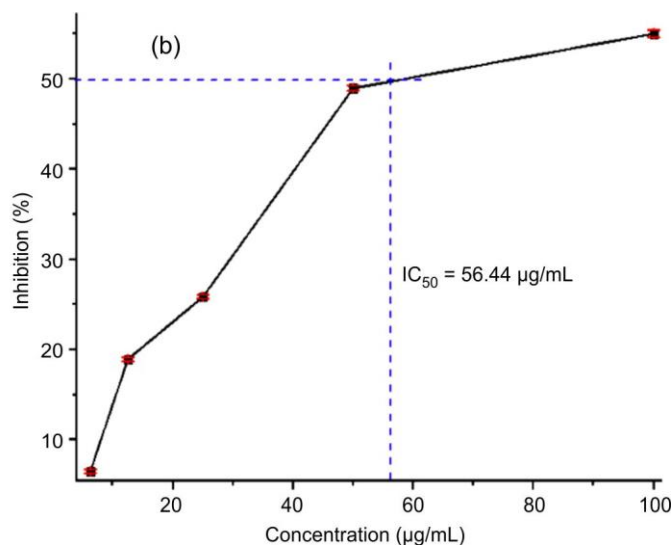
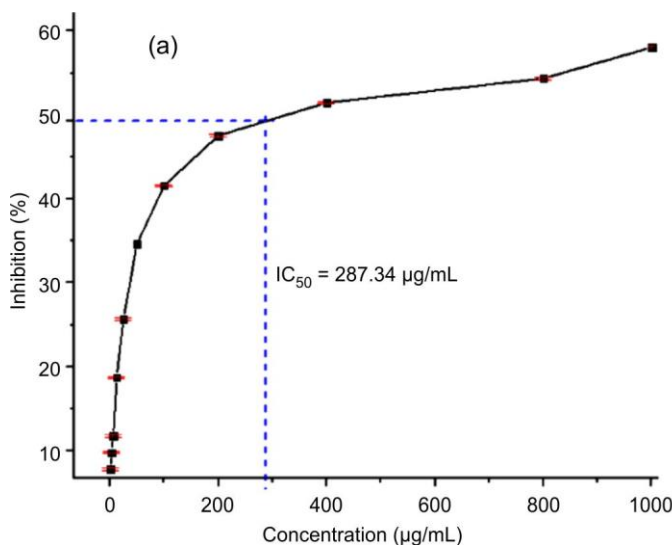


Fig. 5. (a) Antioxidant activity and (b) anti-inflammatory activity of GM-MgO NPs

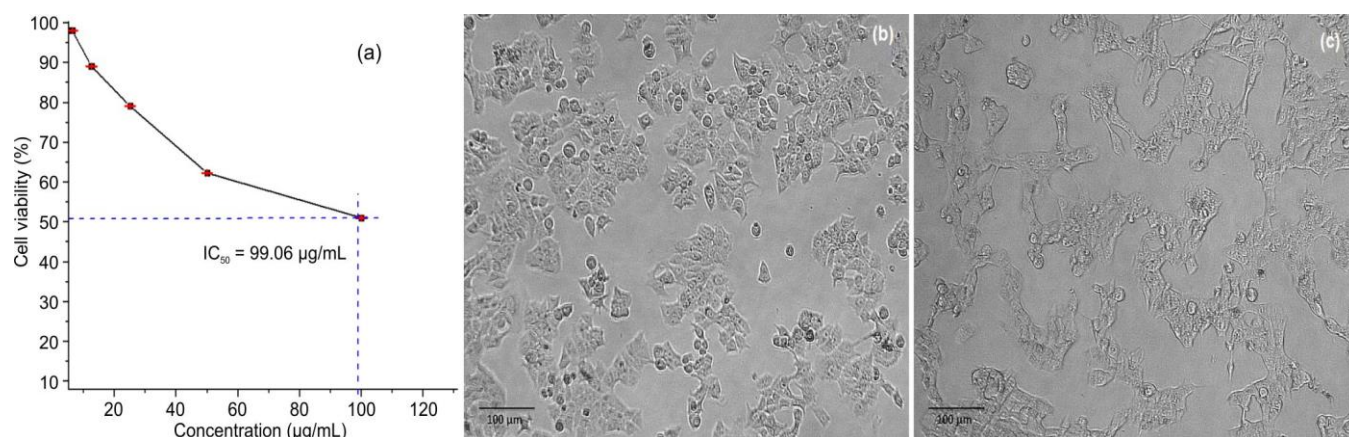


Fig. 6. (a) IC₅₀ graph of GM-MgO NPs on MCF-7 cell viability; (b) MCF-7 viability at 50 µg/mL and (c) MCF-7 viability at 100 µg/mL

