

From Waste to Wealth: Entrepreneurial Ventures in Chitosan Extraction for Environmental Sustainability

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ABSTRACT

The degradation of **water quality** in the environment can be attributed to the discharge of **wastewater** from shrimp ponds. Conversely, **solid waste** in the form of **shrimp shells** presents an entrepreneurial opportunity through the extraction of **chitosan**, a substance with the potential to enhance **water quality** while contributing to **environmental sustainability**. **Sampling** for this study was conducted at the Vannamei Nusantara Gemilang pond, located in Tambakrejo Village, Malang Regency, East Java. The research employed an **experimental methodology** with a **quantitative approach**, supplemented by a **literature review**. Various doses of **chitosan solutions** were tested on **shrimp pond wastewater**. The **optimal results** were obtained at a dosage of 80 mg/L, significantly outperforming the untreated water. The test outcomes for the 80 mg/L dosage included: **BOD (Biochemical Oxygen Demand)** at 4.62 mg/L, **Nitrite concentration** at 0.045 mg/L, **turbidity** at 3.55 NTU (Nephelometric Turbidity Units), **TSS (Total Suspended Solids)** at 14.6 mg/L, **TDS (Total Dissolved Solids)** at 2974 mg/L, **pH level** at 6.31, and **temperature** at 31.40°C. Notably, the **Total Dissolved Solids (TDS)** levels did not meet **quality standards**, highlighting the need for further process optimization. These findings emphasize the potential of **chitosan extraction** as a sustainable solution, while also underscoring the importance of continued research into the economic feasibility of this **waste-to-wealth** approach. Further studies are necessary to refine the wastewater treatment process, quantify the **economic benefits**, and ensure the long-term viability of this **entrepreneurial venture** in **environmental sustainability**.

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1. INTRODUCTION

Shrimp farming is a thriving industry in Indonesia, driven by high demand and generating an export value of approximately US\$ 1.5 billion, surpassing fish exports at US\$ 1 billion and seaweed at US\$ 0.2 billion

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[1]. One of the most popular shrimp varieties is the Vanamei shrimp, also known as white shrimp. This species is prized for its disease resistance, rapid growth, adaptability to environmental changes, and high stocking density [2].

Efforts to increase production [3] are ongoing to maximize profits, enhance production efficiency, and meet the demand for Vanamei shrimp products [4]. However, shrimp pond activities also lead to significant organic matter pollution, primarily due to the underutilization of shrimp pond waste and insufficient reprocessing efforts [5, 6]. Shrimp pond wastewater is a major waste contributor, containing various substances such as shrimp excrement, uneaten feed, and other insoluble materials, all of which require continuous processing to mitigate their environmental impact. Approximately 85% of the feed is consumed by shrimp, while 15% is wasted in pond cultivation water. Of the feed consumed, 17% becomes market-ready shrimp, 15% remains unconsumed, 20% is excreted as shrimp feces, and 48% is used for energy [7]. Proper waste management is essential to prevent the proliferation of pathogenic bacteria, which pose a threat to aquatic life [8].

Shrimp shells, another abundant waste product, represent a valuable resource for entrepreneurial ventures. These shells contain high economic value due to their potential for chitin extraction, particularly for the production of chitosan. Shrimp shells are rich in protein, minerals, and chitin [9], a polysaccharide that ranks as the second most abundant biopolymer on Earth, following cellulose. Found in the exoskeletons of shrimp and other crustaceans [10], as well as in fungal cell walls, arthropod exoskeletons, and certain mollusks [11], chitin can be transformed into chitosan through deacetylation, producing a versatile material with wide-ranging applications. Chitosan, a deacetylated form of chitin, is derived from β -1,4-N-acetyl glucosamine [12]. It has been widely used in industries such as pharmaceuticals [13, 14], food preservation [15, 16], agriculture [17, 18], cosmetics [19], and most importantly, water treatment [20–23], offering both environmental and economic benefits.

The need for clean water is fundamental for all living organisms, making water purification a key focus in environmental management and sustainability efforts [24]. Wastewater from shrimp ponds requires effective and efficient treatment processes to minimize its environmental impact and comply with regulatory standards [25]. The transformation of shrimp shells into chitosan offers a sustainable solution, as chitosan is proven to be effective in reducing water pollution and enhancing water quality, particularly in aquaculture settings [20]. By utilizing shrimp shell waste, this process not only improves environmental sustainability but also provides economic opportunities, turning waste into wealth through entrepreneurial ventures focused on chitosan extraction.

