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From Waste to New Ways: Feasibility of Microwave-Assisted Extraction of Chitin from Green Mussels (*Perna Viridis*) for Development of TEA-Functionalized CO_2 Capture Adsorbent

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Abstract

As the world progresses, environmental problems emerge, such as the rise in global greenhouse gas emissions, specifically carbon dioxide (CO_2) and improper waste management. To address these issues, this study aims to extract a natural polymer, chitin, from waste green mussel shells using a novel microwave-assisted extraction method. The extracted chitin was used as a support material for the functionalization of the adsorbent for potential CO_2 capture. The process involves demineralization and deproteinization for mussel shells under the influence of a microwave unit. Results show that microwave power level 2 has produced the highest chitin yield (6.40%) among all the power levels. To enhance its CO_2 adsorption capacity, the extracted chitin underwent a sol-gel pre-treatment followed by functionalization with triethanolamine (TEA). Scanning electron microscopy (SEM) revealed a "brick wall-like" or flaky crystal structure with an increased surface roughness, suggesting successful TEA incorporation. Fourier-transform infrared spectroscopy (FTIR) and thermogravimetric analysis (TGA) confirmed the presence of amine groups and enhanced thermal stability of the functionalized chitin. These characteristics are essential for CO_2 capture applications. This research demonstrates that waste green mussel shells coupled with microwave-assisted extraction can be a promising route in extracting chitin and its potential application to CO2 capture. Future work will focus on improving the pre-treatment process to produce a more suitable chitin support and optimizing the adsorbent's CO_2 capture capacity.

Keywords: adsorption, CO_2 capture, chitin, mussel shells

1. Introduction

Greenhouse gases (GHGs) emitted from various human activities, such as fossil fuel extraction and goods production, contribute to global warming by trapping heat in the atmosphere. The most common GHGs include carbon dioxide (CO_2), methane, nitrous oxide, and fluorinated gases. According to the U.S. Environmental Protection Agency (EPA), CO_2 emissions from human activities, like transportation, electricity use, and industrial processes, accounted for approximately 79% of total U.S. GHG emissions in 2020 [1, 2].

Global CO_2 emissions have risen exponentially over the years, leading to observable consequences such as altered weather patterns, rising global temperatures, and melting glaciers [3, 4]. In response, international organizations like the United Nations have implemented regulations such as the 2015 Paris Agreement, which aims to reduce global GHG emissions across all industries and limit global temperature increase to 1.5°C [5].

Beyond the adoption of renewable energy sources like solar panels and wind farms, various technologies are under development to reduce and mitigate CO_2 emissions. One promising approach is carbon capture and storage (CCS). This technology is being piloted at the industrial scale to capture CO_2 emissions that are otherwise difficult to avoid. Captured CO_2 is then stored and sequestered underground [6, 7]. In addition to that, this technology showed promising outcomes in several industrial applications; in the powerplants and stations in the United Kingdom that have been installed with carbon capture storage technology, it was deduced that only about 0.12kg of CO_2 per KWh were produced in a CCS installed power plants which is significantly lower as compared to 0.96kg of CO_2 per KWh for non-CCS power plants [8].

One of the standard methods used for CO_2 capture is the utilization of aqueous alkanolamines through liquid absorption due to their recyclability and the ability to reversibly react with CO_2 through the amine groups present [9]. However, the main disadvantages of using aqueous alkanolamines are their high energy consumption and corrosiveness, which may cause secondary pollution in some instances [10]. Due to their properties, regular maintenance is essential, increasing the expenditure for treatment and maintenance costs. Alternatives of alkanolamines such as Ionic Liquids (ILs) and analogues-deep eutectic solvents (DESs) have certain limitations where their viscosities increase exponentially during CO_2 absorption, thus deeming them impractical for industrial use [11, 12]. Recent studies suggest polyamines as a better alternative where solid materials such as zeolites [13], alumina [14], porous silica [15], porous carbons [16], and porous polymer frameworks [17], which are aided by different polyamines (e.g., triethylenetetramine) to enhance its CO_2 adsorption. GHG emissions are not the only issues currently being addressed worldwide; waste management and utilization are also being tackled globally to minimize and properly dispose of waste [18]. About 250,000 metric tons of marine waste are produced in the Philippines annually, where approximately 65,000 to 93,000 tons of green mussel shell waste are produced [19, 20]. Green mussels (*Perna viridis*), locally known as tahong, comprise a compound called chitin. This biopolymer is a building block in organism structures and readily available in natural sources. In quantitative terms, around 8-10 billion tons of chitin can be naturally derived [21]. It is also the second most abundant natural polymer [22], commonly found on marine creatures such as shrimps, crabs, shellfish, milkfish, oysters and even tilapia [19, 23]. In addition, green mussel shell can theoretically have at least 20 to 30% of chitin and aside from that, it is also composed of calcium carbonate which accounts to at least 78 to 95% of the shell and a protein content of 5% [24].

However, the extraction of biopolymers from these marine creatures necessitated the use of chemical treatments. Deproteinization and demineralization are the standard chemical treatments for extracting chitin from green mussel shells in order to remove other components of the mussel shells and to isolate the chitin itself [25, 26]. Microwave-assisted extraction was also explored as an alternative approach to extract chitin at a specified power, temperature, and time. Studies show that it has significantly reduced the heating temperature and time for extractions and increased the chitin yield [27].

Chitin and chitosan, derived from marine waste such as crabs, shrimps, and mussels, have garnered significant interest due to their unique properties, including biodegradability, biocompatibility, and nontoxicity [28]. The growing amount of marine waste contribute to the realization of the United Nations' Sustainable Development Goals (SDGs) 12 ("Responsible Consumption and Production") and 13 ("Climate Action") by offering a means to harness waste materials [29]. The inherent presence of hydroxyl and amino groups in chitin and chitosan facilitates their facile modification through controlled chemical reactions. This tunability allows for the processing of these biopolymers into various forms, such as microparticles, nanoparticles, aerogels, beads, and membranes, with tailored physicochemical properties [30]. Notably, the reactive amino ($-NH_2$) and hydroxyl (-OH) groups of chitin and chitosan make them ideal support materials. These functional groups can be utilized through various chemical modifications to enhance the adsorption capacity of the final material [31]. Recent studies explore the pairing of chitin with materials like polyethylenimine (PEI), poly(propyleneimine) (PPI), and triethylenetetramine (TETA) due to their potential CO_2 capture capabilities [32].

