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Original Article

Biogenic Cerium Oxide Nanoparticles Synthesized Using *Scutellaria baicalensis* Root and *Moringa oleifera* Leaf Extracts: Characterization and Evaluation of Antimicrobial, Antioxidant, Anti-Inflammatory, and Cytocompatibility Activities

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ABSTRACT

Introduction: Green synthesis of cerium oxide nanoparticles using medicinal plant extracts provides an eco-friendly strategy for developing biologically active nanomaterials. Using extracts from the roots of *Scutellaria baicalensis* and the leaves of *Moringa oleifera*, this study sought to create biogenic cerium oxide nanoparticles and assess their biological characteristics. **Materials and Methods:** Aqueous plant extracts were used to create cerium oxide nanoparticles, which were then examined using Scanning Electron Microscopy (SEM). The brine shrimp lethality assay was used to measure cytotoxicity; the agar well diffusion method was used to measure antimicrobial activity against *Streptococcus mutans* and *Staphylococcus aureus*; the 2,2-Diphenyl-1-Picrylhydrazyl (DPPH) assay was used to measure antioxidant activity; and the Bovine Serum Albumin (BSA) protein denaturation assay was used to measure anti-inflammatory activity. One-way Analysis of Variance (ANOVA) and the independent samples *t*-test were used to analyze the data. **Results:** SEM analysis confirmed the successful formation of predominantly spherical, agglomerated cerium oxide nanoparticles with nanoscale morphology. The nanoparticles demonstrated concentration-dependent antioxidant, antimicrobial, and anti-inflammatory properties along with minimal cytotoxicity. As the concentration of nanoparticles increased, there were notable increases in DPPH radical scavenging, protein denaturation inhibition, and antibacterial activity ($p<0.001$). The nanoparticles and the corresponding standard controls did not differ significantly ($p>0.05$). **Conclusion:** Biogenic cerium oxide nanoparticles synthesized using *Scutellaria baicalensis* root and *Moringa oleifera* leaf extracts demonstrated favorable cytocompatibility and potent antioxidant, antimicrobial, and anti-inflammatory properties, highlighting their potential for biomedical and dental applications.

Keywords: Green synthesis, Herb, Metal oxide, Nanoparticles, Nanotechnology, Phytotherapy.

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INTRODUCTION

Innovative methods for the management and prevention of inflammatory and infectious diseases have made nanotechnology a breakthrough in biomedical research. Cerium Oxide Nanoparticles (CeO_2 NPs) have garnered significant interest among different metal oxide nanomaterials because of their exceptional biological activities, high surface area, and distinct redox characteristics (Singh *et al*., 2020). The ability of CeO_2 NPs to switch between Ce^{3+} and Ce^{4+} oxidation states enable them to scavenge reactive oxygen species and mimic the activity of endogenous antioxidant enzymes (Corsi *et al*., 2023). Because of these qualities, CeO_2 NPs are attractive options for use in drug delivery, tissue regeneration, antimicrobial therapy, and the treatment of disorders linked to oxidative stress (Selvaraj *et al*., 2024).

The biomedical applicability of conventional physical and chemical methods for nanoparticle synthesis may be limited because they frequently call for high energy input, hazardous reagents, and complicated processing conditions (Singh *et al*., 2024). On the other hand, biogenic or green synthesis, which uses phytochemicals derived from plants as reducing, stabilizing, and capping agents, has become a viable and economical substitute (Shereen *et al*., 2024; Varghese *et al*., 2024; Nedumaran *et al*.,

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2025; Srinivasan *et al*., 2025). By adsorbing phytoconstituents onto the surface of the nanoparticles, plant-mediated synthesis not only reduces the use of dangerous chemicals but also gives them additional bioactive qualities.

The medicinal herb *Scutellaria baicalensis* is well known for its abundance of flavonoids, including wogonin, baicalin, and baicalein, which have strong antimicrobial, anti-inflammatory, and antioxidant properties (Wang *et al*., 2018). Similar to this, *Moringa oleifera* leaves are rich in vitamins, flavonoids, polyphenols, and other bioactive substances with anti-inflammatory, antimicrobial, and free-radical scavenging properties (Farooq *et al*., 2012). A synergistic phytochemical environment that promotes effective nanoparticle synthesis and improves their biological functionality may be produced by combining the root extract of *Scutellaria baicalensis* with the leaf extract of *Moringa oleifera*.

