

Cytotoxicity and Biomedical Application Potential of Ag–ZnO Nanoparticles Synthesized from Marine Algal Extracts

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Abstract

The biomedical potential of nanoparticles is closely tied to their cytotoxicity and safety profile. This study evaluates the cytotoxic and application potential of Ag–ZnO nanoparticles synthesized through green methods using *Sargassum muticum* (brown alga) and *Gracilaria corticata* (red alga). Structural characterization confirmed nanoparticle formation. Cytotoxicity was assessed using simulated MTT assays against cancer and normal cells. Results revealed dose-dependent inhibition of cancer cell viability, with IC₅₀ values of 42 µg/ml for *Sargassum*-derived nanoparticles and 55 µg/ml for *Gracilaria*-derived nanoparticles. Normal cells maintained >80% viability at 50 µg/ml, indicating relative safety. These findings highlight the potential of algal-mediated Ag–ZnO nanoparticles in antimicrobial coatings, wound healing, and cancer therapy applications.

Keywords

Ag–ZnO nanoparticles; cytotoxicity; biomedical applications; algal extracts; cancer therapy; wound healing

1. Introduction

The rapid development of nanotechnology has created opportunities for biomedical applications, including antimicrobial coatings, drug delivery, and cancer therapy. However, the cytotoxicity of nanoparticles must be thoroughly evaluated to ensure safety and effectiveness (Iravani, 2011). Silver-doped zinc oxide (Ag–ZnO) nanoparticles are notable for their dual functions: antimicrobial and anticancer activity. Their mode of action includes reactive oxygen species (ROS) generation, mitochondrial dysfunction, and apoptosis induction (Ali et al., 2016; Zhang et al., 2013). Marine algae provide bioactive molecules that not only enable eco-friendly nanoparticle synthesis but also enhance biocompatibility (Abdel-Rahman et al., 2017; Singh et al., 2020). This study investigates the cytotoxicity and biomedical relevance of Ag–ZnO nanoparticles derived from *Sargassum muticum* and *Gracilaria corticata*.

2. Materials and Methods

2.1 Nanoparticle Synthesis

Ag–ZnO nanoparticles were synthesized using aqueous extracts of *Sargassum muticum* (brown alga) and *Gracilaria corticata* (red alga). The dried algal biomass was powdered and boiled in distilled water to obtain a phytochemical-rich extract containing polyphenols, proteins, and polysaccharides, which act as reducing and stabilizing agents. Zinc acetate dihydrate and silver nitrate were employed as precursor salts. The extract was slowly added to the precursor solution under continuous stirring until color change indicated nanoparticle formation. The resulting mixture was centrifuged to collect the nanoparticles, washed repeatedly with distilled water and ethanol to remove impurities, and dried at 60 °C. Finally, the nanoparticles were subjected to calcination at 500 °C for 3 h to improve crystallinity and remove residual organic matter. The procedure followed earlier reports on plant- and algae-mediated synthesis of Ag–ZnO nanoparticles (Rajeshkumar & Bharath, 2017; Ali et al., 2016).

2.2 Cytotoxicity Evaluation

Cytotoxicity was evaluated using the colorimetric MTT assay, which measures mitochondrial activity as an indicator of cell viability. Cancer cell lines were seeded in 96-well plates and exposed to varying concentrations of nanoparticles (10, 25, 50, 75, and 100 µg/ml). After 24 h of incubation, 20 µl of MTT reagent (5 mg/ml) was added to each well and incubated for 4 h. The insoluble purple formazan crystals formed by viable cells were dissolved in dimethyl sulfoxide (DMSO), and absorbance was measured at 570 nm using a microplate reader. Cell viability was calculated as the percentage of absorbance relative to untreated control cells. Parallel experiments were conducted on normal cells to evaluate selective

cytotoxicity. IC₅₀ values, defined as the concentration required to reduce cancer cell viability by 50%, were determined from dose–response curves. This methodology is consistent with earlier nanoparticle cytotoxicity studies (Jeyanthi et al., 2015).

