Dhaka University Nanotechnology Center (DUNC)

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Dhaka-1100, Bangladesh

Project Title: Green-Synthesized Metal Nanoparticle-Doped Coastal Shell-Derived Hydroxyapatite for Enhanced Antimicrobial Activity

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Green-Synthesized Metal Nanoparticle-Doped Coastal Shell-Derived Hydroxyapatite for Enhanced Antimicrobial Activity

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2. Place of the Lab work

Sonochemistry, Material Development & Green Chemistry Lab
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3. Objective

The research project aims to develop an eco-friendly nanocomposite by doping hydroxyapatite—derived from coastal shells—with green-synthesized metal nanoparticles.

Primary goal: Create a sustainable, low-cost material via green synthesis, converting coastal shell waste into hydroxyapatite enhanced for superior antibacterial activity against pathogens like Salmonella.

Key innovations:

- Uses marine waste for hydroxyapatite production through precipitation methods.
- Incorporates metal nanoparticle doping to boost bioactivity and antimicrobial effects.

- Targets biomedical applications including bone regeneration, implants, and infection-resistant coatings.

Broader impacts:

- Promotes circular economy by addressing waste management.
- Enables scalable production of nanomaterials with Oste-conductivity, mechanical strength, and antimicrobial properties for tissue engineering.

4. Background of the Study

Green synthesis of metal nanoparticle-doped hydroxyapatite (HA) from coastal shells addresses the need for eco-friendly biomaterials with enhanced antimicrobial properties for biomedical uses like bone regeneration and infection control.

Study Context

Hydroxyapatite, a primary mineral in human bones and teeth, offers excellent biocompatibility but limited antimicrobial activity in its pure form. Doping with metal nanoparticles (e.g., silver, copper) boosts this property, while green synthesis uses natural reducing agents to avoid toxic chemicals found in traditional methods like sol-gel or hydrothermal processes.

Coastal Shell Source

Coastal shells, rich in calcium carbonate, serve as a sustainable, waste-derived precursor for HA via processes like calcination and phosphorylation. This approach recycles marine waste, reduces environmental impact, and yields nanostructured HA with natural impurities that may enhance bioactivity.

Green Synthesis Role

Plant extracts or biological agents cap and stabilize metal nanoparticles during doping, preventing aggregation and improving dispersion in the HA matrix. This method ensures biocompatibility, cost-effectiveness, and scalability compared to chemical routes.

Antimicrobial Enhancement

The doped nanoparticles release ions that disrupt bacterial membranes, showing efficacy against pathogens like *E. coli* and *S. aureus*. Applications target implant infections and wound healing, combining HA's osteoconductive with potent antibacterial action.

5. Outline of the Proposed Research

The research on green-synthesized metal nanoparticle-doped coastal shell-derived hydroxyapatite (HA) follows a structured outline emphasizing sustainable synthesis, material enhancement, and biomedical validation.

Materials Preparation

Coastal shells undergo calcination to extract calcium oxide, followed by phosphorization with phosphate sources to form HA. Metal precursors (e.g., silver or copper salts) integrate via green routes using plant extracts as reducing and capping agents [from prior context].

Synthesis Process

HA forms through wet chemical precipitation or sol-gel methods under controlled pH (>10) and temperature. Metal nanoparticles dope in situ during synthesis, with ultrasound or emulsion aiding uniform dispersion and nanostructure control (e.g., rods <100 nm).

Characterization

Techniques include XRD for phase purity and crystallite size (via Debye-Scherrer), FTIR for functional groups, SEM/TEM for morphology, and ICP for Ca:P ratio (ideally 1.67). Doping confirms via UV-Vis or EDS.

Antimicrobial Testing

Zone of inhibition assays evaluate efficacy against *E. coli*, *S. aureus*. Ion release and biofilm disruption mechanisms assessed via MIC/MBC, cytotoxicity via MTT on osteoblast cells [from prior context].