This study investigated the potential application of chitin, extracted from waste green mussel shells via microwave-assisted extraction, as a sustainable adsorbent for CO_2 capture. This addressed the high-temperature requirement of traditional chemical extraction methods and the limited application of microwave-assisted extraction, which focuses primarily on shrimp and crab shells. To achieve these goals, the study aimed to identify the microwave power level for maximizing chitin yield from green mussel shells. In an attempt to improve the structure of the extracted chitin for CO_2 capture performance, a sol-gel process was applied. The resulting material, hereafter referred to as the chitin support, was then functionalized with triethanolamine (TEA), a well-established polyamine known for enhancing CO_2 adsorption [33]. Finally, the resulting TEA-functionalized chitin-supported adsorbent was characterized to assess its potential as a CO_2 capture material. This approach was undertaken to gain insight into its potential as a CO_2 capture adsorbent.

2. Methodology

2.1. Procurement and Preliminary Preparation for Chitin Extraction

1000 g of green mussel shells were obtained in a seafood restaurant in Pasay City, Philippines. The shells were cleaned with mild detergent to remove unwanted impurities on the shell’s surface and were rinsed with water afterward. The moisture content was reduced by air-drying the sample for three days. Afterward, size reduction was employed using a Wiley mill until the green mussel shells reached a particle size of 500 to 2000 microns using ASTM mesh numbers 10 and 35 with the aid of a sieve shaker.

2.2. Extraction of Chitin

After preparation, the shells were subjected to demineralization and deproteinization using microwave irradiation. A domestic microwave oven (American Home model no. AMW-ST1920LW) was employed at power levels ranging from I to V for 4 minutes per extraction step.

Demineralization. Demineralization was performed to remove calcium carbonate from the pre-weighed mussel shells. The shells were demineralized using a 3 M hydrochloric acid (HCl) solution with a 1:10 (w/w) solute-to- solvent ratio [34, 35]. Microwave irradiation (4 minutes) was applied at varying power levels (I to V). The demineralized shells were then filtered, washed with distilled water to eliminate residual solvent, and air-dried in a desiccator for at least one week.

Deproteinization. Following demineralization, deproteinization was achieved by mixing the shells with a 5% sodium hydroxide (NaOH) solution (1:10 w/w solute-to-solvent ratio) for 4 minutes at the same microwave power level used previously [34, 35]. The deproteinized shells were then filtered, washed with distilled water to remove residual NaOH, and air-dried in a desiccator for at least one week.

Yield Quantification and Characterization. The extracted chitin was weighed in order to check for the percent yield after conducting the chemical treatments. Equation 1 was used to quantify the percent yield of chitin [19].

$$\%\text{Chitin Yield} = \frac{\text{Weight of extracted chitin}}{\text{Initial weight of mussel shells prior to demineralization}} \text{ x } 100 \qquad (1)$$

Fourier-transform infrared (FTIR) spectroscopy was employed to characterize the chitin isolated using the microwave power level that yielded the highest amount of product. This analysis identified the functional groups present in the chitin.

2.3. Synthesis of Adsorbent for Potential Carbon Capture Applications

This section details the sol-gel process employed for the pre-treatment of the chitin support and subsequent incorporation of triethanolamine (TEA) as the functionalizing amine. The adsorbent was prepared with a weight ratio of 1:0.72 (chitin to TEA loading) for potential CO_2 capture applications, adapting the method reported by Xu et al. with slight modifications [36]. The synthesized chitin-TEA adsorbent was then characterized using various instrumental techniques, including scanning electron microscopy (SEM), thermogravimetric analysis (TGA), and Fourier-transform infrared spectroscopy (FTIR), to evaluate its properties.

2.3.1. Synthesis of Chitin Support

Approximately 4 g of purified chitin powder, obtained from waste mussel shells using the microwave-assisted extraction with the highest yield, was further treated with a mixture of distilled water, NaOH, and urea (85:11:4 mass ratio). The total solvent weight was approximately 68 g. After thorough mixing, the sample was frozen at -20 °C for 6 hours and thawed at room temperature.

The thawed sample was then treated with a mixture of 72 g of 2,2,4-trimethylpentane and 6 g of Span 80 under stirring at 0 °C for 1 hour. Subsequently, 3 g of Tween 80 and 14 g of 2,2,4-trimethylpentane were added, and the mixture was stirred at 60 °C for 1 hour.

To neutralize the sample, a 10 wt% HCl solution was added until a neutral pH was reached. The chitin product was then collected from the lower layer by filtration and washed with distilled water. A solvent exchange with tert-butanol was performed, followed by freeze-drying at -85 °C for 12 hours.

Finally, the prepared chitin support was recovered by heating the freeze-dried sample in a furnace at 200 °C for 4 hours.

2.3.2. TEA Functionalization of the Chitin Support

Approximately 1 g of the pre-heated adsorbent was mixed with TEA at a weight ratio of 1:0.72 (adsorbent:TEA). The mixture was then stirred in methanol at room temperature for 2 hours. Following the stirring, the methanol was removed using a rotary evaporator at 60 °C. The resulting TEA-functionalized adsorbent was air-dried for at least one week and stored in a desiccator to minimize moisture and CO_2 uptake.

2.3.3. Characterizations

The morphology and microstructure of the chitin support and TEA-functionalized chitin-supported adsorbents were investigated using scanning electron microscopy (SEM). Energy-dispersive X-ray spectroscopy (EDX) was employed for further elemental analysis [37].

Additional characterization techniques, including Fourier-transform infrared (FTIR) spectroscopy and thermogravimetric analysis (TGA), were utilized to elucidate the characteristics of the synthesized adsorbent and the effects of incorporating TEA at a ratio of 0.72. The data obtained from FTIR and TGA analyses complemented the information regarding the morphology observed in the SEM images. FTIR analysis identified the functional groups present in the samples based on the characteristic wavenumbers of their corresponding peaks. TGA was employed to determine the thermal degradation profile of the adsorbent.