TABLE-3
ANTIMICROBIAL ACTIVITY DATA OF GM-MgO NPs

Microorganisms	Sample	Triplicate (mm)			Zone (average) mm ± standard deviation
		1	2	3	
<i>Escherichia coli</i>	T1 (500 µg)	7.0	6.0	7.0	7.0 ± 0.5
	T2 (1000 µg)	13.0	13.0	12.4	13.0 ± 0.7
	Gentamycin (160 µg)	19.1	20.0	20.0	20.0 ± 0.3
<i>Candida albicans</i>	T1 (500 µg)	12.7	14.0	14.0	14.0 ± 0.4
	T2 (1000 µg)	18.0	17.9	18.0	18.0 ± 0.6
	Clotrimazole (120 µg)	21.9	22.0	22.0	22.0 ± 0.5

impact on MCF-7 cell lines (Fig. 6a). Low concentrations of 6.25 and 12.5 µg/mL exhibited minimal cytotoxicity, with high cell viability of 98.17% and 89.17%, respectively. However, as the concentration increased, cell viability progressively decreased to 76.17% at 25 µg/mL, 62.34% at 50 µg/mL (Fig. 6b) and 51.1% at 100 µg/mL, respectively (Fig 6c). The IC₅₀ value was 99.06 µg/mL, with significant cytotoxicity observed only at higher concentrations.

In the comparison with *G. mangostana* leaf dye extract (IC₅₀ = >100 µg/mL), GM-MgO NPs showed enhanced cytotoxicity effect, likely due to the combined effects of MgO and phytochemical capping agents [52,53]. Although the cytotoxic effect was moderate, the biocompatibility and eco-friendly synthesis of the GM-MgO NPs highlight their potential for safe application in therapeutic optimization [54-56].

Antimicrobial activity: The GM-MgO NPs was assessed for its antimicrobial potential against *E. coli* and *C. albicans* in two different concentrations (500 µg and 1000 µg) using the well diffusion method. The results were compared with the positive controls (gentamicin/clotrimazole) and a negative control (DMSO). The results revealed that GM-MgO NPs showed an enhanced antifungal effect (14 mm at 500 µg and 18 mm at 1000 µg) compared to the antibacterial effect (7 mm at 500 µg and 13 mm at 1000 µg). The activity was dose-dependent and increased concentration led to increased activity (Table-3). However, GM-MgO NPs exhibited moderate activity compared to the standard, while nanoparticles exhibited significant activity relative to the GM-leaf dye extract. The observed selectivity, with enhanced activity against *C. albicans*, may be attributed to the structural

differences between fungal and bacterial membranes, as well as the electrostatic interactions between MgO NPs and microbial surfaces [24,57-60].

The minimum inhibitory concentration (MIC), minimum bactericidal concentration (MBC) and minimum fungicidal concentration of the synthesized GM-MgO NPs were further evaluated (Table-4). The MIC data indicated 500 µg/mL against *E. coli* and 250 µg/mL against *C. albicans*. The MBC (1000 µg/mL) and MFC (500 µg/mL) data showed that a higher concentration was required for the bactericidal and fungicidal effects [61].