The creation of multifunctional nanomaterials that can concurrently fight microbial infection, lower oxidative stress, regulate inflammation, and preserve cellular compatibility has received more attention in recent years. For biomedical and dental applications, where tissue damage frequently coexists with chronic infection and inflammation, such characteristics are especially desirable. To the best of our knowledge, this is the first study to synthesize cerium oxide nanoparticles using a combination of *Scutellaria baicalensis* root and *Moringa oleifera* leaf extracts, thereby providing a novel green synthesis approach for developing multifunctional nanoparticles. Accordingly, the current study aimed to synthesize and characterize biogenic cerium oxide nanoparticles using extracts from the roots of *Scutellaria baicalensis* and the leaves of *Moringa oleifera*.

MATERIALS AND METHODS

The study protocol was approved by the Institutional Scientific Board of Saveetha Dental College and Hospitals, Chennai, India.

Preparation of *Scutellaria baicalensis* Root and *Moringa oleifera* Leaf Extracts

The dried leaves of *Moringa oleifera* and the roots of *Scutellaria baicalensis* were obtained from a certified herbal supplier. To remove surface contaminants, each plant material was cleaned with distilled water, allowed to air dry, and then ground into a fine powder. Five grams each of *Scutellaria baicalensis* root powder and *Moringa oleifera* leaf powder were mixed with 100 mL of distilled water and heated at 60-70°C for approximately 15-20 min under continuous stirring. Whatman No. 1 filter paper was used to filter the extract after it had cooled to room temperature in order to remove plant debris. A mixed aqueous extract was created by combining equal volumes of the filtered extracts, and it was kept at 4°C until it was needed.

Green Synthesis of Cerium Oxide Nanoparticles

The combined aqueous extract was used as the stabilizing and reducing agent in the synthesis of biogenic cerium oxide nanoparticles. Briefly, 0.1 M cerium nitrate hexahydrate [$Ce(NO_3)_3{\cdot}6H_2O$] solution was prepared in distilled water. Under constant magnetic stirring, 100 mL of the cerium nitrate solution was gradually supplemented with about 80 mL of the mixed plant extract. For 2 hr, the reaction mixture was kept at 70°C until a noticeable color shift that indicated the formation of nanoparticles was seen. To guarantee that the cerium ions were completely reduced, the suspension was left to stand at room temperature. The synthesized nanoparticles were collected by centrifugation at 10,000 rpm for 15 min and washed three times with distilled water followed by ethanol to remove residual impurities and unbound phytochemicals. The purified pellet was dried overnight in a hot air oven at 60°C. The dried powder was lightly ground and stored in sterile airtight containers for further characterization and biological evaluation.

CHARACTERIZATION

Surface Morphology Analysis

Scanning Electron Microscopy (SEM) was used to analyze the surface morphology of the biosynthesized cerium oxide nanoparticles. To improve electrical conductivity, conductive carbon tape was used to mount the powdered, dried nanoparticles onto aluminum stubs, and a sputter coater was used to apply a thin layer of gold. A field-emission scanning electron microscope (JEOL JSM-IT800, JEOL Ltd., Japan) was used to examine the coated samples. The SEM micrographs were used to evaluate the morphology, and surface characteristics of the synthesized nanoparticles.

Cytotoxicity Assessment - Brine Shrimp Lethality Assay

The brine shrimp (*Artemia salina*) lethality assay was used to assess the cytotoxicity of the biosynthesized cerium oxide nanoparticles. A commercial supplier provided the brine shrimp eggs, which were then incubated in artificial seawater made by dissolving 40 g/L of sea salt in distilled water and adding 6 mg/L of dried yeast as a source of nutrients. Hatching was done at 25±2°C for 48 hr, with continuous aeration during the incubation period. Ten nauplii were placed in each well of a 24-well culture plate with 1 mL of artificial seawater after actively motile nauplii were collected using a sterile Pasteur pipette following hatching. The corresponding wells were filled with varying concentrations of the biosynthesized cerium oxide nanoparticles (10, 20, 30, 40, and 50 µL). The positive control was potassium dichromate ($K_2Cr_2O_2$), while the negative control was artificial seawater containing nauplii without nanoparticles. The plates were maintained under static conditions at room temperature for 24 hr. Following incubation, the numbers of live and dead nauplii

were counted under a stereomicroscope, and the percentage mortality was calculated using the following equation:

$$\text{Mortality (\%)} = \frac{\text{Dead nauplii}}{\text{Total nauplii}} \times 100$$