Applications and Outlook

Focuses on bone scaffolds, coatings for implants. Study validates scalability, biocompatibility, and superiority over undoped HA.

6. Materials and Equipment

Raw Materials:

- Coastal shells (e.g., oyster, clam, crab shells as $CaCO_3$ source)

Chemicals for Hydroxyapatite Synthesis:

- Nitric acid (HNO_3) or hydrochloric acid (HCl) for dissolving CaO
- Diammonium hydrogen phosphate ($(NH_4)_2HPO_4$) or phosphoric acid (H_3PO_4) as phosphate source
- Ammonium hydroxide (NH_4OH) for pH adjustment (9-10)

For Green Metal Nanoparticle Synthesis:

- Plant extracts (leaf/fruit extracts as reducing agents)

- Metal salts (e.g., $AgNO_3$ for silver, $CuSO_4$ for copper)

Equipment & Consumables:

- Calcination furnace (900°C, 600-800°C)
- Ball mill/pulverizer for crushing shells
- Magnetic stirrer/hotplate (40-60°C)
- Filter paper (Whatman), deionized water
- Drying oven (60-120°C)

These enable complete green synthesis from waste shells to antimicrobial nanocomposite.

7. Methodology

Hydroxyapatite Synthesis from Coastal Shells

Coastal shells are collected, washed thoroughly with water (tap and deionized), boiled to remove impurities like algae and meat, dried, and calcined at 900°C for 3 hours to convert $CaCO_3$ into CaO.

Precipitation Process

CaO is dissolved to form calcium nitrate or hydroxide solution, mixed dropwise with phosphoric acid or diammonium hydrogen phosphate ($(NH_4)_2HPO_4$) at controlled ratios (Ca/P ≈1.67), pH adjusted to 9-10 using ammonium hydroxide (NH_4OH), stirred at 40-60°C for 2-5 hours to form precipitate.

Post-Processing

Precipitate is aged, filtered (e.g., Whatman paper), washed, dried at 60-120°C, mechanically milled for nanoscale particles, and calcined at 600-800°C to enhance crystallinity and purity.

Green Synthesis of Metal Nanoparticles

Metal nanoparticles (e.g., Ag, Cu) are synthesized using plant extracts or eco-friendly reducers, then doped into the hydroxyapatite matrix via co-precipitation or impregnation.

8. Characterization

Structural and Phase Analysis:

- X-ray Diffraction (XRD): Confirms hydroxyapatite phase purity, crystallinity, and Ca/P ratio (target 1.67)
- Fourier Transform Infrared Spectroscopy (FT-IR): Identifies functional groups like PO_4^{3-} (1030-1090 cm^{-1}), OH^- (3570 cm^{-1}), and detects carbonates

Morphological and Compositional Analysis:

- Scanning Electron Microscopy (SEM)/Field Emission SEM (FE-SEM): Reveals particle morphology (rod-like, hexagonal), size (nano-scale), and agglomeration
- Energy Dispersive X-ray Spectroscopy (EDS/EDX): Verifies elemental composition (Ca, P, O, metal dopants like Ag/Cu)

Thermal and Surface Analysis:

- Thermogravimetric Analysis/Differential Thermal Analysis (TGA-DTA): Assesses thermal stability, decomposition, and phase transitions up to 800°C

Functional Performance Testing:

- Antimicrobial assays: Zone of inhibition tests against pathogens (e.g., Salmonella, E. coli) to validate metal nanoparticle doping efficacy
- Zeta potential: Evaluates surface charge and stability in biological media

These techniques comprehensively validate synthesis success, purity, and enhanced antimicrobial properties.

9. Application of the Project

The green-synthesized metal nanoparticle-doped coastal shell-derived hydroxyapatite nanocomposite offers versatile applications spanning biomedical engineering, environmental sustainability, and advanced materials science. In the biomedical domain, its primary role centers on bone tissue engineering, where it acts as a biocompatible scaffold mimicking the mineral composition of natural bone, facilitating osteoblast adhesion, proliferation, and mineralization for repairing fractures, defects, or osteoporosis-related damage. Orthopedic and dental implants benefit significantly from its use as a coating, enhancing osseointegration—the direct bonding of bone to implant surfaces—while the embedded antimicrobial metal nanoparticles (such as silver or copper) combat implant-associated infections by inhibiting pathogens like Salmonella and Staphylococcus.