TABLE-4
MIC, MBC AND MFC DATA OF GM-MgO NPs

Microorganisms	MIC (µg/mL)	MBC (µg/mL)	MFC (µg/mL)
<i>E. coli</i>	500	1000	—
<i>C. albicans</i>	250	—	500

Conclusion

This study demonstrated a green synthesis route for the formation of GM-MgO NPs using a *Garcinia mangostana* L. leaves derived dye. The phytochemical constituents present in the extract played a significant role in facilitating nanoparticle formation and stabilization, resulting in well-defined nanorod structures. The structural and spectroscopic analyses confirmed the successful formation of crystalline MgO nanorods. The synthesized GM-MgO NPs exhibited antioxidant, anti-inflammatory, cytotoxic and antimicrobial activities, with anti-inflammatory activity being the most pronounced. The

antioxidant and cytotoxic effects were moderate and concentration dependent, while stronger antimicrobial activity was observed against *C. albicans* than *E. coli*. These biological responses may arise from the nanoscale MgO structure and surface-associated phytochemicals from the *G. mangostana* leaf dye extract.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. Mahesh, Assist. Prof., Department of Botany, for his valuable support. The authors acknowledge Athmic Biotech Solutions Private Limited, Trivandrum, India for conducting the biological activity assessments. Gratitude is also extended to Holy Cross College, Nagercoil and St. Joseph's College, Tiruchirappalli, for their support with the spectroscopic studies.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

DECLARATION OF AI-ASSISTED TECHNOLOGIES

During the preparation of this manuscript, the authors used an AI-assisted tool(s) to improve the language and no data, results or scientific conclusions were generated by AI. All analyses, interpretations and conclusions are the authors' own. The authors reviewed and edited the content and take full responsibility for the published work.