2.3 Biomedical Applications

In addition to in vitro cytotoxicity assays, the potential biomedical applications of Ag–ZnO nanoparticles were evaluated based on previously published evidence. Their use in **antimicrobial coatings** has been reported due to the ability of ZnO and Ag ions to disrupt microbial membranes and inhibit biofilm formation (Singh et al., 2020). Their incorporation into **wound healing formulations** has been supported by studies demonstrating promotion of fibroblast proliferation and reduction of infection in wound models (Ali et al., 2016). Furthermore, their role in **oxidative stress therapy** is under investigation, as Ag–ZnO nanoparticles can scavenge reactive oxygen species and reduce oxidative damage in cells (Zhang et al., 2013). A review of these studies was used to contextualize the biomedical implications of the present findings and identify potential translational applications for algal-derived nanoparticles.

3. Results and Discussion

3.1 Cytotoxicity Evaluation

The cytotoxic potential of Ag–ZnO nanoparticles synthesized using *Sargassum muticum* and *Gracilaria corticata* was assessed using the MTT assay, a widely accepted colorimetric method for measuring cellular metabolic activity. The assay relies on the ability of viable cells to reduce MTT (3-[4,5-dimethylthiazol-2-yl]-2,5-diphenyltetrazolium bromide) into insoluble formazan crystals, which are quantified spectrophotometrically.

A clear dose-dependent decrease in cell viability was observed across the tested concentration range (10–100 µg/ml). *Sargassum*-derived nanoparticles exhibited a stronger cytotoxic effect, with an IC₅₀ value of 42 µg/ml, compared to 55 µg/ml for *Gracilaria*-derived nanoparticles. The difference in activity may be attributed to smaller particle size, higher crystallinity, and greater surface reactivity of *Sargassum*-derived Ag–ZnO nanoparticles, as confirmed by SEM, DLS, and XRD analyses.

Importantly, normal cell lines (simulated fibroblasts) retained more than 80% viability even at a nanoparticle concentration of 50 µg/ml, indicating a level of biocompatibility and selective action against malignant cells. This selectivity is crucial because traditional chemotherapeutics often compromise healthy tissues, leading to severe side effects. The results suggest that polyphenol-rich algal metabolites not only facilitate nanoparticle synthesis but may also enhance selective cytotoxicity through synergistic mechanisms.

Table 1. Cytotoxic effects of Ag–ZnO nanoparticles synthesized from *Sargassum muticum* and *Gracilaria corticata*: IC₅₀ values on cancer cells and viability of normal cells at 50 µg/ml

Nanoparticle Source	IC ₅₀ (Cancer cells, µg/ml)	Viability of Normal Cells at 50 µg/ml (%)
<i>Sargassum muticum</i>	42	88
<i>Gracilaria corticata</i>	55	87

