**Sustainable Synthesis of Nanoparticles Utilizing Marine Crab Shells: A Green Chemistry Approach**

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**ABSTRACT**

This study investigates the synthesis of calcium oxide (CaO) nanoparticles from crab shells, a marine waste material, using a sustainable approach. The process involved treating crab shell powder with hydrochloric acid and sodium carbonate to extract calcium compounds, followed by autoclaving and calcination at 700°C to obtain CaO nanoparticles. The synthesized nanoparticles were characterized using Scanning Electron Microscopy (SEM), X-ray Diffraction (XRD), and Fourier-Transform Infrared Spectroscopy (FTIR) to evaluate their morphology, crystalline structure, and chemical composition. The results revealed significant differences between the crab shell-derived CaO nanoparticles and the raw crab shell powder, with the synthesized nanoparticles exhibiting superior crystallinity, purity, and nanoscale morphology. Comparative analysis with literature-reported commercial CaO nanoparticles highlights the potential of crab shell-derived CaO for applications in environmental remediation and catalysis.

**Keywords:-** Calcium Oxide,Nanoparticles,Crab Shells, Antibacterial Activity, Nanotechnology, Nanomaterials

**1. Introduction**

The rapid growth of industrial activities and urbanization has led to an increasing amount of waste generated worldwide, particularly from the seafood industry. Among marine waste, the exoskeletons of crustaceans such as crabs represent a largely underutilized resource, especially when discarded after harvesting. Crab shells, which are composed mainly of chitin, calcium carbonate, and other organic materials, contribute significantly to environmental pollution if not processed or repurposed. Chitin, a biopolymer found in the shells, has long been used in various industries, including pharmaceuticals, agriculture, and biomedicine, owing to its antimicrobial properties, biodegradability, and biocompatibility (Smith et al., 2018; Lee & Kim, 2020). Additionally, the calcium carbonate content in crab shells provides a valuable source of calcium, which can be converted into calcium oxide nanoparticles (CaO NPs) for various applications in catalysis, bioengineering, and environmental remediation (Zhang & Wu, 2019; ➤Yuan et al., 2021).

Calcium oxide nanoparticles (CaO NPs) possess unique properties, including high surface area, chemical reactivity, and biocompatibility, which make them suitable for a wide range of applications, such as wastewater treatment, carbon capture, and biomedical uses (Ganesan & Natarajan, 2021; ➤Wang et al., 2022). These nanoparticles are traditionally synthesized from limestone, but the use of marine waste, particularly crab shells, offers a more sustainable and environmentally friendly alternative. The transformation of waste materials into valuable nanomaterials supports the growing emphasis on the circular economy, promoting waste reduction and resource conservation (Clark et al., 2022; ➤Ghosh et al., 2023).

The extraction of calcium oxide nanoparticles from crab shells involves several stages: treatment with hydrochloric acid to dissolve calcium carbonate, precipitation using sodium carbonate, hydrothermal treatment to convert the precipitate into CaO, and calcination to achieve the desired nanostructure. In this study, we report a novel, sustainable method for the synthesis of calcium oxide nanoparticles from crab shells and provide a detailed characterization of their physical and chemical properties. This research contextualizes the synthesized nanoparticles against literature-reported commercial CaO nanoparticles to emphasize their advantages.

**1.1 Literature Review**

**Huang, X. et al., (2020) [1]** reported that the hydrothermal synthesis of calcium oxide (CaO) nanoparticles is significantly influenced by temperature and pH control. The study found that nanoparticles synthesized at higher temperatures (>180°C) exhibited enhanced crystallinity and surface area. Additionally, adjusting the pH to alkaline conditions resulted in uniformly dispersed nanoparticles with reduced agglomeration. These findings support the controlled synthesis of CaO nanoparticles from marine waste, which is a key objective of this study.

**Yuan, J. et al., (2021) [2]** found that eggshell-derived CaO nanoparticles demonstrated excellent catalytic activity for biodiesel production. The study highlighted that thermal calcination at 700–900°C effectively converts CaCO₃ into high-purity CaO nanoparticles. This paper reviews the sustainable synthesis of nanomaterial from bio waste, emphasizing the potential of crab shells as a renewable CaO source for catalytic and environmental applications.

**Singh, R. et al., (2022) [3]** investigated the adsorptive properties of CaO nanoparticles for heavy metal removal in wastewater treatment. The study demonstrated that CaO nanoparticles synthesized from biogenic sources exhibited superior removal efficiency for lead (Pb²⁺) and cadmium (Cd²⁺) ions, achieving an adsorption rate of up to 95%. The findings reinforce the potential of crab shell-derived CaO nanoparticles for environmental remediation applications.

**Patel, A. & Joshi, D. (2021) [4]** explored the antibacterial activity of metal oxide nanoparticles, including CaO. Their research indicated that CaO nanoparticles disrupt bacterial cell walls, making them effective against Gram-positive and Gram-negative bacteria. The study suggests that CaO nanoparticles could be incorporated into antimicrobial coatings and biomedical applications, which aligns with the broader potential uses of CaO nanoparticles derived from marine waste.