This study focuses on the "*Vannamei Nusantara Gemilang*" shrimp pond in Tambakrejo Village, Malang Regency, aiming to explore the entrepreneurial potential of extracting chitosan from shrimp shell waste to meet the demand for clean water in aquaculture. The research evaluates the characteristics of chitosan, its effects on water quality, and the impact of various chitosan doses on reducing pollutants, this research provides insights into the potential of transforming waste into wealth, aligning with broader sustainability and entrepreneurial goals.

2. THE COMPREHENSIVE THEORETICAL BASIS

2.1. Literature Review

Water quality management is fundamental in aquaculture, directly influencing the health and productivity of aquatic organisms [26]. Key parameters such as pH, turbidity, nitrite, Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), and Total Dissolved Solids (TDS) are critical indicators of water quality, and maintaining these within optimal ranges is essential for sustainable aquaculture practices [27]. Poor water quality can lead to higher disease incidence and reduced growth rates in shrimp farming, necessitating effective water treatment solutions [28].

This study aligns closely with the Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation) and SDG 12 (Responsible Consumption and Production). The extraction of chitosan from shrimp shell waste provides a sustainable solution for organic waste management while also enhancing water quality by reducing pollutants in shrimp farm wastewater [29]. This innovation promotes recycling practices in aquaculture, reducing dependence on less environmentally friendly synthetic chemicals and transforming waste into economically valuable products. The approach exemplifies how science-based methods can strengthen the circular economy, providing economic benefits to local communities while reducing the environmental impact of the aquaculture industry.

Chitosan, a natural biopolymer derived from chitin, has garnered attention for its potential in water

purification. Studies by [30] have demonstrated chitosan's efficacy in removing heavy metals and reducing turbidity in industrial wastewater, while [31] highlighted its potential in treating municipal waste, particularly in improving water clarity and reducing contaminants. By comparing our findings with these studies, we show that chitosan's versatility extends beyond aquaculture, as it proves effective in various contexts of wastewater management. Its biocompatibility, biodegradability, and non-toxicity make it an attractive alternative to synthetic chemicals in treating wastewater [32]. Various studies have demonstrated the effectiveness of chitosan in improving water quality by reducing turbidity, TSS, and BOD levels in different types of wastewater, including that from shrimp ponds [5]. The mechanisms through which chitosan operates include coagulation and flocculation, which help in the removal of suspended particles and organic matter [33].

This study specifically builds upon prior findings, such as those by [30] and [31], which demonstrated chitosan's versatility in reducing turbidity and removing heavy metals across various wastewater contexts. However, unlike earlier research that primarily addressed municipal or industrial wastewater, our research examines chitosan's application within the shrimp aquaculture sector, where unique challenges, such as organic waste from shrimp excrement and feed residues, complicate water treatment. Additionally, while previous studies confirmed chitosan's efficacy at higher doses in treating turbidity, Total Suspended Solids (TSS), and Biochemical Oxygen Demand (BOD), our findings indicate that these parameters improve most significantly at an 80 mg/L dose in shrimp wastewater [34], [35]. This research uniquely highlights chitosan's limitations in reducing Total Dissolved Solids (TDS) to meet quality standards, underscoring the need for combined treatment methods a gap in the research not addressed by [36] and others focused on non-aquaculture wastewater contexts [37]. Our study not only confirms the efficacy of chitosan at higher doses (up to 80 mg/L) in reducing parameters like BOD, turbidity, and TSS, but it also emphasizes a novel focus on the practical limitations concerning TDS levels, which have not been sufficiently addressed in earlier works.

This underscores the need for continued research to enhance the efficacy of chitosan in aquaculture water management.

2.2. Research Approach

The research employed an experimental methodology with a quantitative approach, complemented by a literature review. In this study, the independent variable was the dosage of chitosan used as a water purification agent. Meanwhile, the dependent variables consisted of various water quality parameters, including Biochemical Oxygen Demand (BOD), nitrite concentration, turbidity, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), pH level, and temperature. To maintain consistency and control in the study, the control variables included the type of solid waste and the nature of liquid waste.

2.3. Research Location and Time

The water and shrimp shell samples used in this study were collected from Tambakrejo Village, located in Malang Regency, East Java, specifically from the "Vannamei Nusantara Gemilang" shrimp pond in Figure 1. The research was conducted over a period spanning from June 18, 2023, to August 2, 2023.