REFERENCES

1. S. Jadoun, R. Arif, N.K. Jangid and R.K. Meena, *Environ. Chem. Lett.*, **19**, 355 (2021); <https://doi.org/10.1007/s10311-020-01074-x>
2. T. Mustapha, N. Misni, N.R. Ithnin, A.M. Daskum and N.Z. Unyah, *Int. J. Environ. Res. Public Health*, **19**, 674 (2022); <https://doi.org/10.3390/ijerph19020674>
3. A. Sharmila, A.R. Darshan, V.M. Hadkar, N.K. Sishu and C.I. Selvaraj, *Inorg. Chem. Commun.*, **172**, 113730 (2025); <https://doi.org/10.1016/j.inoche.2024.113730>
4. S. Vijayakumar, V.N. Punitha and N. Parameswari, *Arab. J. Sci. Eng.*, **47**, 6729 (2022); <https://doi.org/10.1007/s13369-021-06107-3>
5. L. Umaralikhan and M. Jamal Mohamed Jaffar, *Iran. J. Sci. Technol. Trans. A Sci.*, **42**, 477 (2018); <https://doi.org/10.1007/s40995-016-0041-8>
6. J. Hornak, *Int. J. Mol. Sci.*, **22**, 12752 (2021); <https://doi.org/10.3390/ijms222312752>
7. N.T.T. Nguyen, L.M. Nguyen, T.T.T. Nguyen, U.P.N. Tran, D.T.C. Nguyen and T.V. Tran, *Chemosphere*, **312**, 137301 (2023); <https://doi.org/10.1016/j.chemosphere.2022.137301>
8. M. Pirsaeheb, T. Gholami, H. Seifi, E.A. Dawi, E.A. Said, A.-H.M. Hamood, U.S. Altimari and M. Salavati-Niasari, *Environ. Sci. Pollut. Res.*, **31**, 24768 (2024); <https://doi.org/10.1007/s11356-024-32983-x>
9. N.T. T. Nguyen, L.M. Nguyen, T.T.T. Nguyen, T.T. Nguyen, D.T.C. Nguyen and T.V. Tran, *Environ. Chem. Lett.*, **20**, 2531 (2022); <https://doi.org/10.1007/s10311-022-01425-w>
10. A.K. Tiwari, S. Jha, S.K. Tripathi, R. Shukla, R.R. Awasthi, A.K. Bhardwaj, A.K. Singh and A. Dikshit, *Discov. Appl. Sci.*, **6**, 399 (2024); <https://doi.org/10.1007/s42452-024-06049-z>
11. A.K. Tiwari, S. Jha, A.K. Singh, S.K. Mishra, A.K. Pathak, R.P. Ojha, R.S. Yadav and A. Dikshit, *Crystals*, **12**, 1063 (2022); <https://doi.org/10.3390/cryst12081063>
12. A.K. Tiwari, S. Jha, S.K. Tripathi, R.R. Awasthi, A.K. Bhardwaj, A.K. Singh and A. Dikshit, *Mater. Res. Express*, **11**, 085005 (2024); <https://doi.org/10.1088/2053-1591/ad6ca9>
13. T. Sambandam, G. Karuppasamy, G. Perumal and E.C. Rajasingh, *J. Photochem. Photobiol. B*, **262**, 113084 (2025); <https://doi.org/10.1016/j.jphotobiol.2024.113084>
14. P. Govindhan, *Nat. Prod. Res.*, **40**, 215 (2024); <https://doi.org/10.1080/14786419.2024.2402474>
15. S. Khadem and R.J. Marles, *Nat. Prod. Res.*, **39**, 2252 (2025); <https://doi.org/10.1080/14786419.2024.2357663>
16. Y.B. Chan, M. Aminuzzaman, X.-T. Chuah, K. Li, P. Balu, L.S. Wong, S.K. Guha and L.-H. Tey, *Nanotechnol. Rev.*, **14**, 20250157 (2025); <https://doi.org/10.1515/ntrev-2025-0157>
17. I.J. Lithi, K.I.A. Nakib, A.S. Chowdhury and M.S. Hossain, *Nanoscale Adv.*, **7**, 2446 (2025); <https://doi.org/10.1039/D5NA00037H>
18. M.M. Ragab, A.G. Hassabo and H. Othman, *Colorat. Polym. Sci.*, **19**, 137 (2022); <https://doi.org/10.21608/jtpps.2022.130253.1115>