Antimicrobial Activity

Using the agar well diffusion method, the antibacterial activity of the biosynthesized cerium oxide nanoparticles against *Streptococcus mutans*, and *Staphylococcus aureus* was assessed. Sterile cotton swabs were used to evenly inoculate Mueller-Hinton agar plates with fresh bacterial cultures. A sterile cork borer was used to create wells with a diameter of about 6 mm. Different concentrations of cerium oxide nanoparticles (10, 20, 30, 40, and 50 µL) were dispensed into the respective wells. Amoxicillin served as the positive control, while sterile distilled water was used as the negative control. A digital vernier caliper was used to measure the inhibition zone diameters in millimeters after the inoculated plates were incubated at 37°C for 24 hr.

Antioxidant Activity - DPPH Radical Scavenging Assay

The free radical scavenging ability of the biosynthesized cerium oxide nanoparticles was determined using the 2,2-Diphenyl-1-Picrylhydrazyl (DPPH) assay. 450 µL of 50 mM Tris-HCl buffer (pH 7.4) and 1 mL of 0.1 mM DPPH solution made in methanol were combined with varying concentrations of the nanoparticle suspension (10, 20, 30, 40, and 50 µL). The reaction mixtures were incubated in the dark at room temperature for 30 min. A UV-visible spectrophotometer was used to measure absorbance at 517 nm. The standard antioxidant used was Butylated Hydroxytoluene (BHT). The following formula was used to determine the percentage of DPPH radical scavenging activity:

$$\text{Inhibition (\%)} = \frac{\text{Absorbance of control} - \text{Absorbance of sample}}{\text{Absorbance of control}} \times 100$$

Anti-inflammatory Activity - Protein Denaturation Assay (Bovine Serum Albumin Method)

The Bovine Serum Albumin (BSA) protein denaturation assay was used to assess the biosynthesized cerium oxide nanoparticles' anti-inflammatory activity. Different concentrations of cerium oxide nanoparticles (10, 20, 30, 40, and 50 µL) were mixed with 2 mL of 1% bovine serum albumin solution. The pH of the reaction mixture was adjusted to 6.8 using 1 N hydrochloric acid. To cause protein denaturation, the mixtures were heated to 70°C for 5 min after being incubated at 37°C for 20 min. A UV-visible spectrophotometer was used to measure absorbance at 660 nm after it had cooled to room temperature. The reference standard was diclofenac sodium. The following formula was used to determine the percentage inhibition of protein denaturation:

$$\text{Inhibition (\%)} = \frac{\text{Absorbance of control} - \text{Absorbance of sample}}{\text{Absorbance of control}} \times 100$$

Statistical Analysis

All experimental assays were performed in triplicate, and the data are presented as mean±Standard Deviation (SD). One-Way Analysis of Variance (ANOVA) was used to evaluate differences among the five tested concentrations (10-50 µL) for each assay. Additionally, independent samples *t*-tests were performed at each concentration to compare the biosynthesized cerium oxide nanoparticles with their respective standard controls. A *p*-value of <0.05 was considered statistically significant. Statistical analyses were performed using SPSS software (Version 23.0; IBM Corp., Armonk, NY, USA).

RESULTS

Surface Morphology

SEM analysis confirmed the successful formation of biosynthesized cerium oxide nanoparticles. The micrograph revealed predominantly spherical nanoparticles that were highly agglomerated, forming porous, interconnected clusters (Figure 1). The observed agglomeration is likely attributable to the high surface energy of the nanoparticles and intermolecular interactions among phytochemical capping agents derived from *Scutellaria baicalensis* and *Moringa oleifera* extracts. The nanoparticles exhibited a relatively rough surface morphology with uniformly distributed granular structures throughout the aggregates. Overall, the SEM findings indicate the successful green synthesis of cerium oxide nanoparticles with characteristic aggregated nanostructures suitable for subsequent biological evaluation.