3. Results and Discussion

3.1. Microwave-Assisted Extraction for Chitin

The microwave-assisted extraction process yielded samples with varying masses depending on the applied microwave power level as shown in Table 1. Note that all samples initially weighed 20 grams. The percentage yield of chitin from these samples was calculated using the formula provided by Cadano et al. [19] (Equation 1).

Table 1. Summary of the Microwave-Assisted Extraction of Chitin

Demineralization		**Deproteinization**	
Microwave Power Level	**Weight (grams)**	**Microwave Power Level**	**Weight (grams)**
I	1.05	I	0.67
II	2.32	II	1.28
III	1.44	III	0.79
IV	1.23	IV	0.29
V	1.19	V	0.13

Table 1 and Figure 1 present the overall chitin yield obtained at each microwave power level. Microwave power level 2 yielded the highest amount of chitin, while power level 5 produced the least. This observation differs from the findings of Knidri et al. [34], where the highest power level promoted effective demineralization and deproteinization for chitin extraction from shrimp shells. This discrepancy might be attributed to the different source material. Knidri et al. [34] used shrimp shells, whereas this study focused on green mussel shells, for which optimal microwave extraction conditions have not been established, as highlighted by Mohan et al. [27] in their compilation of microwave-assisted chitin extraction methods using various sources like shrimp shells, crab shells, fungal biomass, and spider molt cuticle. As microwave-assisted extraction of chitin from green mussel shells is a novel approach, our findings suggest that power level 2 using the American Home model AMW-ST1920LW microwave oven yielded the highest chitin content.

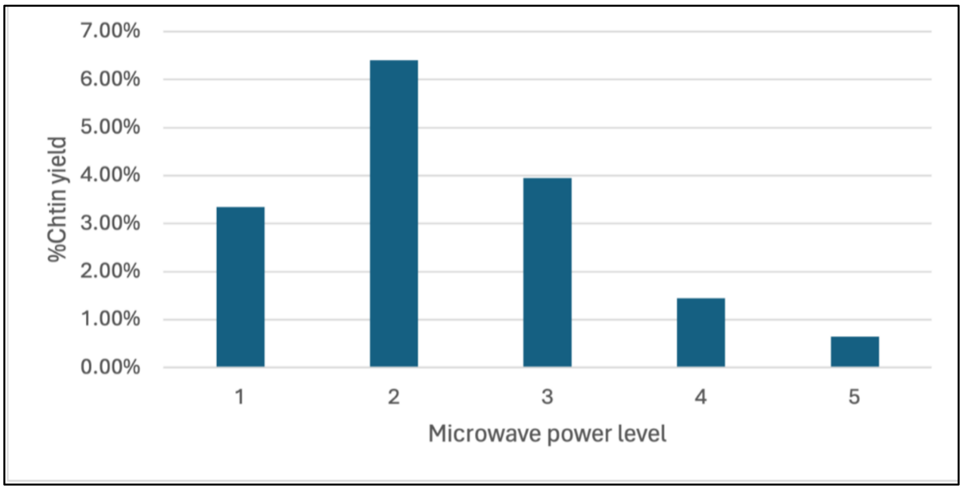


Figure 1. Chitin Yield Across Different Microwave Power Levels

Demineralization, a crucial step, removes mineral components from the green mussel shell. Notably, calcium carbonate ($CaCO_3$) constitutes 78-95% of the shell [24, 38-39]. Therefore, the significant mass loss observed during demineralization can be attributed to the elimination of $CaCO_3$. Deproteinization further reduces the sample mass by removing protein content. Both demineralization and deproteinization processes involve temperatures exceeding ambient conditions, which, along with $CaCO_3$ removal, can lead to color changes in the extracted chitin [39]. Figure 2 visually demonstrates these changes – the green mussel shell transforms into extracted chitin, exhibiting a distinct color and reduced mass.

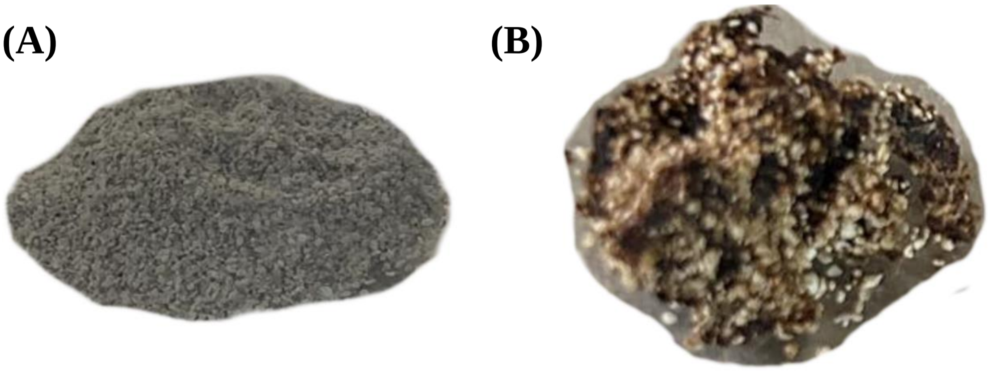


Figure 2. Green Mussel Shells (A) Before and (B) After Chitin Extraction and Treatment

3.2. FTIR Spectra for Chitin Extraction

The extracted chitin was characterized using FTIR spectroscopy to identify its functional groups and compare them with reference data for chitin from various sources [39]. The FTIR spectrum of the extracted chitin is presented in Figure 3. Peak assignments were performed based on the reference data provided by Nandiyanto et al. [40].

Cadano et al. employed commercial chitin as a reference standard for comparison with their extracted chitin [19]. The observed peaks in the commercial chitin spectrum at 3510-3410 cm^{-1} and 1620 cm^{-1} correspond to O-H stretching, secondary N-H bending, and α-chitin bonds, respectively [19]. The extracted chitin from green mussel shells exhibits peaks consistent with these reference values, indicating successful extraction. Additionally, the peak at 1430 cm^{-1} suggests the presence of bending and deforming

CH and CH_2 groups, further supporting the chitin structure. The presence of C-O-C chitin chains is also confirmed by the peak observed at 1050 cm^{-1}.

Peaks at 712 cm^{-1} and 857 cm^{-1} were also identified in the FTIR spectrum. These peaks can be attributed to the presence of calcium carbonate ($CaCO_3$) components [41]. As green mussel shells, the source material for the extracted chitin, typically contain 78-95% $CaCO_3$, these additional peaks suggest residual traces of $CaCO_3$ in the extracted sample [38].