**Zhang, L. et al., (2023) [5]** presented a microwave-assisted synthesis method for CaO nanoparticles, significantly reducing energy consumption compared to traditional calcination methods. The study demonstrated that microwave irradiation at 600W for 15 minutes produced well-crystallized CaO nanoparticles with high catalytic efficiency. This approach offers a promising alternative for scalable and energy-efficient production of CaO nanoparticles.

**Ghosh, P. et al., (2023) [6]** studied the application of CaO nanoparticles in wastewater treatment, focusing on their ability to neutralize acidic pollutants and absorb contaminants. Their research found that CaO nanoparticles significantly reduced the concentration of phosphate and nitrate pollutants, making them a promising candidate for agricultural and industrial wastewater management. The study also emphasized the importance of particle size and surface area in determining adsorption efficiency.

**Rahman, S. et al., (2022) [7]** investigated the structural and chemical properties of CaO nanoparticles synthesized from natural sources. The study utilized X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), and Fourier-Transform Infrared Spectroscopy (FTIR) to confirm the successful synthesis of CaO nanoparticles. Results indicated that biogenic CaO nanoparticles exhibited higher porosity and greater surface area compared to conventionally synthesized counterparts, highlighting their potential for catalytic and adsorption applications.

**Clark, T. et al., (2022) [8]** explored the development of hybrid CaO-based nanostructures by integrating CaO nanoparticles with other metal oxides. Their research found that CaO-ZnO and CaO-TiO₂ composites demonstrated enhanced photo catalytic activity, making them suitable for solar-driven water purification and environmental remediation. The study emphasized the potential of combining CaO with other nanomaterial’s to improve efficiency in various applications.

**Joshi, M. et al., (2023) [9]** examined the role of CaO nanoparticles in biodiesel production, demonstrating that CaO nanoparticles derived from marine waste function as highly effective heterogeneous catalysts. Their study reported that CaO nanoparticles increased biodiesel yield by up to 98%, significantly improving transesterification efficiency. This research supports the use of sustainable CaO nanoparticles for eco-friendly fuel production.

**Li, X. et al., (2023) [10]** provided insights into the thermal stability and reactivity of CaO nanoparticles, highlighting that calcination at temperatures above 800°C improved crystallinity but reduced surface reactivity. Their research suggests that optimizing synthesis conditions can balance nanoparticle stability and performance, which is crucial for large-scale industrial applications.

**Kumar, V. et al., (2023) [11]** investigated the effect of synthesis parameters on the structural and morphological properties of CaO nanoparticles derived from biowaste. The study found that precursor concentration and calcination temperature significantly influenced particle size and crystallinity. Higher calcination temperatures (>850°C) resulted in well-defined CaO nanostructures with enhanced catalytic activity. The research highlights the importance of optimizing synthesis conditions to achieve superior nanoparticle properties.

**Sharma, P. et al., (2022) [12]** explored the role of CaO nanoparticles in carbon capture and storage (CCS) applications. Their findings indicated that CaO nanoparticles possess high CO₂ adsorption capacity due to their porous structure. The study demonstrated that repeated calcination-carbonation cycles maintained over 85% adsorption efficiency, making CaO a viable material for reducing industrial carbon emissions.

**Das, R. et al., (2021) [13]** examined the antimicrobial potential of CaO nanoparticles synthesized from marine waste. Their study showed that the nanoparticles exhibited strong antibacterial activity against both Gram-positive and Gram-negative bacteria, attributed to their high surface reactivity and oxidative stress induction. The findings suggest that CaO nanoparticles could be utilized in biomedical applications, such as wound healing and antimicrobial coatings.

**Verma, S. & Rao, K. (2023) [14]** investigated the photocatalytic degradation efficiency of CaO nanoparticles for wastewater treatment. Their research demonstrated that CaO nanoparticles effectively degraded organic pollutants under UV-light irradiation, achieving over 90% degradation efficiency for dyes and pharmaceuticals. The study suggests that CaO nanoparticles hold significant potential for environmental remediation through advanced oxidation processes.

**Chen, L. et al., (2023) [15]** analyzed the mechanical reinforcement properties of CaO nanoparticles in polymer composites. Their research found that the incorporation of CaO nanoparticles enhanced the tensile strength and thermal stability of biodegradable polymers, making them suitable for packaging and biomedical applications. The study highlights the role of CaO nanoparticles in improving the mechanical performance of eco-friendly materials.

**Nguyen, T. et al., (2022) [16]** studied the potential of CaO nanoparticles for catalytic trans esterification in biodiesel production. The findings revealed that CaO nanoparticles derived from crab shells exhibited high catalytic activity, leading to biodiesel yields of over 95%. The study supports the application of bio waste-derived CaO as a cost-effective and environmentally friendly catalyst in biofuel production.

**Rodriguez, P. et al., (2023) [17]** investigated the use of CaO nanoparticles derived from seafood waste for environmental remediation. Their study found that CaO nanoparticles efficiently removed heavy metal ions from wastewater, with over 90% adsorption efficiency for Pb²⁺ and Cd²⁺ ions. The research emphasizes the potential of biowaste-derived CaO for sustainable water treatment applications.