Brine Shrimp Lethality Assay

With values rising from 3.02±1.08% at 10 µL to 6.00±2.02% (20 µL), 11.41±2.51% (30 µL), 24.62±3.54% (40 µL), and 30.00±4.34% (50 µL), the nanoparticles showed a concentration-dependent increase in brine shrimp mortality. A statistically significant difference between the tested concentrations was shown by one-way ANOVA ($F=61.87$, $p<0.001$), suggesting a dose-dependent response. The nanoparticles showed comparatively low cytotoxicity, indicating good biocompatibility, despite the increase in mortality with concentration (Table 1). Comparable cytotoxicity was indicated by the independent samples *t*-test, which showed no statistically significant difference with the positive control (potassium dichromate) at any concentration ($p>0.05$) (Table 2).

DPPH Radical Scavenging Assay

As the concentration of the biosynthesized cerium oxide nanoparticles increased, consequently increased their antioxidant activity. The DPPH radical scavenging percentage increased from 32.24±4.66% at 10 µL to 39.86±4.85% at 20 µL, 45.29±5.30% at 30 µL, 54.82±5.77% at 40 µL, and 62.12±6.06% at 50 µL. A concentration-dependent increase in antioxidant activity was statistically significant ($F=26.54$, $p<0.001$) according to one-way

ANOVA (Table 1). At all tested concentrations, the independent samples *t*-test revealed no statistically significant difference ($p>0.05$) between the nanoparticles and the standard antioxidant (BHT) (Table 2).

Data are expressed as mean±SD. Cytotoxicity is presented as % mortality, DPPH and BSA activities as % inhibition, and antimicrobial activity as zone of inhibition (mm). [b]Independent *t*-test. $p<0.05$ was considered statistically significant.

Antimicrobial Activity

The zone of inhibition gradually increased as the concentration of the biosynthesized cerium oxide nanoparticles increased, indicating concentration-dependent antibacterial activity against both *Staphylococcus aureus* and *Streptococcus mutans*. The zone of inhibition against *Streptococcus mutans* increased from 4.12±1.03 mm at 10 µL to 9.79±2.22 mm, 11.71±3.21 mm, 14.92±3.57 mm, and 19.26±4.93 mm at 50 µL. Comparably, the zone of inhibition against *Staphylococcus aureus* increased from 3.24±1.12 mm at 10 µL to 7.82±2.73 mm, 12.31±3.42 mm, 16.87±3.62 mm, and 20.14±4.66 mm at 50 µL. Table 1 shows that these concentration-dependent increases were statistically significant ($p<0.001$). Comparable antibacterial efficacy was indicated by the independent samples *t*-test, which showed no statistically significant difference between the nanoparticles and the standard antibiotic (amoxicillin) at any concentration ($p>0.05$) (Table 2).

Protein Denaturation Assay

BSA protein denaturation assay was used to measure the anti-inflammatory activity of the biosynthesized cerium oxide nanoparticles, and the results showed a significant increase with increasing concentration. The percentage of protein denaturation inhibition rose from 28.53±3.82% at 10 µL to 34.23±3.95% at 20 µL, 39.65±4.73% at 30 µL, 47.24±5.83% at 40 µL, and 53.79±6.29% at 50 µL. A statistically significant concentration-dependent increase in anti-inflammatory activity (F=22.31, $p<0.001$) was shown by one-way ANOVA (Table 1). Comparable inhibition of protein denaturation was indicated by the independent samples *t*-test, which showed no statistically significant difference between the nanoparticles and the common anti-inflammatory drug, diclofenac sodium, at any concentration ($p>0.05$) (Table 2).