The research process encompassed several laboratory-based activities. The production of chitosan and the assessment of water quality parameters such as temperature and pH were carried out at the Water Quality and Waste Treatment Laboratory, Faculty of Agricultural Technology, Brawijaya University. Evaluation of the characteristics of chitosan, including water content and ash content, was conducted by a third-party entity at the Central Laboratory of Biological Sciences, University of Brawijaya. Additionally, the degree of deacetylation, a critical aspect of chitosan quality, was assessed at the Central Laboratory of Minerals and Advanced Materials, FMIPA, State University of Malang. The examination of other water quality parameters, including BOD, nitrite, turbidity, TSS, and TDS, was outsourced to the Laboratory of Perum Jasa Tirta I Malang.

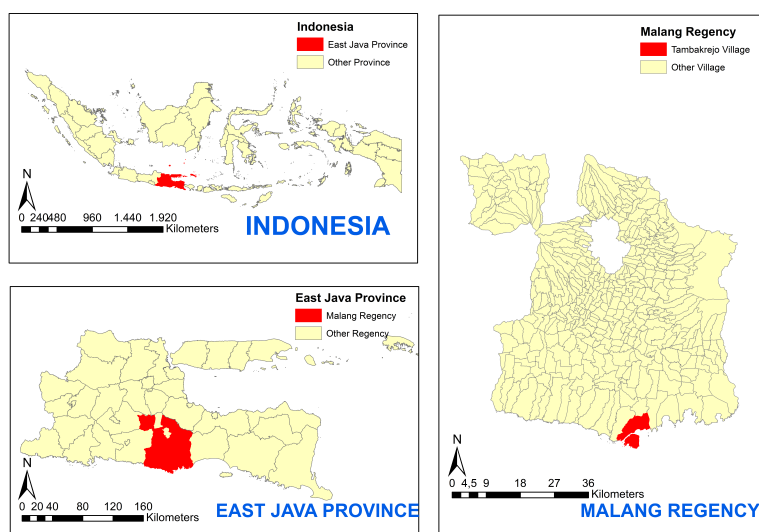


Figure 1. Orientation Map of Tambakrejo Village

As shown in Figure 1, the map provides a detailed orientation of Tambakrejo Village, located in Malang Regency, East Java. The figure highlights the exact location of the "Vannamei Nusantara Gemilang" shrimp pond, which serves as the study area for sample collection. This geographical information is crucial for understanding the environmental context in which the research was conducted, and it can serve as a reference for future studies looking to replicate or expand upon this research in similar geographical regions [38].

2.4. Tools and materials

The tools used are beaker glass, oven, blender, analytical balance, hotplate magnetic stirrer, vacuum filtration, pH meter, porcelain cup, jerry can, styrofoam box, thermometer, pipette and bulb, sample bottle, camera, filter paper, and 100 mesh sieve. The materials used included samples of shrimp pond wastewater, shrimp shells, 1% acetic acid, distilled water, 3.5% NaOH solution, 1.1 N HCl solution, 50% NaOH solution, and ice cubes.

2.5. Deproteination

The initial step of deproteination involved the thorough cleaning of shrimp shell waste. The shrimp shells were subjected to a boiling process in water at 80°C for duration of 15 minutes. Subsequently, the shells were dried in an oven at 110°C for 1 hour and then processed into a powder form using a blender. The resulting shrimp shell powder was then dissolved in a 3.5% NaOH solution at a ratio of 1:10 (grams of powder per milliliter of solution).

The solution was meticulously heated and agitated with a magnetic stirrer, maintaining a temperature of 100°C for duration of 120 minutes. Following this, the solution was allowed to cool for 30 minutes. The resulting precipitate was thoroughly washed with distilled water until reaching a neutral pH, and the precipitate was subsequently separated using vacuum filtration [39]. Finally, the precipitate was dried in an oven at 65°C for a period of 24 hours.

2.6. Demineralization

In the demineralization stage, shrimp shell powder was dissolved in a 1.1 N HCl solution at a ratio of 1:10 (grams of powder per milliliter of solution). The solution was subsequently heated and agitated using a magnetic stirrer at a temperature of 80°C for duration of 60 minutes. After this period, the solution was allowed to cool for 30 minutes. Following cooling, the precipitate was washed meticulously with distilled water until achieving a neutral pH, and the precipitate was separated by means of vacuum filtration. Finally, the resulting precipitate was dried in an oven set at 65°C for a period of 24 hours.