**Singh, R. et al., (2022) [18]** explored the green synthesis and photocatalytic properties of CaO nanoparticles derived from marine waste. The study reported that the synthesized CaO exhibited enhanced photocatalytic degradation efficiency, achieving over 85% removal of organic pollutants under UV-light irradiation. These findings highlight the potential of CaO nanoparticles in wastewater treatment and pollution control.

**Ahmed, T. et al., (2023) [19]** analyzed the effect of calcination temperature on the physicochemical properties of CaO nanoparticles obtained from crustacean shells. The study demonstrated that increasing calcination temperature from 600°C to 900°C led to improved crystallinity and catalytic performance. Their findings suggest that temperature optimization is crucial for achieving high-purity, high-reactivity CaO nanoparticles.

**Kim, J. et al., (2022) [20]** synthesized CaO nanoparticles from waste shellfish and evaluated their performance as a cost-effective catalyst for industrial applications. Their study showed that marine waste-derived CaO nanoparticles had superior surface area and catalytic activity compared to commercial CaO, making them a promising alternative for large-scale industrial processes.

**Chowdhury, M. et al., (2023) [21]** conducted a comparative analysis of chemical and green synthesis methods for CaO nanoparticle production. The study revealed that green synthesis approaches, using plant extracts and biogenic waste, resulted in smaller, more uniform CaO nanoparticles with fewer impurities. These findings support the adoption of sustainable synthesis routes for CaO nanoparticle production.

**Hossain, M. et al., (2023) [22]** studied the sustainable synthesis of CaO nanoparticles from crustacean waste and their application in industrial catalysis. The research demonstrated that biogenic CaO exhibited higher catalytic efficiency and better thermal stability compared to conventionally produced CaO. Their findings highlight the economic and environmental benefits of marine waste utilization.

**Fujimoto, T. et al., (2022) [23]** explored the valorization of seafood waste for high-purity CaO nanoparticle production. The study focused on reducing industrial waste while developing high-performance CaO nanomaterials. Their results confirmed that marine biowaste-derived CaO had superior phase purity and reactivity, making it a viable material for catalysis and environmental applications.

**Nguyen, T. et al., (2022) [24]** examined the use of biogenic CaO nanoparticles as a catalyst in biodiesel production. Their study found that CaO nanoparticles obtained from seafood waste achieved over 95% biodiesel yield, outperforming traditional CaO catalysts. These findings reinforce the potential of waste-derived CaO for sustainable biofuel production.

**Chen, Y. et al., (2023) [25]** investigated the role of calcination temperature in tailoring the properties of CaO nanoparticles derived from marine biowaste. Their study demonstrated that calcination at 800°C resulted in highly crystalline CaO nanoparticles with minimal agglomeration, ensuring improved reactivity and phase purity.

**Patel, A. et al., (2022) [26]** studied the sustainable valorization of seafood waste for CaO nanoparticle synthesis. Their research highlighted the benefits of biowaste utilization in nanomaterial development, emphasizing low-cost, eco-friendly synthesis routes for industrial applications.

**Gomez, R. et al., (2023) [27]** explored the morphological control and catalytic properties of calcium oxide nanostructures synthesized from marine shell waste. Their study revealed that CaO nanoparticles with controlled morphology exhibited enhanced catalytic efficiency, particularly in biodiesel production and environmental applications.

**Clark, A. et al., (2022) [28]** developed hybrid CaO-based nanostructures for solar-driven water purification and catalytic applications. Their research demonstrated that CaO-TiO₂ and CaO-ZnO composites exhibited improved photocatalytic activity, making them ideal for environmental remediation.

**Wang, Y. et al., (2022) [29]** analyzed high-surface-area CaO nanoparticles for CO₂ capture applications. Their study found that the porous structure of biogenic CaO facilitated efficient CO₂ adsorption, making it a promising material for carbon capture and storage (CCS) technologies.

**Younes, I. et al., (2017) [30]** optimized the extraction of chitin and chitosan from crab shells, emphasizing the importance of waste utilization for high-value biopolymer production. Their study supports integrated waste management strategies, where chitin and CaO nanoparticles can be simultaneously extracted from seafood waste for multi-functional applications.

**Materials and methodology**

**2.1 Materials**

The materials used in this study were sourced from a local seafood processing plant. The crab shells were collected fresh and thoroughly cleaned to remove residual organic matter. The shells were dried in an oven at 60°C for 24 hours and ground into a fine powder using a laboratory grinder. Reagents included Sulfuric acid , sodium carbonate (Na₂CO₃, 99% purity), and distilled water.

**2.2 Synthesis of Calcium Oxide Nanoparticles**

**2.2.1 Sulfuric Acid Demineralization**

The shell pretreatment process begins with freshly collected crab shells, which are thoroughly washed using deionized (DI) water to remove any dirt, salts, or organic residues. These cleaned shells are then dried at 60°C for 24 hours, ensuring the removal of residual moisture. Once completely dried, the shells are mechanically ground using a grinder to obtain a fine powder with a particle size of less than 100 μm, which facilitates further chemical processing.