DISCUSSION

The biological characteristics of biosynthesized cerium oxide nanoparticles made with *Scutellaria baicalensis* root extract were examined in this study. Because green synthesis uses

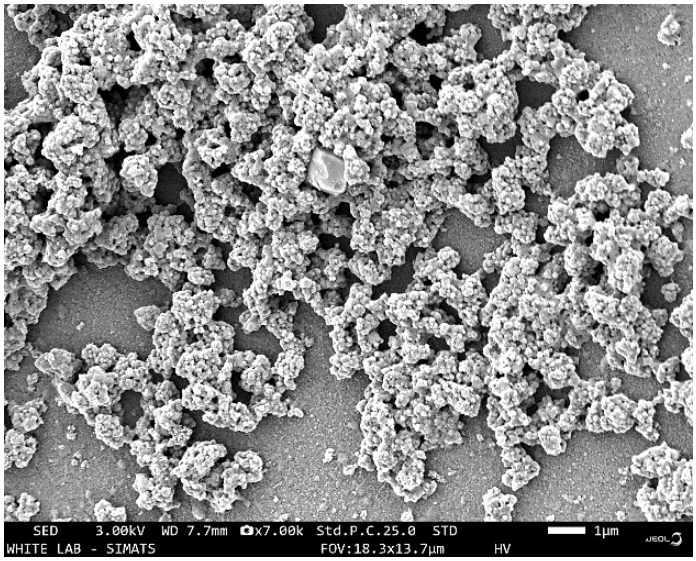


Figure 1: SEM micrograph of biogenic cerium oxide nanoparticles synthesized using *Scutellaria baicalensis* root and *Moringa oleifera* leaf extracts.

Table 1: Cytocompatibility, antioxidant, antimicrobial, and anti-inflammatory activities of biosynthesized cerium oxide nanoparticles at different concentrations (10-50 µL).

Assay	10 µL (Mean±SD)	20 µL (Mean ± SD)	30 µL (Mean±SD)	40 µL (Mean±SD)	50 µL (Mean ± SD)	F-statistic	*p*-value[a]
Cytotoxicity (% mortality)	3.02±1.08	6.00±2.02	11.41±2.51	24.62±3.54	30.0±4.34	61.87	<0.001*
DPPH (% inhibition)	32.24±4.66	39.86±4.85	45.29±5.30	54.82±5.77	62.12±6.06	26.54	<0.001*
Streptococcus mutans-Zone of inhibition (mm)	4.12±1.03	9.79±2.22	11.71±3.21	14.92±3.57	19.26±4.93	18.96	<0.001*
Staphylococcus aureus-Zone of inhibition (mm)	3.24±1.12	7.82±2.73	12.31±3.42	16.87±3.62	20.14±4.66	20.47	<0.001*
BSA (% inhibition)	28.53±3.82	34.23±3.95	39.65±4.73	47.24±5.83	53.79±6.29	22.31	<0.001*

Data are expressed as Mean±SD. Cytotoxicity is presented as % mortality, DPPH and BSA activities as % inhibition, and antimicrobial activity as zone of inhibition (mm). [a]One-way ANOVA. $p<0.05$ was considered statistically significant; *Statistical significance.

Table 2: Comparison of the cytotoxic, antioxidant, antimicrobial, and anti-inflammatory activities of biosynthesized cerium oxide nanoparticles with standard controls at different concentrations (10-50 µL).