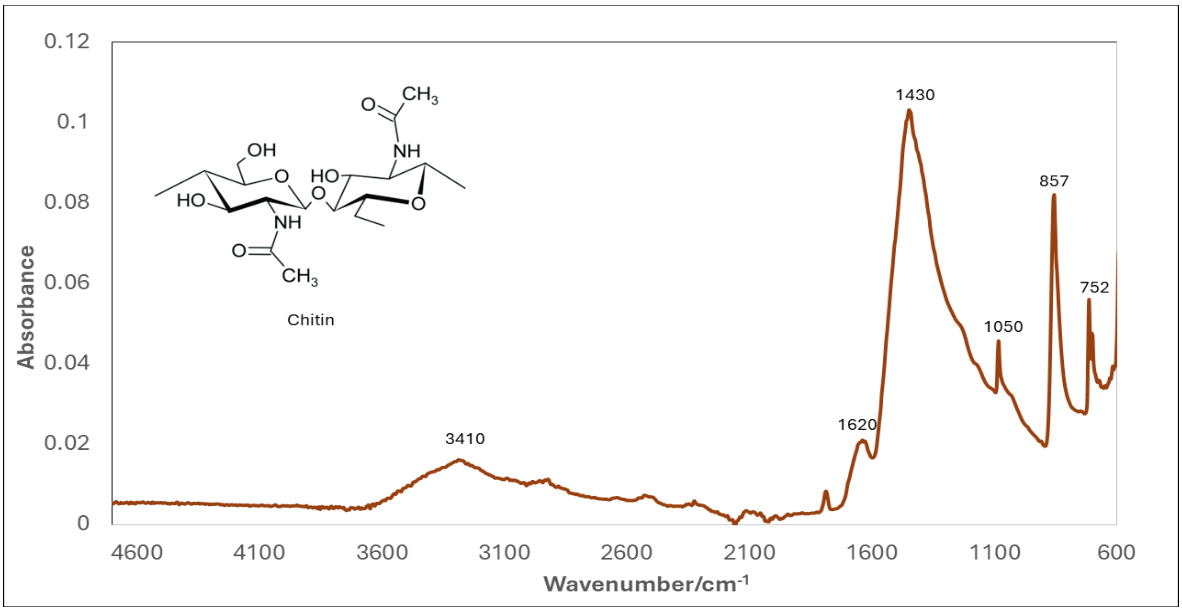


Figure 3. FTIR Spectrum of Extracted Chitin Sample

3.3. Elemental Analysis

Energy-dispersive X-ray spectroscopy (EDX) analysis was employed to determine the elemental composition of the samples. As shown in Figure 4a (electron mapping), the chitin support (Figure 4c) was primarily composed of calcium (49.32 wt%), followed by oxygen (40.64 wt%) and carbon (10.04 wt%). These results suggest that more rigorous pre-treatment procedures, such as deproteinization and demineralization, might be necessary to achieve higher chitin content. However, the presence of a significant amount of carbon and oxygen indicates the presence of chitin in the support, which aligns with the findings of Xu et al. [36].

Figure 4d displays a similar elemental composition trend to Figure 4c. The slight increase in carbon content observed in the TEA-functionalized adsorbent compared to the untreated support could be attributed to an unideal furnace temperature during the TEA incorporation process. This hypothesis is supported by the study of El-Harbawi et al. [42] on date palm molasses, which showed a similar influence of temperature on elemental composition.