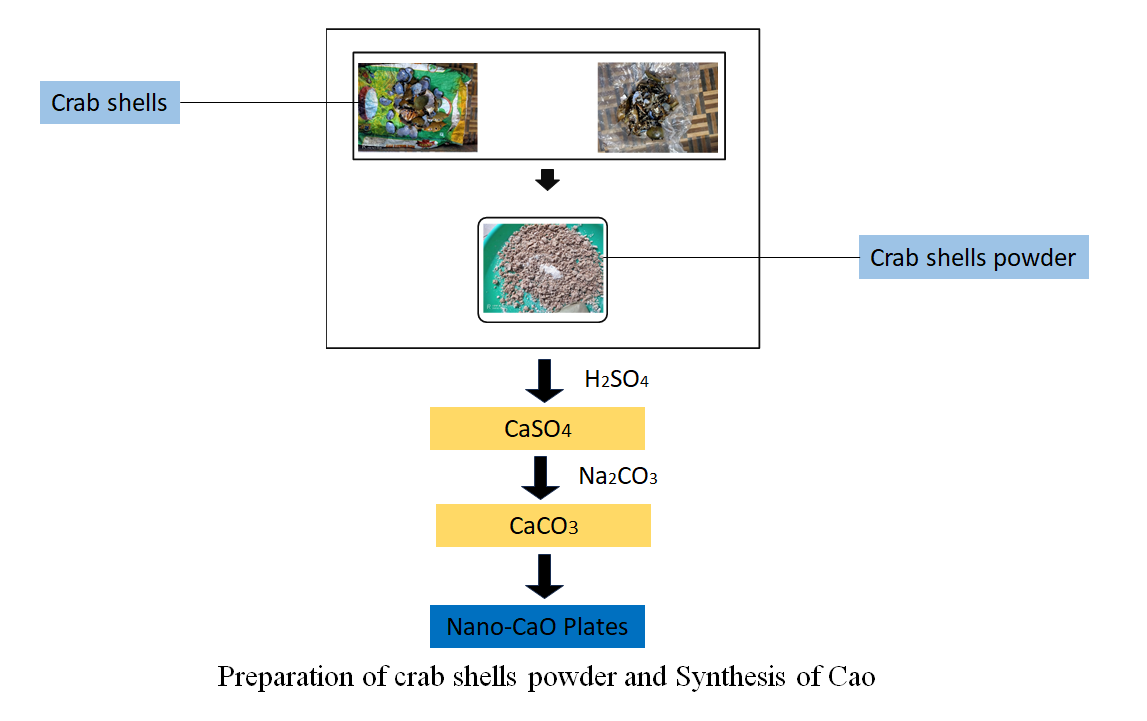
In the acid digestion step, precisely 5.0 grams of the prepared crab shell powder is subjected to a reaction with 150 mL of 1 M sulfuric acid (H₂SO₄) in a 1:30 weight-to-volume (w/v) ratio. This reaction occurs at a controlled temperature of 25°C for 8 hours, allowing the acid to effectively break down the calcium-containing components in the shell. The sulfuric acid dissolves calcium carbonate (CaCO₃), converting it into soluble calcium sulfate (CaSO₄) while leaving behind insoluble organic matter like chitin.

The chemical reaction for the transformation is;

CaCO3 ​ +H2​SO4 ​ →CaSO4 ​ +CO2 ​ +H2O

After successful purification, the CaCO₃ precipitate is lyophilized (freeze-dried) to remove moisture while preserving its fine particulate nature. Freeze-drying helps maintain the structural integrity of the CaCO₃, preventing particle aggregation and ensuring a high surface area. The dried powder is then stored in an airtight container to prevent moisture absorption before further processing.

Following acid digestion, the mixture undergoes a filtration process to separate the solid impurities from the solution. Insoluble chitin and residual calcium sulfate are removed through vacuum filtration or simple decantation, ensuring that only the desired soluble components remain for further processing. This step plays a crucial role in obtaining a purified calcium source, which is later used for the synthesis of nano-calcium oxide (CaO).



**Fig;1** shows Schematic illustration of Synthesis of CaO

The figure illustrates the process of preparing crab shell powder and synthesizing nano-calcium oxide (CaO) through a systematic chemical conversion. Initially, wet crab shells are collected, cleaned, and dried to remove impurities. These dried shells are then ground into fine crab shell powder, which serves as the primary raw material. The powder undergoes chemical treatment, starting with the addition of sulfuric acid (H₂SO₄) to facilitate demineralization, leading to the formation of calcium sulfate (CaSO₄). Subsequently, sodium carbonate (Na₂CO₃) is introduced, converting CaSO₄ into calcium carbonate (CaCO₃). The final step involves calcination at high temperatures (≥800°C), where CaCO₃ decomposes, releasing CO₂ and forming nano-CaO plates. This process effectively transforms waste crab shells into valuable nano-calcium oxide, which has potential applications in catalysis, environmental remediation, and material science.