Assay	10 µL (Mean±SD)	20 µL (Mean±SD)	30 µL (Mean±SD)	40 µL (Mean±SD)	50 µL (Mean±SD)
Cytotoxicity-Test	3.02±1.08	6.00±2.02	11.41±2.51	24.62±3.54	30.0±4.34
Cytotoxicity-Standard	3.58±1.12	6.74±2.08	12.26±2.63	25.47±3.48	31.18±4.27
Cytotoxicity-t-value	-0.79	-0.57	-0.53	-0.38	-0.43
Cytotoxicity-p-value[b]	0.47	0.60	0.62	0.72	0.69
DPPH-Test	32.24±4.66	39.86±4.85	45.29±5.30	54.82±5.77	62.12±6.06
DPPH-Standard	33.08±4.51	40.74±4.69	46.31±5.18	55.76±5.62	63.05±5.91
DPPH-t-value	-0.32	-0.33	-0.34	-0.29	-0.27
DPPH-p-value[b]	0.76	0.74	0.73	0.78	0.79
Streptococcus mutans-Zone of inhibition-Test	4.12±1.03	9.79±2.22	11.71±3.21	14.92±3.57	19.26±4.93
Streptococcus mutans-Zone of inhibition-Standard	4.45±0.98	10.15±2.10	12.04±3.08	15.33±3.41	19.81±4.72
Streptococcus mutans-Zone of inhibition-*t*-value	-0.58	-0.30	-0.18	-0.21	-0.20
Streptococcus mutans-Zone of inhibition-*p*-value[b]	0.59	0.77	0.86	0.84	0.85
Staphylococcus aureus-Zone of inhibition-Test	3.24±1.12	7.82±2.73	12.31±3.42	16.87±3.62	20.14±4.66
Staphylococcus aureus-Zone of inhibition-Standard	3.62±1.06	8.26±2.60	12.82±3.29	17.35±3.48	20.73±4.52
Staphylococcus aureus-Zone of inhibition-*t*-value	-0.61	-0.29	-0.27	-0.23	-0.22
Staphylococcus aureus-Zone of inhibition-*p*-value[b]	0.57	0.78	0.80	0.83	0.83
BSA-Test	28.53±3.82	34.23±3.95	39.65±4.73	47.24±5.83	53.79±6.29
BSA-Standard	29.21±3.76	35.02±3.88	40.48±4.62	48.13±5.69	54.71±6.14
BSA-t-value	-0.31	-0.35	-0.31	-0.28	-0.26
BSA-p-value[b]	0.76	0.73	0.76	0.79	0.80

phytochemicals as stabilizing and reducing agents to increase biocompatibility and reduce environmental toxicity, it has become a promising method for creating metal oxide nanoparticles (Sureendar *et al.*, 2025; Thaha *et al.*, 2025; Jabeen *et al.*, 2025). The current study sought to determine whether *S. baicalensis*'s well-known antioxidant, antimicrobial, and anti-inflammatory qualities could be successfully integrated into cerium oxide nanoparticles to produce a multipurpose biomaterial appropriate for dental and biomedical applications.

SEM analysis demonstrated the successful formation of predominantly spherical cerium oxide nanoparticles arranged in agglomerated clusters, which is a common characteristic of green-synthesized metal oxide nanoparticles owing to their high surface energy. The observed morphology suggests effective reduction and stabilization of cerium ions by the bioactive phytoconstituents present in the *Scutellaria baicalensis* and *Moringa oleifera* extracts.

The biosynthesized cerium oxide nanoparticles showed advantageous biological properties after successful synthesis and characterization. Despite a concentration-dependent increase in mortality, the nanoparticles showed low cytotoxicity in the brine shrimp lethality assay, indicating good biocompatibility within the tested concentration range. Improved DPPH radical scavenging showed that antioxidant activity gradually increased

with concentration. Significant anti-inflammatory activity was also demonstrated by the nanoparticles' dose-dependent inhibition of protein denaturation. Furthermore, greater zones of inhibition were seen at higher nanoparticle concentrations, indicating concentration-dependent antibacterial activity against *Staphylococcus aureus* and *Streptococcus mutans*. All of these results point to the biosynthesized cerium oxide nanoparticles' multifunctional biological qualities, which make them attractive options for dental and biomedical uses.

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The biosynthesized nanoparticles' anti-inflammatory activity is consistent with earlier studies outlining *Scutellaria baicalensis's* pharmacological potential. According to a previous research, fractions enriched with *S. baicalensis* active constituents successfully reduced the production of cytokines and inflammatory mediators while preserving high cell viability (Lee *et al*., 2024). Similarly, another study showed that *S. baicalensis* extract reduced inflammatory pain by suppressing inflammatory cytokines (Gao *et al*., 2023). The concentration-dependent inhibition seen is consistent with these studies and supports the anti-inflammatory potential of *S. baicalensis*-mediated cerium oxide nanoparticles, even though the current study assessed anti-inflammatory activity using the bovine serum albumin protein denaturation assay rather than cellular signaling pathways.