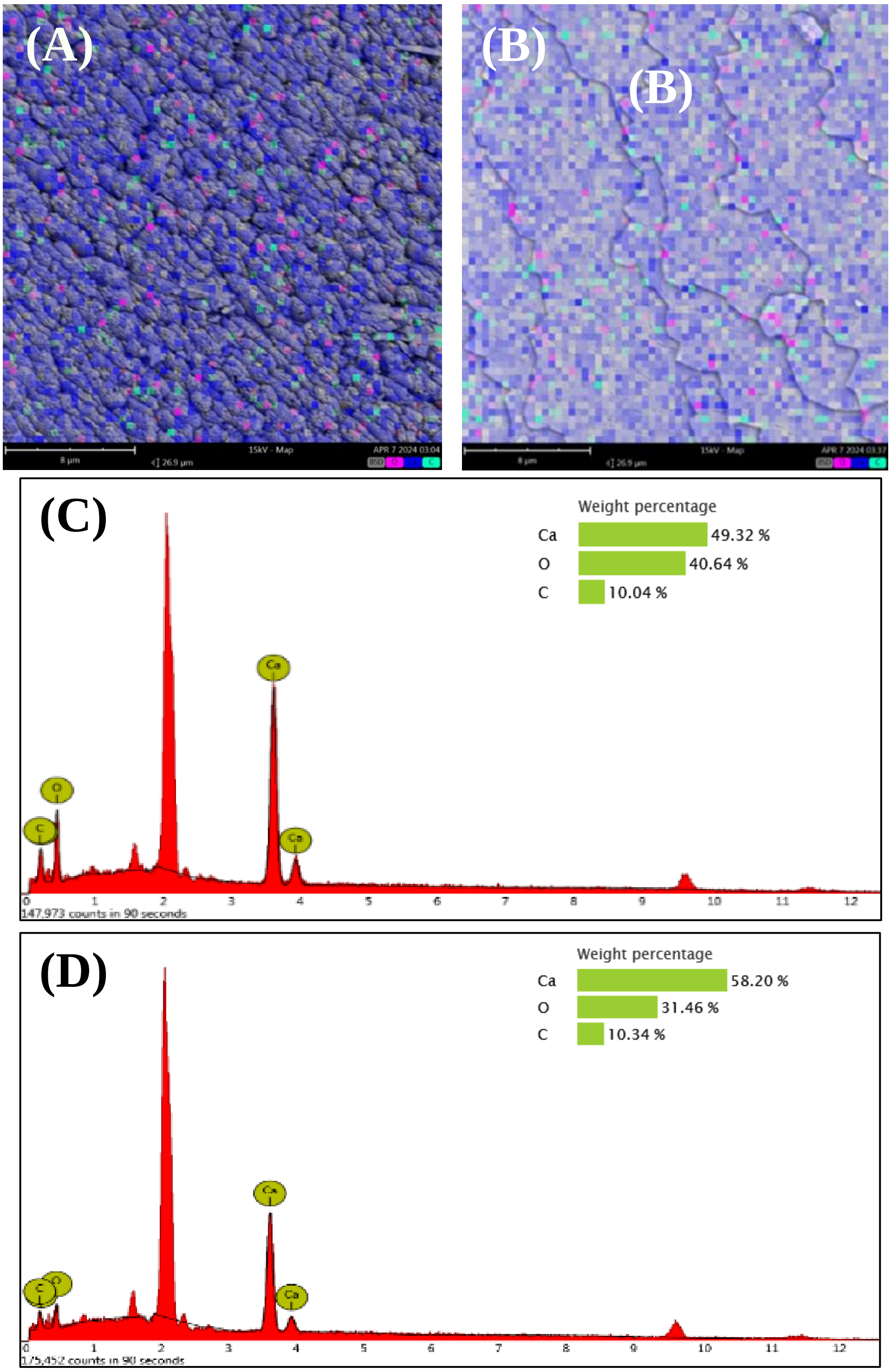


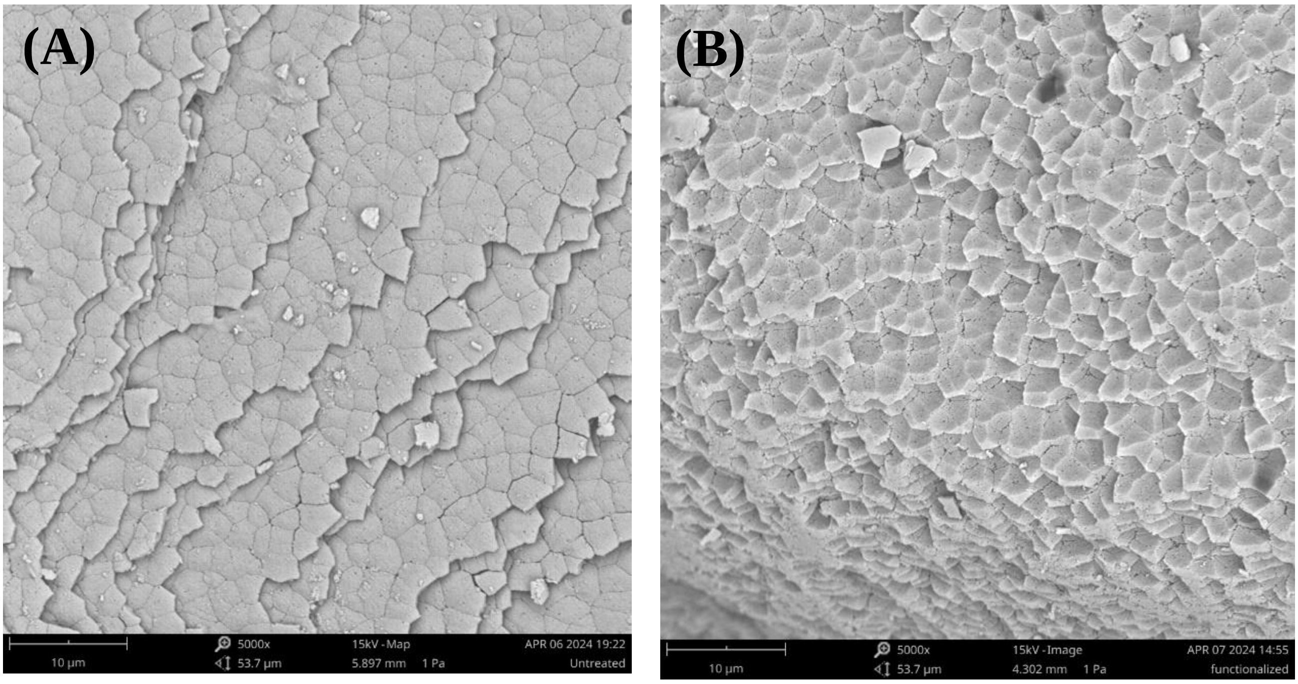
Figure 4. SEM-EDX Elemental Mapping and Composition of Chitin Support (A,C) and TEA-Functionalized Adsorbent (B,D).

3.4. Morphology of Functionalized and Untreated Adsorbent

SEM images of the chitin support and the TEA-functionalized adsorbent at various magnifications are presented in Figure 5. Both samples exhibit a morphology characterized by flaky crystals. Interestingly, the TEA-functionalized adsorbent displays a more prominent stacking arrangement compared to the chitin support and shows a rougher surface, potentially indicative of TEA incorporation.

The observed morphology deviates from the expected fibrous carbon microspheres (FCMs) reported by Xu et al., who utilized commercially available chitin powder and employed a similar sol-gel method [35]. FCMs are typically spherical with interwoven carbon fibers. In contrast, the SEM images of both samples resemble the nacreous layer of mussel shells. This layer, located in the mollusk shell's interior, possesses a well-ordered brick-wall-like or flaky crystal structure, often studied in the context of biomineralization [43]. The brick-wall structure is composed of polygonal aragonite crystals typically ranging from 5-15 μm in diameter [43]. These findings align with the observations of Bhavsar et al., where chitin exhibited a nonporous structure consisting of well-organized, repeating hexagonal units [44]. This further supports the notion that the final morphology of chitin is influenced by its source.

For the TEA-functionalized adsorbent, the sol-gel method, a bottom-up approach [44], was employed to achieve a specific structure. This method utilizes chitin chains under the influence of a NaOH-Urea solvent system. However, in this study, chitin was directly extracted from green mussel shells, which possess a less defined structure compared to commercially available chitin. This difference in source material might have influenced the final morphology, potentially hindering the formation of well-defined fibrous chitin microspheres as observed by Xu et al. [36, 45]. It is noteworthy that other chitin sources, such as crab and mantis shrimp shells, exhibit a bouligand (plywood-like) structure, which facilitates the formation of fibrous chitin through grinding techniques [46, 47]. Conversely, mussel shells naturally adopt a nacreous structure, as previously mentioned [48]. In this case, the desired FCM morphology was not achieved, and the observed microstructures resemble the stacked brick-like arrangement characteristic of the nacreous layer in mussel shells.