Beyond orthopedics, the material finds utility in drug delivery systems, where hydroxyapatite's porous structure enables controlled release of antibiotics, anti-inflammatory agents, or chemotherapeutics directly at bone infection sites like osteomyelitis or tumor regions, improving therapeutic efficacy and reducing systemic side effects. Antimicrobial coatings represent another key application, applicable to wound dressings, catheters, prosthetics, and hospital surfaces, leveraging the eco-friendly nanoparticle doping for broad-spectrum bacterial resistance without promoting resistance development.

On a broader scale, the project's circular economy approach transforms coastal shell waste—abundant from seafood industries—into high-value products, promoting sustainable manufacturing with low-cost, green synthesis methods that minimize chemical use and environmental impact. This extends potential uses to dentistry for enamel repair and fillers, regenerative medicine for cartilage or periodontal tissues, and even environmental remediation, where the nanocomposite adsorbs heavy metals or dyes from wastewater while retaining biomedical viability. Overall, these applications position the material as a multifunctional platform for next-generation healthcare solutions, combining bioactivity, mechanical robustness, and infection control in a scalable, waste-derived format.

10. Environmental, Social and Economic Benefit

Coastal shell-derived hydroxyapatite nanocomposites deliver substantial environmental, social, and economic benefits by transforming seafood industry waste into high-value biomedical materials through green synthesis.

Environmental Benefits

The project diverts abundant coastal shells—typically discarded in landfills—from polluting waterways and coastlines, reducing marine debris, ocean acidification risks, and greenhouse gas emissions from waste decomposition. Green synthesis methods minimize hazardous chemical use, lowering energy demands compared to synthetic hydroxyapatite production, while the final product's antimicrobial properties reduce reliance on synthetic antibiotics that contribute to resistance and pharmaceutical pollution. Additionally, it promotes a circular economy, recycling $CaCO_3$-rich waste to create sustainable scaffolds, indirectly supporting coastal restoration akin to shell reef rebuilding efforts.

Social Benefits

Locally sourced shells from fishing communities foster job creation in collection, processing, and nanocomposite manufacturing, empowering coastal populations economically dependent on seafood industries. The enhanced antimicrobial materials improve public health by enabling infection-resistant implants and wound care, particularly benefiting regions with high bacterial infection rates from pathogens like Salmonella. Community engagement in waste-to-value initiatives builds environmental awareness and supports food security through sustainable practices.

Economic Benefits

Low-cost raw materials from waste shells slash production expenses versus commercial hydroxyapatite (up to 50-70% cheaper), enabling scalable biomedical products like bone grafts and coatings for orthopedic/dental markets projected to exceed $5 billion globally. Restaurants and processors save on disposal fees through shell collection partnerships, while the high-value output generates revenue streams in healthcare and tissue engineering. Overall, the project stimulates rural economies, reduces import dependency on synthetic biomaterials, and opens export opportunities for green nanotechnology.

11. Time Required for Completion of the Project

Activities	Months			
	1	**2**	**3**	**4**
Literature Survey & Design	■	■		
Material Synthesis		■	■	
Characterization		■	■	
Application and Antibacterial Test			■	■
Report writing & preparation of the manuscript				■

12. Requirement of Funds as per the estimate under the heading:

SL no.	Item	Quantity	Cost (BDT)
a	Research Fellowship	4	48,000
b	Accessory, Chemical, Analytical Services		4,000
	Total		52,000
In Words: Fifty-Two Thousand Tk. Only			

13. Any financial assistance received/to be received from any other source for this project: No

Supervisor

Date: 18 January 2026

Signature:

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