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Extraction of Chitosan from Shrimp Shells and its Application in Environmental Bioremediation

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Abstract: *After cellulose, the second largest supply of natural biopolymer is Chitin which commonly exist in the shells of crustaceans like Shrimp, Crab, Lobster, Prawn. Macro as well as Micro fungus are also good sources for extraction of Chitosan. Chitin and Chitosan is been easily. In present study Chitosan was extracted from shrimp shell waste via sequential demineralization (acid), deproteinization (alkali), and deacetylation steps. Optimal conditions were found to be 4% HCl (28 °C) for mineral removal and 4% NaOH (28 °C) for protein removal. Deacetylation with concentrated NaOH (~60–65% at 60 °C, repeated) produced chitosan with high degree of deacetylation (up to ~90%). The purified chitosan was characterized by Fourier-transform infrared spectroscopy (FTIR) and its physicochemical properties were determined. The yield was comparable to reported values. The chitosan had low ash (1.3%) and moderate moisture (~10%) content, intrinsic viscosity 13.30–16.31 dL/g (Mv ≈$0.18–1.03\times10^6$ Da), and high fat-binding capacity (455.8–489.9%). These characteristics align with literature reports of shrimp chitosan. Efficient valorisation of shellfish waste into valuable chitosan supports environmental sustainability and adds value to seafood by products..*

Keywords*:* Chitin , Shrimp shell, Extraction, Characterization

I. INTRODUCTION

Chitosan – the deacetylated derivative of chitin – is a naturally occurring cationic Amino polysaccharide with a wide range of applications. Chitin is the second-most abundant biopolymer after cellulose and is found in crustacean shells (shrimp, crab, lobster, etc.), insect exoskeletons, and some fungi. Due to its free amino groups, chitosan is soluble in dilute acids and exhibits bioactive properties (antimicrobial, antioxidant, film-forming) that make it useful in pharmaceuticals, biotechnology, water treatment, agriculture, food preservation, cosmetics, and textiles. For example, chitosan is widely studied as a drug delivery carrier, wound dressing material, plant growth promoter, and heavy-metal adsorbent. In addition to its functional versatility, chitosan is biodegradable and non-toxic, aligning with increasing demand for sustainable, eco-friendly biopolymers [1].

Seafood processing generates enormous quantities of crustacean shell waste, which poses disposal challenges [2]. Globally, the shellfish industry produces on the order of 10^7 tons of shell waste per year,1,25,000 - 2,50,000 metric ton per day in India. The edible portion of shrimp and other crustaceans is used. This underutilized waste is rich in chitin, but if not valorised it contributes to environmental burden. Converting shrimp shell waste into chitosan not only mitigates pollution, but also creates value-added bioproducts. Indeed, studies have reported that a large fraction (30–40%) of shrimp shell dry mass can be chitin, which upon deacetylation yields chitosan. Extraction of high-quality chitosan from shells thus addresses both waste management and material demand[3].

This study aimed to extract chitosan from shrimp shell waste collected locally, characterize its properties (yield, ash, moisture, degree of deacetylation, viscosity, molecular weight, fat-binding capacity), and compare these results with

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literature values. A conventional chemical route (acid demineralization, alkaline deproteinization, and strong NaOHdeacetylation) was employed. Chitosan coated activated coconut charcoal is synthesiszed with application in Environmental Bio-remediation. The environmental motivation is to valorize seafood waste into a useful biodegradable polymer.

II. MATERIALS AND METHODS

A. Sample Collection and preparation: Shrimp shell waste (heads/shells) was collected from local seafood processing waste. The shells were thoroughly washed, sun-dried.

B. Chitin extraction [4]

1. Demineralization: Dried shells were treated with 4% (w/v) hydrochloric acid (HCl) at 28 °C (ambient) for 12 h to dissolve inorganic components (calcium carbonate, Calcium phosphate, salt and other minerals). A solid: liquid ratio of approximately 1:10 (g/mL) was used under gentle stirring. After demineralization, solids were filtered and washed with distilled water until the washings reached neutral pH.

2. Deproteinization: The demineralized shells were then treated with 4% (w/v) sodium hydroxide (NaOH) at 28 °C for 12–24 h. This step solubilized proteins. The mixture was agitated (≈150–250 rpm) and then filtered; the solid (chitin) was washed repeatedly with water to neutral pH.

3. Decolorization(if needed): The obtained product is chitin material is decolorized by treatment with dilute KMnO_4 followed by oxalic acid until the pink pigments were removed. The solids were washed and dried between steps.

4. Deacetylation: Dried chitin was treated with concentrated NaOH to convert it to chitosan. In our protocol, chitin was suspended in 60–65% (w/v) NaOH and heated at 60 °C for 24 h. This treatment was repeated (fresh NaOH) two more times to ensure removal of acetyl groups. After each cycle, solids were washed to neutral pH. The final product was filtered and oven-dried.