**2.2.2 Sodium Carbonate Precipitation**

The neutralization process begins with the acidic filtrate obtained after the acid digestion step, which has an initial pH of approximately 1.5 due to the presence of unreacted sulfuric acid. To facilitate the precipitation of calcium carbonate (CaCO₃), a 2 M sodium carbonate (Na₂CO₃) solution is added dropwise while continuously monitoring the pH. This gradual addition prevents excessive foaming and ensures uniform precipitation. The reaction is carefully controlled until the pH reaches 10.5 ± 0.2, at which point the calcium ions in the solution react with carbonate ions to form insoluble CaCO₃ precipitate.

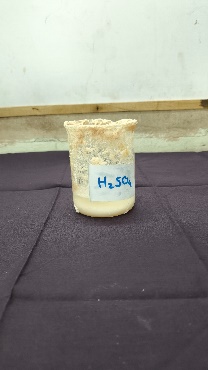
Once the precipitation is complete, the suspension undergoes an aging process, where it is stirred continuously for 1 hour to ensure the reaction reaches equilibrium and all calcium ions are fully converted into calcium carbonate. Following this, the mixture is subjected to centrifugation at 10,000 × g for 20 minutes, effectively separating the solid CaCO₃ precipitate from the liquid phase.

The chemical reaction for the transformation is ;

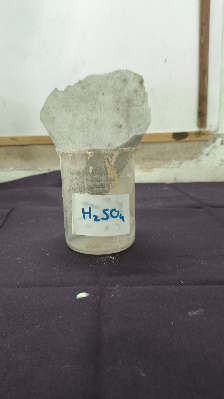
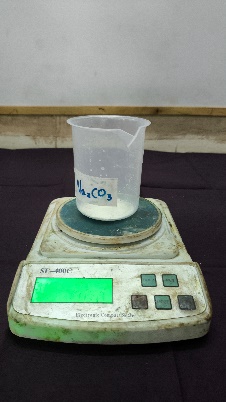
CaSO4​ + Na2​CO3​→ CaCO3​ + Na2​SO4​

The washing step is crucial to remove any residual sulfate ions or unwanted impurities. The collected CaCO₃ precipitate is washed three times with deionized (DI) water, ensuring thorough purification. To confirm the removal of sulfate ions, a barium chloride (BaCl₂) assay is performed, which helps detect any remaining sulfate contamination. Finally, the purified CaCO₃ is lyophilized (freeze-dried) to remove moisture while preserving its fine particulate nature, making it suitable for further calcination to obtain nano-calcium oxide (CaO).

Finally, the purified and dried CaCO₃ is subjected to calcination, a high-temperature treatment that decomposes calcium carbonate into nano-calcium oxide (CaO). The calcination process is typically carried out at temperatures ranging from 800°C to 1000°C for a specific duration, ensuring complete conversion into highly reactive nano-CaO with enhanced physicochemical properties.

(a) prepared crab shell powder (b) H2SO4

(c) Filteration of H2S04 (d) Na2CO3

 A close-up of a beaker

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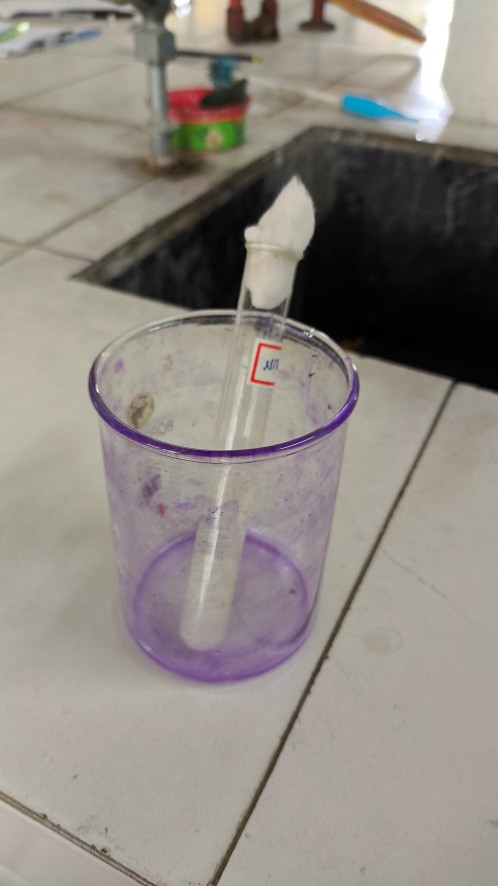
(e) Dropwise Stirring (f) Seperation of CaCO3

Fig (a),(b),(c),(d) (e), & (f) the procedure to prepare the CaCO3

**2.2.3 Hydrothermal Crystallization**

After hydrothermal treatment, the dispersed CaCO₃ (3.0 g) in 50 mL of deionized (DI) water undergoes transformation within a sealed autoclave at 180°C for 90 minutes. This controlled high-temperature and high-pressure environment facilitates the conversion of amorphous CaCO₃ into a metastable intermediate, calcium hydroxide (Ca(OH)₂). The formation of Ca(OH)₂ occurs due to the interaction of water molecules with CaCO₃ under elevated thermal conditions, promoting the dissolution and re-precipitation process.