2.7. Deacetylation

In the deacetylation stage, shrimp shell powder was dissolved in a 50% NaOH solution at a ratio of 1:10 (grams of powder per milliliter of solution). The solution underwent heating and agitation using a

magnetic stirrer, maintaining a temperature of 110°C for a duration of 120 minutes. Following this, the solution was allowed to cool for 30 minutes. After cooling, the precipitate was thoroughly washed with distilled water until reaching a neutral pH, and the precipitate was subsequently separated by vacuum filtration [40]. Finally, the resulting precipitate was dried in an oven set at 65°C for a period of 24 hours. Shrimp shell powder was further processed by sieving it through a 100 mesh sieve. The extraction of chitosan involved the assessment of its characteristics, including color, water content, ash content, and degree of deacetylation [4]. These results were then compared with relevant chitosan quality regulations to ensure compliance. Chitosan was tested for characteristics with several parameters in SNI 7949:2013 which were tested and compared with the chitosan research results.

2.8. Making Chitosan Solution

The optimal chitosan solution was prepared with a concentration of 1%. To achieve this, 1 gram of chitosan derived from shrimp shell waste was dissolved in 100 ml of 1% acetic acid CH_3COOH solution, resulting in a primary chitosan solution with a concentration of 10,000 mg/L (1% w/v). This solution was then subjected to stirring using a magnetic stirrer for approximately 2 hours. For the experimentation, various chitosan doses were prepared, including 0 mg/L, 20 mg/L, 40 mg/L, 60 mg/L, and 80 mg/L. These doses were created by extracting 0, 2, 4, 6, and 8 mL of the primary chitosan solution and diluting them with distilled water to a final volume of 100 ml in a measuring flask. Characteristics of both chitin and chitosan were assessed, encompassing aspects such as color, moisture content, ash content, and degree of deacetylation.

2.9. Shrimp Pond Wastewater Recycling Test

To determine the optimal dosage in comparison to the quality standards for shrimp pond wastewater and clean water, several chitosan doses were tested, including 0 mg/L (control), 20 mg/L, 40 mg/L, 60 mg/L, and 80 mg/L. The testing procedure involved using glass beakers as test containers, with each beaker containing 900 ml of shrimp pond wastewater samples. A total of five containers were employed for testing. Subsequently, varying doses of chitosan were added to each container, followed by a 10-minute stirring period and a 30-minute rest interval. At each dosage level, comprehensive water quality measurements were conducted, encompassing parameters such as Biochemical Oxygen Demand (BOD), nitrite concentration, turbidity, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), pH level, and temperature. The results of the water quality tests were rigorously assessed against the established quality standards for both shrimp pond wastewater and clean water. This analysis aimed to ascertain whether the water quality parameters fell within acceptable limits as per the applicable quality standards or exceeded them. The comparison of the quality standards used is the quality standards for shrimp pond waste water based on Decree of the Minister of Maritime Affairs and Fisheries Number: Kep. 28/Men/2004. Apart from that, it is compared with clean water quality standards based on Minister of Health Regulation no. 32 of 2017 concerning Environmental Health Quality Standards and Water Health Requirements for Sanitation Hygiene, Swimming Pools, Solus Per Aqua and Public Baths.

3. RESULT AND DISCUSSION

3.1. Deproteination

The deproteination stage involves the removal of protein content from the shrimp shells. The result of this deproteination process produced a solution with distinct characteristics. Notably, the solution exhibited the formation of a few bubbles on the surface, a slight thickening of the solution's consistency, and a dark orange coloration. These observed features align with the findings of [41], who suggest that the slight thickening of the solution is indicative of the presence of released proteins from the shrimp shell powder. These proteins subsequently bind with Na^+ ions derived from the NaOH, leading to the binding of these proteins to the ends of the negatively charged protein chains.

3.2. Demineralization

The demineralization stage represents the phase in which chitin formation occurs, involving the removal of minerals from the solution. The results of the demineralization process are characterized by a solution devoid of bubbles and a light orange coloration. In accordance with the findings of [42], the demineralization process is executed employing a 1.1 N HCl solution. During this process, a reaction takes place between a calcium compound and hydrochloric acid, resulting in the production of calcium chloride, which subsequently dissolves in water. Additionally, the reaction yields CO_2 gas and HCl in water.