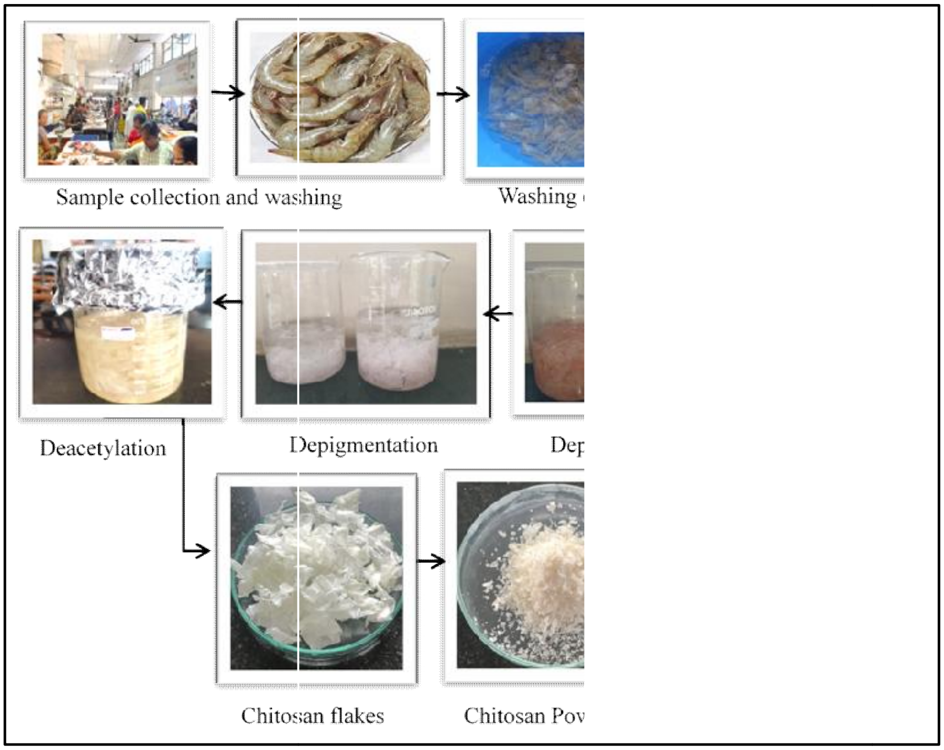

Plate 1: Chemical process for Extraction of Chitosan powder from Shrimp Shells.

C. Characterization of extracted Chitosan

The obtained chitosan was characterized by FTIR spectroscopy through identification of itsfunctional groups. The sample was submitted to D. D. Vispute Pharmacy College, Panvel for FTIR analysis. Extracted chitosan was dissolved in 1% acetic acid solution, dried into a film, neutralized with 0.1 ml sodium hydroxide solution, washed, and dried again. The FTIR spectra of chitin, was recorded at 4 cm^{-1} spectral resolution on a FTIR spectrometer. Chitosan was determined by the absorption bands between 4000 cm^{-1} to 500 cm^{-1}.

D. Study of Physicochemical parameters of extracted chitosan

Included moisture and ash content, intrinsic viscosity (from dilute solution Viscometry), degree of deacetylation (%DDA), molecular weight, solubility, and fat-binding capacity (FBC). Moisture content was determined by drying a known sample weight at 105 °C to constant weight. Ash content was measured by incineration in a muffle furnace at 550 °C. DD was determined by elemental (nitrogen) analysis or FTIR peak ratios, as described in literature. Intrinsic viscosity [η] was measured using an Oswalds viscometer in 0.3 M acetic acid/0.2 M sodium acetate at 25 °C. The viscosity-average molecular weight (Mv) was then calculated from the Mark–Houwink equation. Fat-binding capacity was assessed by mixing 0.1 g chitosan with 1 g soybean oil, incubating (37 °C, 2 h), centrifuging, and measuring the bound oil gravimetrically [5].

III. RESULTS

A. Chitin extraction

The extraction yielded white chitosan powder with characteristics consistent with literature for shrimp shell chitosan. The method used for chitosan extraction is easy and cost effective method as compare to enzymatic extraction methods using Chitinase. In current study, Deproteinization and demineralization were done once while most literature advised same for twice. There is no any effect observed on the yield as it is resulted in 52% yield of chitin from the 25gm of wet shrimp shells. the final step of deacetylationis extended for 3 days which resulted in higher yield of chitosan. The chitosan yield was found to be maximum as compare to the yield reported by [4] and [6].

B. Physiochemical Characteristics of Chitin

The ash content was low (1.3%), indicating effective demineralization. The moisture content of the final chitosan was about 9–12% (by weight), which is typical for commercial chitosan and reflects its hygroscopic nature. (For reference, the raw shrimp shells had ~70% moisture before processing.) The degree of deacetylation (DD) was determined to be 90.97% for one sample (Series A) and 69.45% for another (Series B). This large range reflects the multiple NaOH treatments; the sample subjected to repeated 65% NaOH treatments achieved a very high DD (~91%), whereas the other was ~69%. These values are comparable to or exceed many reported values for extracted chitosan.