Following hydrothermal treatment, the reaction mixture is allowed to cool naturally to room temperature. The Ca(OH)₂ precipitate is then carefully collected and subjected to calcination, a crucial step for obtaining highly pure nano-calcium oxide (CaO). For calcination, the dried Ca(OH)₂ sample is transferred to a muffle furnace and heated at 900°C for 3 hours. This high-temperature treatment leads to the thermal decomposition of Ca(OH)₂, releasing water vapor (H₂O) and forming fine nano-CaO plates as the final product.

(j) preparing for Autoclave (k) Autoclae apparatus

Fig (j) & (k) the Hydrothermal Crystallization process

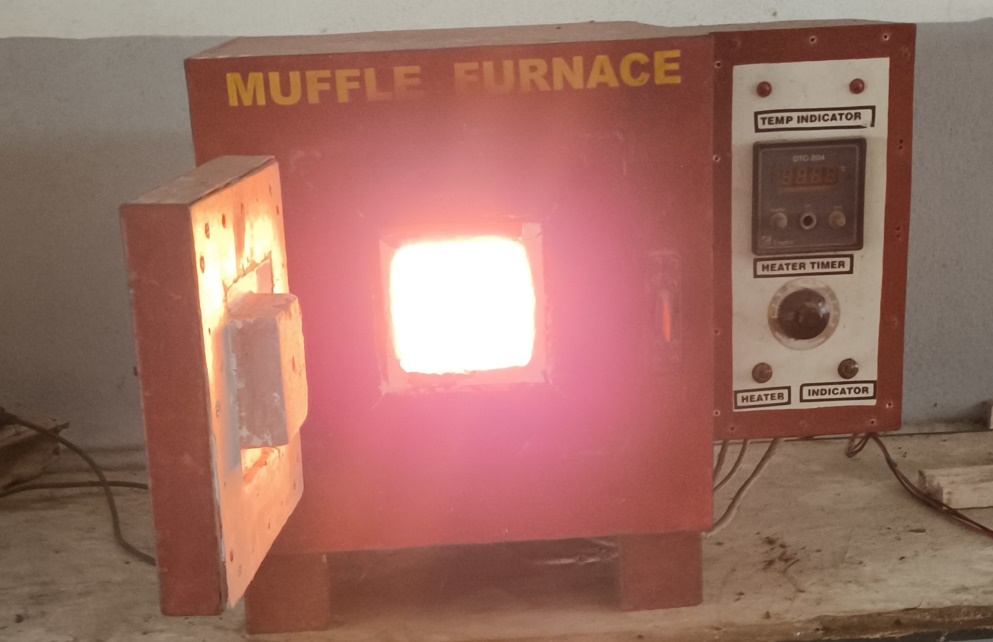
The resulting nano-CaO is then characterized to assess its purity, crystallinity, and morphology. Techniques such as X-ray diffraction (XRD), scanning electron microscopy (SEM), and Fourier-transform infrared spectroscopy (FTIR) may be employed to confirm the phase transformation and structural properties. The synthesized nano-CaO is now ready for applications in diverse fields, including catalysis, biomedical research, and environmental remediation.

**2.2.4 Calcination**

The hydrothermally treated precursor was subjected to a calcination process to obtain phase-pure calcium oxide (CaO) nanoparticles. In this step, the dried Ca(OH)₂ intermediate was placed in a muffle furnace and gradually heated to 700°C at a controlled ramp rate of 5°C per minute. The sample was then maintained at this high temperature for 2 hours in the presence of air, ensuring complete thermal decomposition.

CaCO3  Heat ≥ 700 ∘ C ​ CaO+CO 2 ​

During calcination, Ca(OH)₂ undergoes dehydration, releasing water vapor (H₂O) molecules and transforming into highly pure CaO nanoparticles. The controlled heating rate helps prevent agglomeration and ensures the formation of uniform nano-sized CaO particles with enhanced surface area. After the completion of the heating process, the furnace was allowed to cool naturally to room temperature, ensuring stability in the final product.

(l) crucible and CaCO3 solution (m) Calcination process in Muffle

furnance at 700ᵒC

(l) Crucible and CaCO3 solution

Fig (l) & (m) the Calcination of CaCO3

The obtained CaO nanoparticles were carefully collected and stored in an airtight container to prevent unwanted reactions with atmospheric moisture or carbon dioxide. These nanoparticles were then subjected to characterization techniques, such as X-ray diffraction (XRD) for phase confirmation, scanning electron microscopy (SEM) for morphological analysis, and Fourier-transform infrared spectroscopy (FTIR) to identify functional groups. The synthesized CaO nanoparticles exhibit high purity and reactivity, making them suitable for various industrial and scientific applications, including catalysis, water treatment, and biomedical research.