Additionally, the biosynthesized nanoparticles showed significant antibacterial activity against *Staphylococcus aureus* and *Streptococcus mutans*, with the inhibitory effect growing with nanoparticle concentration. These results are similar to a study, where the authors created a carbon dot hydrogel derived from *Scutellaria baicalensis* that contained baicalein and demonstrated strong antibacterial activity against *Staphylococcus aureus* and *Escherichia coli* in addition to antioxidant and anti-inflammatory properties that aided in wound healing (Zhang *et al*., 2025). Other plant-based biomaterials have also been reported to have similar multifunctional biological properties (Lim *et al*., 2024; Dzięcioł *et al*., 2024; Otunola *et al*., 2018). Also, gelatin-chitosan biopolymer when combined with Moringa leaf extract, showed excellent antibacterial, antioxidant, anti-inflammatory, and hemocompatible properties (Bessalah *et al*., 2024). Also, it was documented that *Moringa oleifera* leaf extract had antibacterial and anti-inflammatory activities with minimal cytotoxicity (Alcântara *et al*., 2023). The results of the current study are consistent with the idea that phytochemical-assisted nanomaterials can concurrently provide antimicrobial, antioxidant, and anti-inflammatory activities, even though various medicinal plants and formulations were examined.

The biocompatibility of the produced nanoparticles is further supported by the brine shrimp lethality assay's low cytotoxicity. It is well known that green synthesis using phytochemicals derived from plants can increase the stability of nanoparticles while lowering their toxicity through natural surface capping. These biosynthesized cerium oxide nanoparticles may have significant potential for uses such as local drug delivery systems, implant surface coatings, regenerative biomaterials, and adjunctive therapies for oral infections and inflammatory conditions, according to the study's favorable cytocompatibility and strong antioxidant, antimicrobial, and anti-inflammatory properties.

The current study has a number of advantages. By concurrently evaluating cytotoxicity, antioxidant, antimicrobial, and anti-inflammatory activities using standardized *in vitro* assays, it offers a thorough biological assessment of green-synthesized cerium oxide nanoparticles. Additionally, the synthesized nanoparticles' novelty and therapeutic significance are enhanced by the use of *Scutellaria baicalensis*, a medicinal plant rich in biologically active flavonoids.

However, it is important to recognize some limitations. Only two bacterial species were evaluated, and the study was restricted to *in vitro* assays. Furthermore, neither cell-based cytocompatibility nor *in vivo* validation were carried out, nor were the molecular mechanisms underlying the observed biological activities investigated. To determine the translational potential of *Scutellaria baicalensis*-mediated cerium oxide nanoparticles for biomedical and dental applications, future research should examine the underlying molecular pathways, evaluate efficacy against a wider range of oral pathogens, evaluate cell compatibility, and conduct preclinical *in vivo* studies.

CONCLUSION

The present study successfully synthesized biogenic cerium oxide nanoparticles using *Scutellaria baicalensis* root and *Moringa oleifera* leaf extracts through a green synthesis approach. The nanoparticles demonstrated promising multifunctional biological properties, including low cytotoxicity and significant antioxidant, antimicrobial, and anti-inflammatory activities. Although more *in vivo* and mechanistic research is needed to validate their clinical utility, these findings demonstrate their potential for biomedical and dental applications.

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ABBREVIATIONS

CeO_2 NPs: Cerium Oxide Nanoparticles; **SEM:** Scanning Electron Microscopy; **ANOVA:** Analysis of Variance; **BHT:** Butylated Hydroxytoluene; **BSA:** Bovine Serum Albumin; **DPPH:** 2,2-Diphenyl-1-Picrylhydrazyl; **SD:** Standard Deviation.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS CONTRIBUTION

NJ: Conceptualization, Methodology, Data curation, Writing-Original draft. **AR:** Supervision, Validation, Review & Editing, Project administration.

SUMMARY

Biogenic cerium oxide nanoparticles were successfully synthesized using *Scutellaria baicalensis* root and *Moringa oleifera* leaf extracts through a green synthesis approach. SEM analysis confirmed the formation of predominantly spherical nanoparticles with nanoscale morphology. The synthesized nanoparticles exhibited low cytotoxicity and significant concentration-dependent antioxidant, antimicrobial, and anti-inflammatory activities, with biological performance comparable to standard controls. These findings demonstrate that the plant-mediated cerium oxide nanoparticles possess promising multifunctional properties, supporting their potential application in biomedical and dental fields.

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