19. T. Mosmann, *J. Immunol. Methods*, **65**, 55 (1983); [https://doi.org/10.1016/0022-1759\(83\)90303-4](https://doi.org/10.1016/0022-1759(83)90303-4)
20. M.M. Joseph, S.R. Aravind, S. Varghese, S. Mini and T.T. Sreelekha, *Mol. Med. Rep.*, **5**, 489 (2012); <https://doi.org/10.3892/mmr.2011.638>
21. Y. Mizushima and M. Kobayashi, *J. Pharm. Pharmacol.*, **20**, 169 (1968); <https://doi.org/10.1111/j.2042-7158.1968.tb09718.x>
22. S. Sakat, P. Tupe and A. Juvekar, *Planta Med.*, **76**, P090 (2010); <https://doi.org/10.1055/s-0030-1264388>
23. K.P. Anthony and M.A. Saleh, *Antioxidants*, **2**, 398 (2013); <https://doi.org/10.3390/antiox2040398>
24. W. Brand-Williams, M.E. Cuvelier and C.L.W.T. Berset, *Lebensm. Wiss. Technol.*, **28**, 25 (1995); [https://doi.org/10.1016/S0023-6438\(95\)80008-5](https://doi.org/10.1016/S0023-6438(95)80008-5)
25. C. Valgas, S.M.D. Souza, E.F. Smânia Jr. and A. Smânia Jr., *Braz. J. Microbiol.*, **38**, 369 (2007); <https://doi.org/10.1590/S1517-83822007000200034>
26. N.Y.T. Nguyen, N. Grelling, C.L. Wetteland, R. Rosario and H. Liu, *Sci. Rep.*, **8**, 16260 (2018); <https://doi.org/10.1038/s41598-018-34567-5>
27. C. Anju and S. Sudha Kumari, *Results Chem.*, **27**, 103443 (2026); <https://doi.org/10.1016/j.rechem.2026.103443>
28. Q.M.N. Alsultan, K. Sijam, T.S. Rashid and K.B. Ahmad, *Am. J. Plant Sci.*, **7**, 1013 (2016); <https://doi.org/10.4236/ajps.2016.77096>
29. D.M. Radulescu, I.A. Neacsu, B.S. Vasile, V.A. Surdu, O.C. Oprea, R.D. Trusca, C. Chircov, R.C. Popescu, C.I. Ilie, L.M. Ditu, V. Drumea and E. Andronescu, *Int. J. Mol. Sci.*, **26**, 9021 (2025); <https://doi.org/10.3390/ijms26189021>
30. D. Kirubakaran and V. Krishnan, *Pharmacol. Res.-Nat. Prod.*, **7**, 100238 (2025); <https://doi.org/10.1016/j.prenap.2025.100238>
31. D. Kirubakaran, *Digit. Chin. Med.*, **8**, 183 (2025); <https://doi.org/10.1016/j.dcm.2025.05.002>
32. H. Amrulloh, A. Fatiqin, W. Simanjuntak, H. Afriyani and A. Annissa, *J. Multidiscipl. Appl. Nat. Sci.*, **1**, 44 (2021); <https://doi.org/10.47352/jmans.v1i1.9>
33. N. John Sushma, D. Prathyusha, G. Swathi, T. Madhavi, B.D. Prasad Raju, K. Mallikarjuna and H.-S. Kim, *Appl. Nanosci.*, **6**, 437 (2016); <https://doi.org/10.1007/s13204-015-0455-1>
34. M. Ramezani Farani, M. Farsadrooh, I. Zare, A. Gholami and O. Akhavan, *Catalysts*, **13**, 642 (2023); <https://doi.org/10.3390/catal13040642>
35. P. Bhattacharya, A. Dey and S. Neogi, *J. Mater. Chem. B*, **9**, 5329 (2021); <https://doi.org/10.1039/D1TB00875G>
36. H.C.S. Perera, V. Gurunathanan, A. Singh, M.M.M.G.P.G. Mantilaka, G. Das and S. Arya, *J. Magnes. Alloy.*, **12**, 1709 (2024); <https://doi.org/10.1016/j.jma.2024.05.003>
37. S. Varshney, A. Nigam, N. Mishra and S.J. Pawar, *J. Korean Ceram. Soc.*, **60**, 62 (2023); <https://doi.org/10.1007/s43207-022-00236-7>
38. A. Muhaymin, H.E.A. Mohamed, K. Hkiri, A. Safdar, S. Azizi and M. Maaza, *Sci. Rep.*, **14**, 20135 (2024); <https://doi.org/10.1038/s41598-024-71149-0>