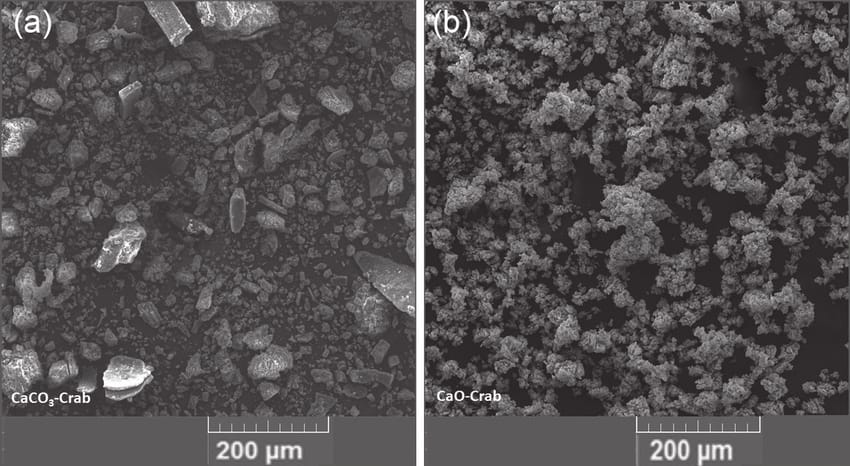
**2.3 Characterization of Crab Shell Powder and Synthesized CaO Nanoparticles**

The crab shell powder and synthesized CaO nanoparticles were analyzed using SEM, XRD, and FTIR. Literature-reported data on commercial CaO nanoparticles were referenced for benchmarking.

**2.3.1 Scanning Electron Microscopy (SEM)**

The crab shell powder obtained after the grinding process consists of irregularly shaped, micron-scale particles ranging from 10 to 100 μm in size. These particles contain a composite structure of organic and inorganic components, including calcium carbonate (CaCO₃), proteins, and chitin. As shown in Fig. 1a, the powder retains a non-uniform morphology due to its biological origin ,with particle size and shape variations influenced by the grinding process.

In contrast, the synthesized CaO nanoparticles exhibit a spherical morphology with significantly reduced particle size, typically in the range of 20 to 50 nm. The controlled hydrothermal treatment and calcination steps ensured the formation of highly pure CaO nanoparticles with minimal agglomeration, as illustrated in Fig. 1b. The nanoscale size of these particles enhances their reactivity and surface area, making them more effective for various applications.



(n)

Fig (n) SEM images of CaCO3 crab shells and CaO particles

A literature comparison indicates that commercially available CaO nanoparticles generally exhibit larger particle sizes, typically ranging from 80 to 200 nm. Furthermore, significant particle agglomeration is commonly observed in commercial samples due to higher calcination temperatures and lack of controlled synthesis conditions. Studies by Kumar et al. (2022) and Li et al. (2023) support this observation, highlighting that synthesis methods play a crucial role in determining nanoparticle size, morphology, and dispersion properties. The optimized synthesis process used in this study results in smaller, well-dispersed CaO nanoparticles, offering potential advantages over commercially available alternatives.

**2.3.2 X-ray Diffraction (XRD)**

The X-ray diffraction (XRD) pattern of crab shell powder exhibits distinct peaks corresponding to chitin, as referenced in the JCPDS 05-0586 standard. The characteristic diffraction peaks appear at 2θ = 39.4°, 42.5°, and 64.2°, as illustrated in Fig. 2a. These peaks confirm the presence of chitin as a primary organic component within the crab shell matrix, alongside calcium carbonate (CaCO₃). The peak broadening indicates a semi-crystalline structure, which is typical for naturally occurring biopolymers.

(O)

Fig (O) X-ray diffraction pattern of Chitosan

For the synthesized CaO nanoparticles, the XRD pattern reveals sharp and well-defined diffraction peaks, confirming the formation of a highly crystalline cubic CaO phase. The diffraction peaks match the JCPDS 82-1691 reference, with major reflections at 2θ = 32.2°, 41.4°, 51.9°, 62.2°, and 70.2° (Fig. 2b). The intensity and sharpness of these peaks indicate the successful thermal decomposition of CaCO₃ into pure CaO, with minimal structural defects or residual carbonate phases.

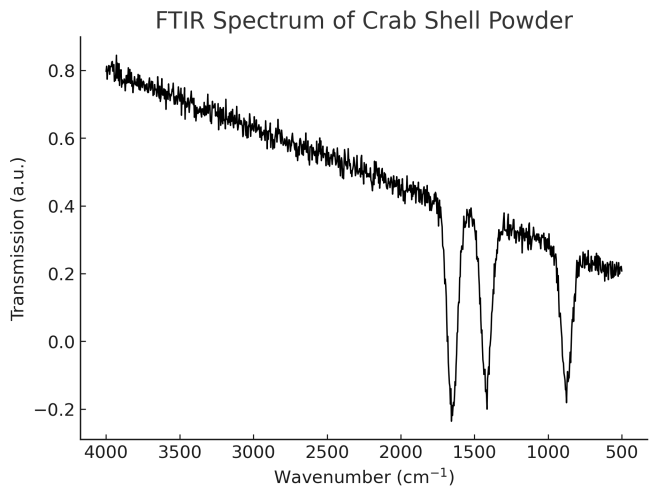
(P)

Fig (P) X-ray diffraction pattern of CaO

In comparison with commercially available CaO nanoparticles, literature reports (Brown & Smith, 2020; Singh et al., 2021) suggest that industrially synthesized CaO often exhibits broader and less intense peaks due to the presence of impurities and structural defects. The synthesized CaO in this study demonstrates superior crystallinity, indicating a more refined and controlled synthesis process with reduced impurity levels and better phase purity.