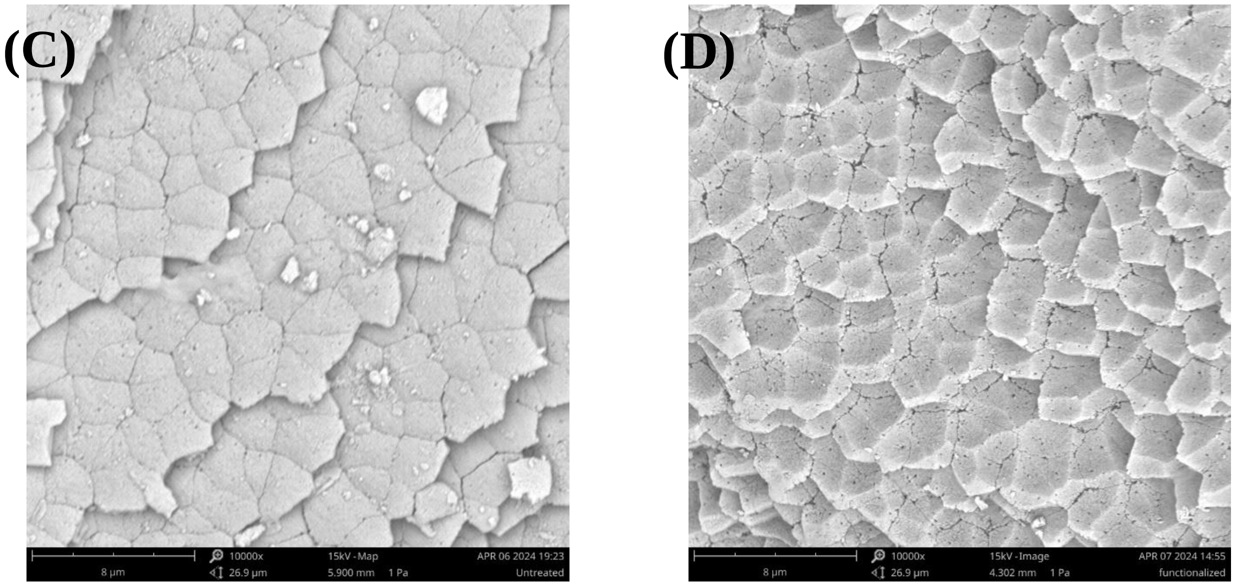


Figure 5. SEM images of (A) Chitin Support at 5000x, (B) Functionalized Adsorbent at 5000x, (C) Chitin Support at 10000x, and (D) Functionalized Adsorbent at 10000x

3.5. FTIR Spectra of the Chitin Support and the TEA-functionalized Adsorbent

Figure 6 presents the FTIR spectra of the chitin support and the TEA-functionalized chitin-supported adsorbent. The peak assignments are based on the reference values established by Nandiyanto et al. [40]. The FTIR spectra of both samples reveal several characteristic peaks for the chitin support. The short double peaks at 2365-2350 cm^{-1} can be assigned to C-C stretching vibrations in alcohols. The minor peak at 1636 cm^{-1} corresponds to an alkenyl C=C stretch. Additionally, the peak at 1785 cm^{-1} suggests the presence of C=O bonds. The broad peak observed in the range of 3600-3100 cm^{-1} for both samples is indicative of O-H stretching vibrations. However, the chitin support spectrum displays multiple spikes and fluctuations between 3900 and 3600 cm^{-1}. These irregularities likely arise from water vapor adsorbed onto the sample from the ambient environment or represent vapor adsorption wavenumbers [49, 50]. Alternatively, these features could be attributed to noise interfering with the analysis. Operating under vacuum conditions could minimize such disturbances [51]. Notably, the TEA-functionalized adsorbent spectrum exhibits a broader curve with lower intensities within the 3600-3100 cm^{-1} range. This observation suggests a reduction in moisture content, possibly due to the use of the rotary evaporator during sample preparation.

The fingerprint regions (1500-500 cm^{-1}) of the FTIR spectra for both samples exhibit a high degree of similarity, with the TEA-functionalized adsorbent displaying a slight upward shift in intensity compared to the chitin support. Several characteristic peaks are observed in this region, located at 712, 854, 1081, 1439, and 1465 cm^{-1}. Based on reference data [40], these wavenumbers can be assigned to various functional groups: 1439 and 854 cm^{-1} correspond to C-O stretching vibrations, 712 cm^{-1} indicates C-H bending vibrations, and 1465 cm^{-1} suggests the presence of C-H deformations. The increased intensity of these peaks suggests successful incorporation of TEA into the chitin support. Additionally, the combined peaks at 1439, 1081, 854, and 712 cm^{-1} could potentially indicate the presence of carbonate ions (CO_3^{2-}), suggesting Ca-O bonds. These observations are somewhat consistent with the findings of Guan et al. and Putra et al., although slight deviations are present [49, 52-55]. However, as noted by Galvan-Ruiz et al., Raman spectroscopy offers a more definitive approach for detecting oxide groups such as CaO, $(CaOH)_2$, and $CaCO_3$ [56]. Therefore, conclusive identification of these species in the current study is not possible based solely on FTIR data.

The FTIR spectra reveal significant changes in the peaks around 1080 cm^{-1} and 1613 cm^{-1}, corresponding to C-N stretching and N-H bending vibrations, respectively [40]. These changes could be attributed to two factors: 1) an increase in carbon content due to potential adsorbent carbonization, and 2) successful TEA functionalization, as evidenced by the higher peak intensities for the TEA-functionalized adsorbent at these wavenumbers compared to the chitin support. Notably, the presence of relatively strong carbon, nitrogen, and oxygen bonds in hydroxyl groups of the treated adsorbent aligns well with desired functionalities for CO_2 capture applications [57, 58].

Furthermore, the peak at 1080 cm^{-1} might be additionally influenced by the treatment with TEA, given its alkaline nature and potential impact on the functional groups present. This could contribute to a more favorable interaction between the adsorbent and CO_2 molecules [59]. Additionally, the presence of C-O and C-N bonds introduced by the amines in the TEA-functionalized adsorbent, compared to the untreated sample, might also enhance gas adsorption [60,61].