3.3. Deacetylation

The transformation of chitin into chitosan is accomplished through the deacetylation step, which involves the removal of the acetyl group. During the deacetylation process, the solution exhibits specific characteristics, notably the absence of bubbles and a change in color to a brownish-orange hue. According to the insights provided by [43, 44], this color change can be attributed to the formation of sodium acetate within the solution. Initially, an addition reaction takes place, with the hydroxyl group $-OH$ entering into the $NHCOCH_3$ group within the chitin molecule. Subsequently, an elimination reaction occurs, leading to the removal of the CH_3COO group $-CH_3COO^-$, resulting in the formation of an amine compound, namely chitosan.

3.4. Shrimp Shell Characteristics

The characterization of chitosan is crucial to evaluate its quality and effectiveness for various applications, particularly in water treatment and waste management. The primary parameters measured in this study include color, water content, ash content, and the degree of deacetylation [45]. These factors are vital as they influence the solubility, purity, and overall performance of chitosan in industrial processes. By comparing the results to the quality standards outlined in SNI 7949:2013, we ensure that the chitosan produced not only meets the required specifications for use in water purification but also adheres to national guidelines for other potential applications, such as in pharmaceuticals or food preservation. The test results for these chitosan characteristics, alongside their comparison to the standard requirements, are detailed in Table 1.

Table 1. Parameter Results of Chitosan Characteristics

Parameter	Quality Requirements	Test results
Color	Light Brown – White	White
Water content	Maximum 12%	12.08%
Ash Content	Maximum 5%	8.34 %
Degree of Deacetylation	Minimum 75%	Domszy and Robert = 57.2% Baxter = 47.1%

As shown in Table 1, the test results for the chitosan characteristics highlight both areas of compliance and deviations from the established quality standards, particularly regarding water content and ash content. These findings underscore the importance of refining the production process to ensure that the resulting chitosan meets the full spectrum of quality requirements for industrial applications. The color parameter was assessed through direct observation by the researchers, revealing that the resulting chitosan exhibited a white color [46]. This color aligns with the quality requirements for chitosan, which specify a range from light brown to white. It's noteworthy that chitosan extraction did not include a depigmentation stage, as the demineralization stage using HCl effectively removed the orange coloration, leaving the chitosan in a light beige state [47] note that the depigmentation stage aims to eliminate color, particularly red-orange astaxanthin, a type of carotenoid, from chitin powder.

The water content parameter was tested, yielding a result slightly exceeding the maximum quality requirement of 12%. Achieving a water content below this threshold would maximize the utility of chitosan. The high concentration of NaOH used can lead to cell wall softening, which increases permeability and facilitates water release from the cell wall, aiding in the drying process. Utilizing a wide-surface pan during drying enhances evaporation, expediting the drying time [48].

The ash content produced in the test exceeded quality requirements, with a difference in yield greater than 3.34%. This discrepancy suggests that the ash content does not align with quality standards, likely due to uneven heat distribution during stirring at the demineralization stage [49]. Consistent stirring is crucial to prevent the creation of an imperfect solvent. Additionally, inappropriate pH adjustment during shrimp shell powder washing can lead to the wastage of minerals when separated from the material [50].

The degree of deacetylation serves as a pivotal quality determination in chitosan parameter testing. A higher degree of deacetylation indicates the loss of more acetyl groups. Fourier Transform Infrared (FTIR) spectroscopy was utilized to analyze the functional groups present in shrimp shell chitosan and determine the degree of deacetylation. FTIR analysis results in Figure 2.