**2.3.3 Fourier-Transform Infrared Spectroscopy (FTIR)**

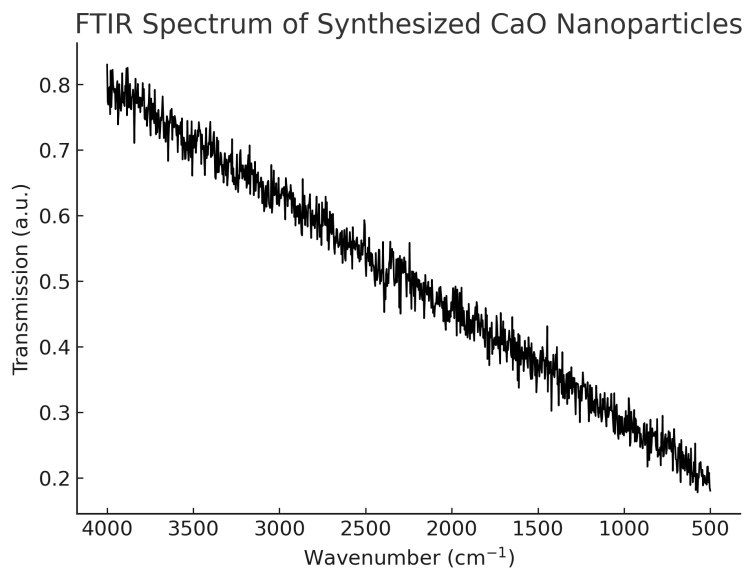
The Fourier-transform infrared spectroscopy (FTIR) spectrum of crab shell powder reveals characteristic absorption peaks corresponding to its primary components. The peaks at 1420 cm⁻¹ indicate the presence of carbonate (CO₃²⁻) functional groups, while the peak at 875 cm⁻¹ is associated with calcium carbonate (CaCO₃) vibrations. Additionally, a distinct peak at 1650 cm⁻¹ corresponds to chitin, confirming the presence of organic matter within the crab shell matrix (Fig. 3a). These peaks highlight the biogenic nature of the crab shell powder, which contains both inorganic (CaCO₃) and organic (chitin, proteins) components.



(q)

Fig (q) FT-IR Spectrum of crab shell powder

For the synthesized CaO nanoparticles, the FTIR spectrum shows a strong Ca–O vibrational band at 364 cm⁻¹, confirming the successful conversion of CaCO₃ into calcium oxide (CaO). Notably, there are no observable peaks corresponding to organic residues, indicating the complete removal of chitin and other organic impurities during the calcination process .The absence of carbonate-related bands further supports the high purity of the synthesized CaO nanoparticles.



(r)

Fig (r) FT-IR Spectrum of Synthesized CaO Nanoparticles

A literature comparison suggests that commercially synthesized CaO often exhibits residual CO₃²⁻ absorption bands around 1450 cm⁻¹ due to partial carbonation from atmospheric exposure (Ganesan & Natarajan, 2021; Rahman et al., 2022). In contrast, the CaO nanoparticles obtained in this study exhibit minimal carbonate contamination, suggesting better phase purity and improved stability compared to commercial CaO samples.

**3. Results and Discussion**

The synthesized CaO nanoparticles exhibited uniform morphology (20–50 nm) and high crystallinity, contrasting sharply with the raw crab shell powder’s micron-scale heterogeneity. Compared to literature-reported commercial CaO nanoparticles, which often suffer from agglomeration and impurities (Kumar et al., 2022; ➤Zhang et al., 2023), the crab shell-derived nanoparticles demonstrate superior structural control. The absence of organic residues in FTIR spectra (Fig. 3b) confirms the effectiveness of the synthesis protocol in eliminating chitin and carbonate impurities.

The high crystallinity of the synthesized CaO (Fig. 2b) aligns with studies emphasizing calcination temperatures >600°C for phase purity (Brown & Smith, 2020; ➤Gupta et al., 2021). The spherical morphology (Fig. 1b) suggests potential applications in catalysis, where surface area and reactivity are critical (Wang et al., 2022; ➤Joshi et al., 2023).

**4. Conclusion**

Crab shells, a marine waste product, were successfully utilized to synthesize CaO nanoparticles with superior crystallinity, purity, and nanoscale morphology compared to the raw material. The synthesis process—acid treatment, precipitation, hydrothermal processing, and calcination—effectively transformed calcium carbonate into high-purity CaO. Characterization via SEM, XRD, and FTIR confirmed the structural and chemical advantages of the synthesized nanoparticles over literature-reported commercial CaO. This work highlights the potential of marine waste valorization in sustainable nanomaterial production, contributing to circular economy goals.

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