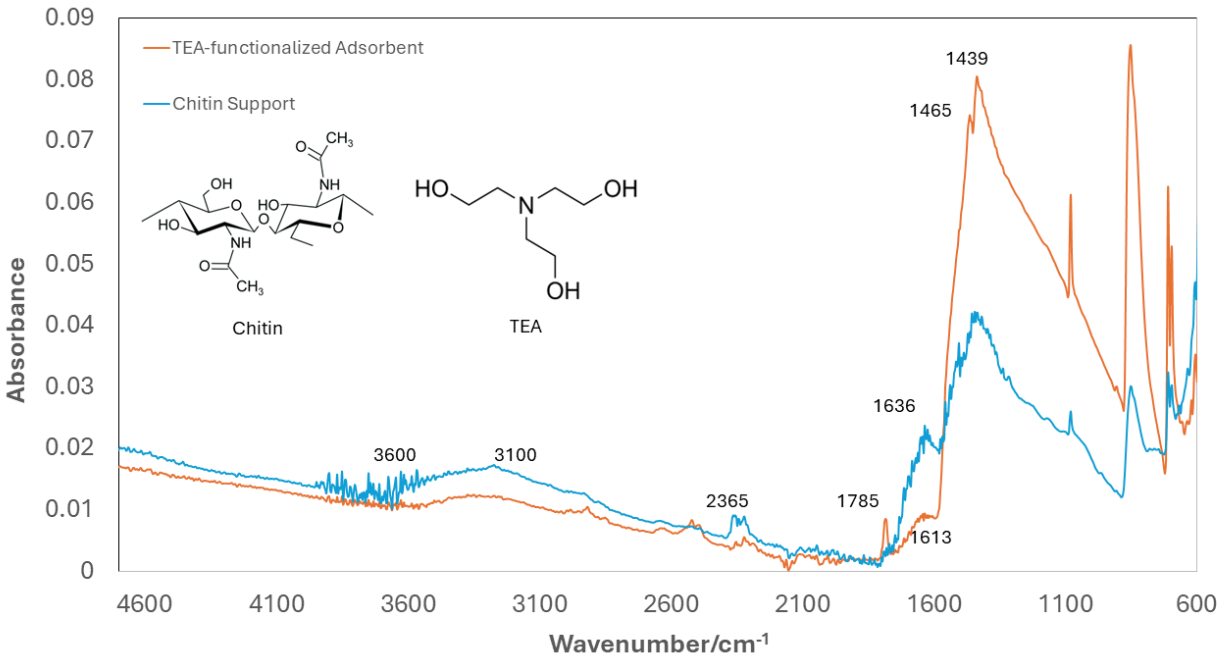


Figure 6. FTIR Spectra of Chitin Support and TEA-Functionalized Chitin-Supported Adsorbent

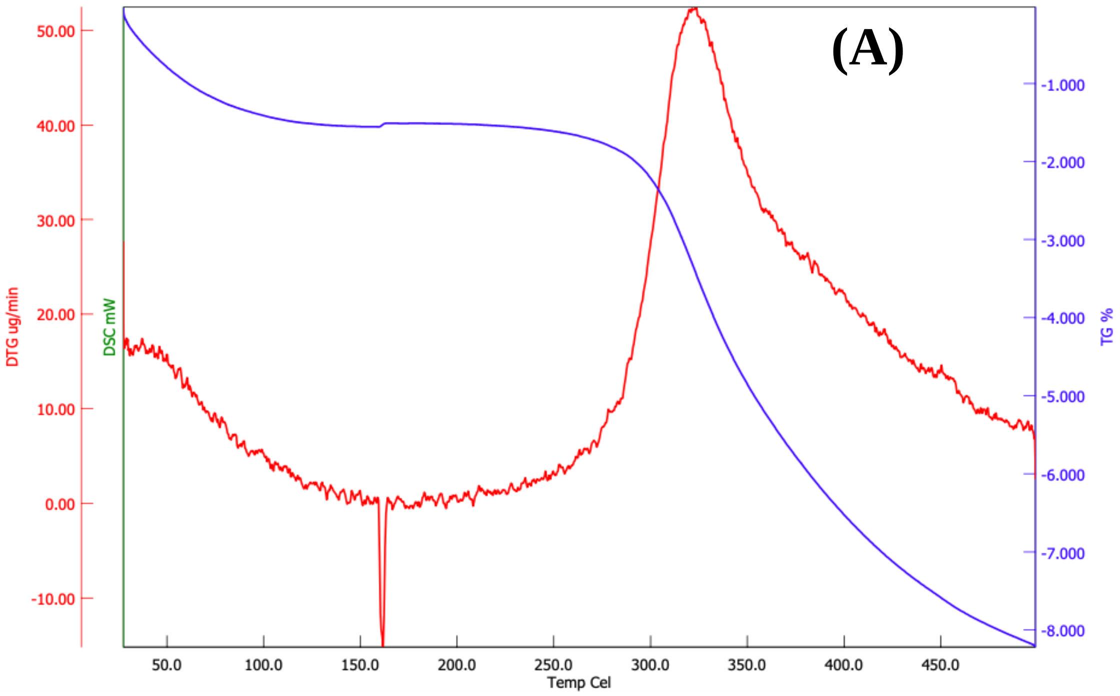
3.6. Thermogravimetric Analysis of Samples

The TGA curves for both the chitin support and TEA-functionalized adsorbent are presented in Figure 7. The similar profiles observed for both samples suggest a close resemblance in their thermal decomposition behavior.

Both the chitin support and TEA-functionalized adsorbents exhibit a noticeable initial mass loss around 90 °C. This initial weight loss, typically observed around this temperature range, is often attributed to the evaporation of moisture present within the sample [59]. Figure 7 shows that the chitin support and TEA-functionalized adsorbent experience approximately 1.8% and 0.3% weight loss, respectively, during this initial stage. This mass loss can be attributed to the desorption of moisture and the removal of volatile compounds such as methanol, tert-butanol, and isooctane [60-62].