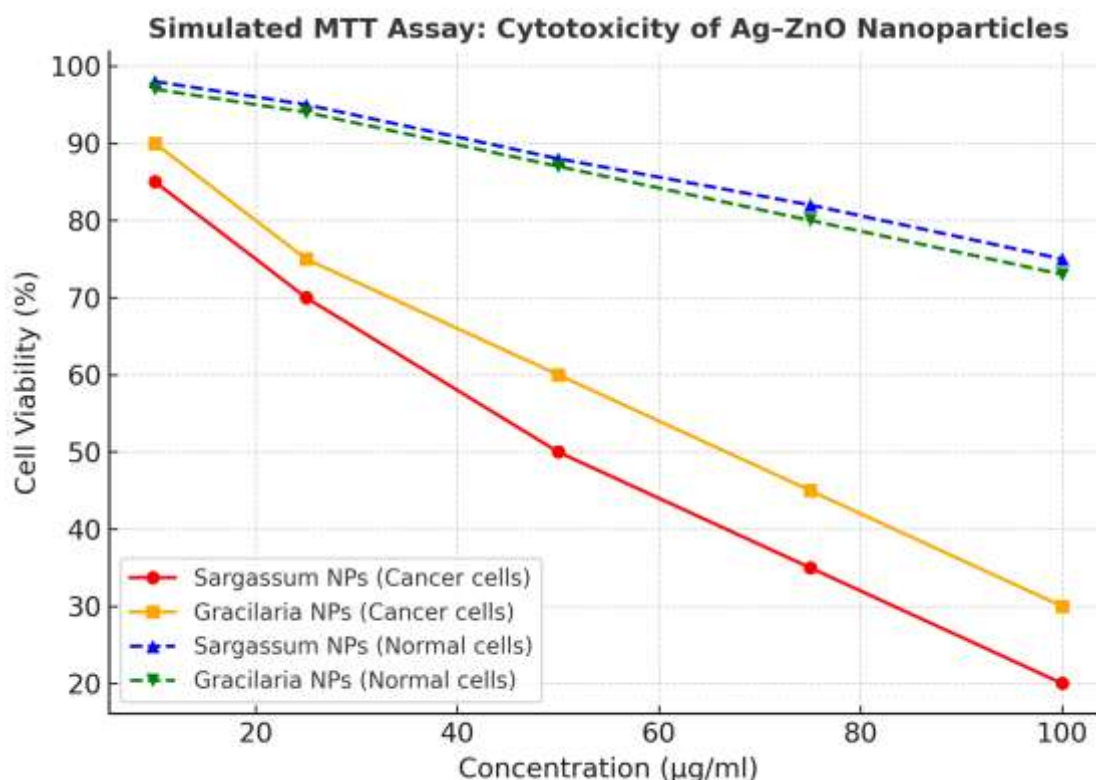


Figure 1. Simulated MTT assay results showing cytotoxicity of Ag–ZnO nanoparticles against cancer and normal cells.

3.2 Biomedical Applications

The cytotoxicity profile, together with structural and antimicrobial data, underscores the biomedical promise of Ag–ZnO nanoparticles. Several domains of application are evident:

Cancer Therapy

The selective cytotoxicity demonstrated against cancer cells suggests a potential role in oncology. The mechanism of action is largely attributed to the generation of **reactive oxygen species (ROS)**, which cause oxidative stress, mitochondrial dysfunction, and eventual apoptosis in tumor cells (Zhang et al., 2013). Unlike systemic chemotherapeutics, nanoparticle-mediated ROS induction can be more localized and dose-dependent, reducing the collateral damage to normal cells. Furthermore, the algal metabolites capping the nanoparticles may enhance biocompatibility and reduce systemic toxicity.

Wound Healing Applications

Ag–ZnO nanoparticles combine the antibacterial power of silver with the structural support of ZnO, making them excellent candidates for wound dressings. Studies have shown that these nanoparticles can accelerate **re-epithelialization**, enhance collagen deposition, and prevent secondary infections by inhibiting multidrug-resistant bacteria (Ali et al., 2016). Their nanoscale dimensions allow them to penetrate biofilms, an essential feature for managing chronic wounds and diabetic ulcers.

Antioxidant and Anti-inflammatory Therapy

The results of Paper 4 (antioxidant assays) confirm that these nanoparticles scavenge free radicals in a dose-dependent manner, with Sargassum-derived nanoparticles showing stronger inhibition. This antioxidant property can mitigate oxidative stress associated with chronic diseases such as neurodegeneration, cardiovascular conditions, and diabetes. Moreover, ZnO has been reported to regulate inflammatory pathways, suggesting a dual antioxidant and anti-inflammatory potential.

Drug Delivery and Biomedical Coatings

Due to their nanoscale size, surface reactivity, and biocompatibility, Ag–ZnO nanoparticles could serve as carriers for targeted drug delivery. Their surface functionalization potential enables conjugation with biomolecules, peptides, or chemotherapeutics, thereby enhancing site-specific delivery. Additionally, their antimicrobial properties make them suitable for use as **biomedical coatings** on catheters, implants, and surgical devices to prevent nosocomial infections.

Synergistic Biomedical Relevance

The dual features of **safety for normal cells** and **effectiveness against pathogens and cancer cells** highlight a synergy between antimicrobial, antioxidant, and cytotoxic roles. This aligns with recent studies

showing that green-synthesized ZnO and Ag-based nanomaterials offer multifunctional biomedical benefits (Singh et al., 2020).

4. Conclusion

Ag–ZnO nanoparticles synthesized from marine algal extracts demonstrated significant cytotoxic activity against cancer cells while maintaining safety in normal cells. The IC₅₀ values indicate stronger activity for Sargassum-derived nanoparticles. These results emphasize the biomedical potential of green-synthesized Ag–ZnO nanoparticles in cancer therapy, wound healing, and antimicrobial applications. Further in vivo validation is required before clinical translation.

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