39. N.B. Arun Kumar, B. Mahendra, J. Sirajudeen, M.R. Anil Kumar, H.P. Nagaswarupa, C.R. Ravi Kumar and B. Umesh, *Mater. Today Proc.*, **5**, 22275 (2018);
<https://doi.org/10.1016/j.matpr.2018.06.593>
40. F. Gu, S.F. Wang, M.K. Lü, W.G. Zou, G.J. Zhou, D. Xu and D.R. Yuan, *J. Cryst. Growth*, **260**, 507 (2004);
<https://doi.org/10.1016/j.jcrysgro.2003.08.044>
41. T.B. Nijalingappa, M.K. Veeraiah, R.B. Basavaraj, G.P. Darshan, S.C. Sharma and H. Nagabhushana, *Biocatal. Agric. Biotechnol.*, **18**, 100991 (2019);
<https://doi.org/10.1016/j.bcab.2019.01.029>
42. E. Proniewicz, A.M. Vijayan, O. Surma, A. Szkudlarek and M. Molenda, *Int. J. Mol. Sci.*, **25**, 4242 (2024);
<https://doi.org/10.3390/ijms25084242>
43. N. Sisubalan, S. Ramadoss, M. Gnanaraj, A. Vijayan, K. Chandrasekaran, S.B. Sundaram, C. Chaiyavat and V. Kokkarachedu, *Eco-friendly Synthesis of MgO Nanoparticles for Biomedical Applications: Advances, Challenges and Future Prospects*, In: *Nanotechnology in the Life Sciences*, Springer: Cham, Switzerland (2024).
44. M.K. Soliman, A.H. Talib, R. Mahmoud, Z.A. Ali, H.H. Al-Haideri, A. Abalkhail, A.S. Binshaya, M.H. Salem, F.O. Al-Otibi and M.T. Yassin, *AMB Express*, **15**, 143 (2025);
<https://doi.org/10.1186/s13568-025-01950-1>
45. Z.X. Tang and B.F. Lv, *Braz. J. Chem. Eng.*, **31**, 591 (2014);
<https://doi.org/10.1590/0104-6632.20140313s00002813>
46. H. Kaur, S. Kumar and G. Bouzid, *Interactions*, **245**, 234 (2024);
<https://doi.org/10.1007/s10751-024-02088-5>
47. M.F. Khan and M.A. Khan, *Future Pharmacol.*, **3**, 252 (2023);
<https://doi.org/10.3390/futurepharmacol3010018>
48. D. Kirubakaran, K. Selvam, P. Prakash, M.S. Shivakumar and M. Rajkumar, *OpenNano*, **14**, 100188 (2023);
<https://doi.org/10.1016/j.onano.2023.100188>
49. D. Kirubakaran, G. Bupesh, R. Murugeswaran, J. Ramalingam, J.B.A. Wahid, S. Arokiyaraj, V. Sivasakthi and J. Panigrahi, *Biomed. Mater. Devices*, **4**, 552 (2025);
<https://doi.org/10.1007/s44174-025-00283-8>
50. S. Ali, K.G. Sudha, M. Thiruvengadam and R. Govindasamy, *Biomass Convers. Biorefin.*, **14**, 21431 (2024);
<https://doi.org/10.1007/s13399-023-04252-3>
51. D. Kirubakaran, K. Selvam, P. Prakash, P. Manimegalai, M.S. Shivakumar and S. SenthilNathan, *Biotechnol. Appl. Biochem.*, **70**, 870 (2023);
<https://doi.org/10.1002/bab.2406>
52. M.R. Khan, N.O. Alafaleq, A.K. Ramu, K. Alhosaini, M.S. Khan, T.A. Zughaibi and S. Tabrez, *Saudi J. Biol. Sci.*, **31**, 103874 (2024);
<https://doi.org/10.1016/j.sjbs.2023.103874>
53. T. Shekofteh Narm, H. Hamidinezhad and M. Darroudi, *Waste Biomass Valoriz.*, **16**, 2459 (2024);
<https://doi.org/10.1007/s12649-024-02823-7>
54. H. Dayalan, G. Bupesh, D. Kirubakaran, D. Mathe and J. Panigrahi, *Med. Oncol.*, **42**, 245 (2025);
<https://doi.org/10.1007/s12032-025-02780-8>
55. M. Rajkumar, S.D. Presley, P. Govindaraj, D. Kirubakaran, F. Farahim, T. Ali, M. Shkir and S. Latha, *Sci. Rep.*, **15**, 3931 (2025);
<https://doi.org/10.1038/s41598-025-87932-6>
56. A.R. Ribeiro, S.S. Silva and R.L. Reis, *Biomater. Adv.*, **134**, 112720 (2022);
<https://doi.org/10.1016/j.msec.2022.112720>
57. A. Carrapiço, M.R. Martins, A.T. Caldeira, J. Mirão and L. Dias, *Microorganisms*, **11**, 378 (2023);
<https://doi.org/10.3390/microorganisms11020378>
58. D. Kirubakaran, K. Selvam, M.S. Shivakumar, M. Rajkumar, S. Kannan and B. Navina, *ChemistrySelect*, **9**, e202302792 (2024);
<https://doi.org/10.1002/slct.202302792>
59. T. Jin and Y. He, *J. Nanopart. Res.*, **13**, 6877 (2011);
<https://doi.org/10.1007/s11051-011-0595-5>
60. Y.H. Leung, A.M. Ng, X. Xu, Z. Shen, L.A. Gethings, M.T. Wong, C.M. Chan, M.Y. Guo, Y.H. Ng, A.B. Djurišić, P.K. Lee, W.K. Chan, L.H. Yu, D.L. Phillips, A.P.Y. Ma and F.C.C. Leung, *Small*, **10**, 1171 (2014);
<https://doi.org/10.1002/smll.201302434>
61. S. Hayat, S. Muzammil, M.H. Rasool, Z. Nisar, S.Z. Hussain, A.N. Sabri and S. Jamil, *Microbiol. Immunol.*, **62**, 211 (2018);
<https://doi.org/10.1111/1348-0421.12580>