Both chitin support and TEA-functionalized adsorbents exhibit a significant mass loss within the temperature range of 275-360 °C. This observation differs from the findings of Xu et al., where a more pronounced weight decrease was observed for the PEHA ratio of 0.72 compared to the synthesized Fibrous Carbon Microsphere [59]. In their study, this phenomenon was attributed to the decomposition of PEHA and its interaction with the adsorbent. The relatively similar weight loss profiles observed in this study might be due to an insufficient TEA ratio compared to the adsorbent mass. Additionally, the TGA curves show that significant decomposition commences around 275 °C for both samples, with the TEA-functionalized adsorbent exhibiting a slightly faster decomposition rate at higher temperatures. This could be attributed to the presence of functional groups introduced during TEA functionalization of the chitin support. Similar observations were reported by Xu et al. for PEHA-treated adsorbents, which also displayed a faster mass loss compared to the untreated samples [65]. The maximum degradation temperatures were determined to be 319.76 °C and 331.66 °C for the chitin support and TEA-functionalized adsorbent, respectively. These thermal stabilities suggest the potential applicability of these materials as CO_2 adsorbents. Thermal stability is a crucial property for CO_2 adsorbents due to the high temperatures employed during the desorption process, which is essential for their reusability.

Consequently, it can be deduced that at these temperatures, both of the samples started to lose their mass or degrade due to the various solvents present in the sample. Urea was added in the pre-treatment with a boiling point of 332°C. Thus, this suggests that the traces of urea present in the sample contribute to the sample's degradation at the stated temperature. Aside from this, in the functionalized adsorbent, TEA was added, similar to the untreated adsorbent, it also degrades at this temperature range, which can be attributed to Urea and TEA that has a boiling point of 335°C [66, 67].



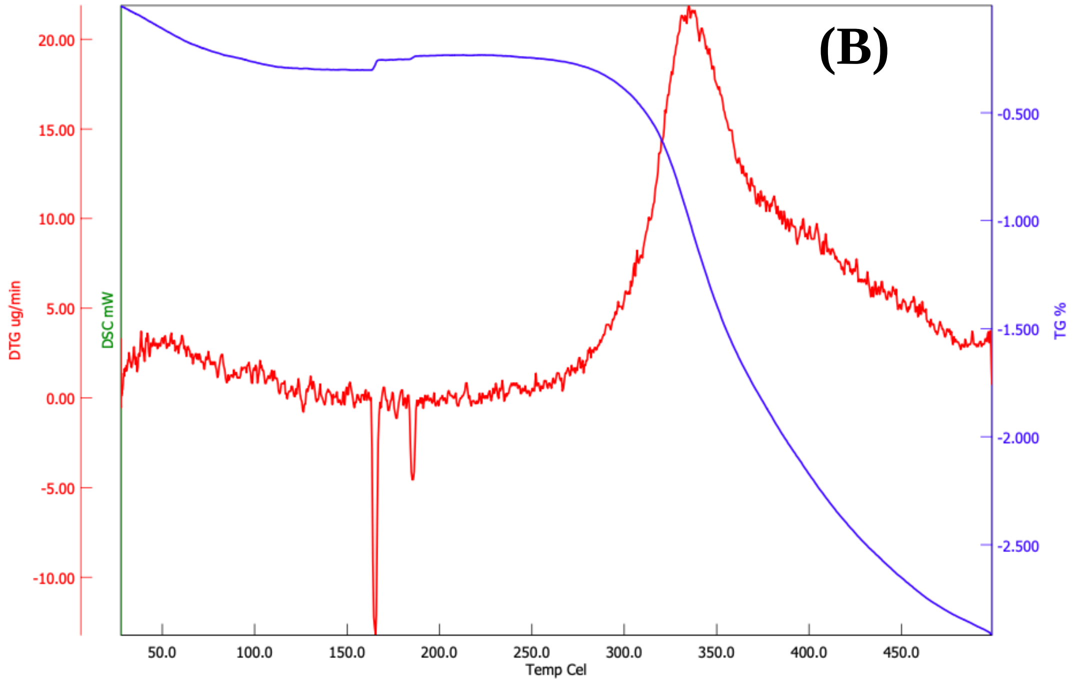


Figure 7. TGA (blue) and DTG (red) Curves of (A) Chitin support and (B) TEA-Functionalized Adsorbent

4. Conclusion and Recommendations

This study explored the potential of chitin, extracted from waste green mussel shells via microwave-assisted extraction, as an adsorbent for CO_2 capture. Microwave-assisted extraction using a domestic microwave (AMW-ST1920LW) system was evaluated to identify the power level that produced the highest chitin yield. The results demonstrate that microwave power level 2 yielded the highest percentage (6.40%) of chitin.

FTIR spectroscopy analysis of the extracted chitin exhibited good agreement with literature values for commercial chitin, indicating successful extraction. However, the presence of $CaCO_3$, identified by a peak at 712 cm^{-1}, necessitates further optimization to improve the purity of the chitin support for CO_2 capture applications. Notably, following microwave-assisted extraction, the chitin was subjected to a sol-gel process with the aim of synthesizing a support material with an improved structure for CO_2 capture. While elemental analysis confirmed the presence of calcium in both the chitin support and the subsequently TEA-functionalized adsorbent, likely attributable to residual $CaCO_3$, further investigations are needed to optimize the sol-gel process for an improved structure. Scanning electron microscopy (SEM) revealed a "brick wall-like" or flaky crystal structure for both the chitin support and the TEA-functionalized adsorbent, consistent with the nonporous structure reported by Bhavsar et al. These observations confirm successful chitin extraction but highlight the need for process modifications to introduce porosity, a crucial property for effective CO_2 capture.

The TEA-functionalized chitin adsorbent displayed successful incorporation of amine (TEA) as evidenced by increased surface roughness observed in SEM images and intensified absorption peaks corresponding to amine functional groups. This suggests the potential for improved CO_2 capture due to the increased amine content. Finally, thermogravimetric analysis confirmed the stability of the adsorbent at high temperatures, a crucial property for CO_2 capture due to the high temperatures used during the desorption process for reusability.

Although CO_2 capture performance was not measured in this study, the characterization results provide a foundation for further research. Future studies should focus on evaluating the CO_2 capture capacity of the amine-functionalized chitin supported adsorbent and explore methods for enhancing its adsorption performance.

This work demonstrates the promise of utilizing waste green mussel shells and microwave-assisted extraction as a sustainable strategy for chitin production with potential applications in CO_2 capture.

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