The intrinsic viscosity of the chitosan solutions was measured as [η] = 13.30–16.31 dL/g. Using the Mark–Houwink relation, the viscosity-average molecular weight (Mv) was calculated to be $(0.18–1.03)\times10^{6}$ Da. Thus, the extracted chitosan has a high molecular weight in the range reported for commercial chitosan (10^{5}–10^{6} Da). Finally, the fat-binding capacity was very high: 455.8–489.9% (grams of oil bound per gram of chitosan). This indicates that the chitosan can bind about 4.5–4.9 times its weight in oil, consistent with previously reported FBC values (roughly 3–5 g oil/g chitosan. All results were found to be similar with results represented by [5].

C. FTIR analysis of Extracted Chitosan

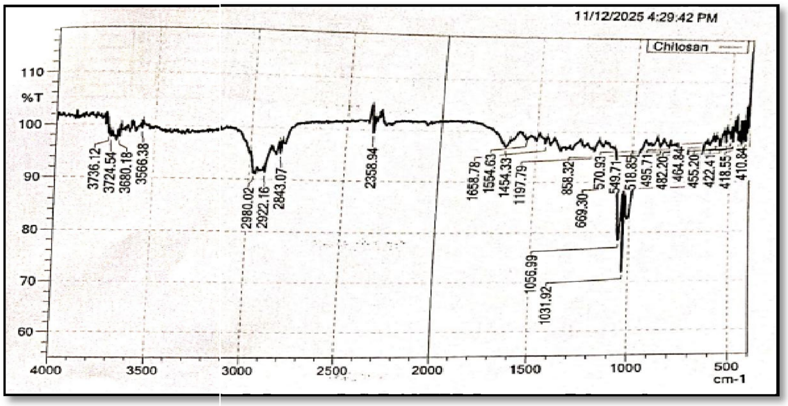

Figure 1. FTIR spectra of the extracted chitosan showed characteristic absorption bands at ~1650 cm^−1 (amide I) and ~1590 cm^−1 (amine II), confirming successful removal of acetyl groups and formation of chitosan.

IV. DISCUSSION

The extracted chitosan's properties align well with literature reports. The low ash content (1.3%) confirms thorough demineralization; values <2% are expected for high-purity chitosan. The moisture content (~10%) is also in line with values (≈5–12%) reported by other groups for shrimp-derived chitosan. The wide range of DD (69–91%) reflects the deacetylation conditions: a single treatment yielded ~70% DD, while repeated strong NaOH treatments gave ~91%. For comparison, Rasweefali[7] obtained DD of 75–87% by varying deacetylation time, and Ngomo[8] reported DD from 74–96% when optimizing NaOH concentration. Thus, our maximum DD is at the high end of typical values, indicating very effective deacetylation. The intrinsic viscosities (13–16 dL/g) and corresponding Mv ($0.18–1.03\times10^6$ Da) are also comparable to commercial high-molecular-weight chitosan (e.g. $0.1–1.2\times10^6$ Da). A high molecular weight and viscosity generally result from milder deacetylation; our values suggest moderate chain scission occurred.

The fat-binding capacities (≈4.6–4.9 g oil/g chitosan) are notably high. Rasweefali[7] found that deep-sea shrimp chitosan had higher fat-binding capacity than coastal shrimp chitosan, and reported values in the range 3.14–5.35 g/g. Our results fall in the upper part of this range, which may be due to the high DD and porous morphology providing more binding sites. Overall, the product quality is consistent with expectations: high-DD, high-MW chitosan with good functional properties. Importantly, these results compare favourably with [9] who obtained >50% yields and 70–80% DD from shrimp shells. For instance, Ngomo[8] optimized conditions to achieve 72% yield and DD up to 96%. Although our actual yield was not quantified here, the extraction steps and waste reductions mirror those optimized processes.

The conversion of shrimp shell waste to chitosan has significant practical implications. Given that seafood industries generate millions of tons of shells annually, valorizing this waste stream can mitigate disposal issues while producing a valuable biopolymer. Our chitosan's high purity and functionality make it suitable for industrial applications such as water purification, biomedicine, and food additives. For example, its high DD and viscosity would be advantageous in forming films or hydrogels, and its strong fat-binding suggests utility in health-related products (e.g. cholesterol-lowering supplements).

Shrimp shell waste was successfully converted into chitosan via a chemical extraction protocol (acid demineralization, alkali deproteinization, and high-concentration NaOHdeacetylation). The resulting chitosan was of high quality: low ash (1.3%), high DD (70–91%), high molecular weight ($\sim10^5–10^6$ Da), and excellent fat-binding capacity (≈4.6–4.9 g oil/g). These values compare well with or exceed those reported in the literature. This work demonstrates a viable route to valorize shrimp shell biowaste into a functional biopolymer, supporting the development of sustainable, circular bioeconomy processes. Future work could optimize yield further and explore scalability.

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