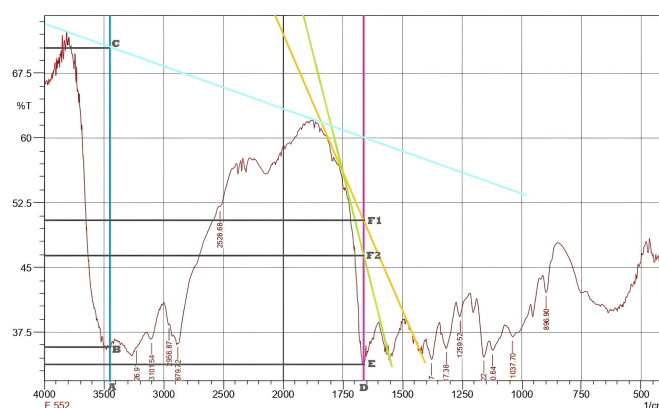


Figure 2. Deacetylation Degree Test Graph with FTIR Spectra

As shown in Figure 2, the FTIR spectra illustrate the characteristic peaks corresponding to the functional groups present in shrimp shell chitosan, which are used to determine the degree of deacetylation. The absorption bands at specific wavenumbers indicate the presence of key functional groups such as amine ($-\text{NH}_2$) and hydroxyl ($-\text{OH}$) groups, which play a critical role in the deacetylation process. The degree of deacetylation, calculated from the FTIR data, reveals the extent of acetyl group removal, with higher values indicating a more effective conversion of chitin into chitosan. This analysis is crucial in assessing the quality and potential applications of the chitosan produced in this study.

According to [51] the structure of chitosan contains several functional groups including $-\text{OH}$ groups, $\text{CH}(\text{sp}^3)$, and $-\text{NH}_2$ groups. In Table 2, the absorption vibrations at wave numbers $2879.72\text{--}2956.87\text{ cm}^{-1}$ appear in the CH group in aliphatic CH_2 . The presence of a $-\text{CH}_3$ group bound to an amide, absorption with a wave number of 1377.17 cm^{-1} indicates that chitosan still contains chitin. The absorption band at wave number $3101.54\text{--}3226.91\text{ cm}^{-1}$ shows overlapping stretching vibrations of $-\text{OH}$ and NH_2 stretching. The COC absorption band is found at wave numbers $1120.64\text{--}1259.52\text{ cm}^{-1}$.

Table 2. Comparison of FTIR Spectra Result Data with Literature Absorption

Functional groups	Wave Number (cm^{-1})	
	Literature	Isolation Results
OH stretches	3000 - 3600	3101.54-3226.91
NH bending	1550 - 1640	Do not appear
COC	1080 - 1300	1120.64-1259.52
CH stretching	2800 - 2960	2879.72-2956.87
CH bending	1350 - 1470	1377.17

As illustrated in Table 2, the FTIR spectra results provide a detailed comparison between the literature values and the isolated results for various functional groups. Notably, the NH bending group does not appear in the FTIR spectra, which, according to [52], is likely due to overlap with the $-\text{CH}_3$ amide functional group, as indicated by the broad absorption band at 1377.17 cm^{-1} . This finding suggests that the chitosan still retains some chitin characteristics, highlighting the importance of further refining the deacetylation process to improve purity.

Building on the analysis of functional groups, the degree of deacetylation was calculated using both the Domszy and Robert method and the Baxter method, as shown in Table 3. The degree of deacetylation is a critical parameter in determining the effectiveness of the chitin-to-chitosan conversion process. The Domszy and Robert method resulted in a degree of deacetylation of 57.2%, while the Baxter method produced a lower value of 47.1%. This discrepancy can be attributed to the different calculation approaches used by each method, with Domszy and Robert focusing on the carbonyl region and Baxter on the amide region. These results emphasize the need for consistent methodology when assessing deacetylation, as variations in calculation can significantly impact the reported values.

The values obtained from both methods indicate that the chitosan produced has not yet reached the op-

timal degree of deacetylation (above 75%), as outlined in quality standards, suggesting that further optimization of the deacetylation process is necessary to enhance its quality and functionality.

Table 3. Data for Calculation of Degrees of Deacetylation

Information	Domszy and Robert (%)	Baxter (%)
DF1	50.125	-
DF2	-	46.5
DE	33.75	33.75
AC	70.5	70.5
AB	35.125	35.125
Degree of Deacetylation	57.2	47.1

As shown in Table 3, the degree of deacetylation values obtained using both the Domszy and Robert method (57.2%) and the Baxter method (47.1%) indicate that the chitosan produced in this study does not meet the desired deacetylation level of at least 75%, as required for high-quality chitosan. The differences between the two methods can be attributed to the distinct ways each method calculates deacetylation, with Domszy and Robert focusing on the carbonyl region, and Baxter emphasizing the amide region of the FTIR spectra. This highlights the importance of choosing an appropriate method for determining deacetylation, as different methods can yield varying results.

3.5. Baseline by Domszy and Robert

The degree of deacetylation is a crucial metric for evaluating the quality of chitosan, as it influences many of its functional properties such as solubility, reactivity, and effectiveness in various industrial applications. The most commonly used method to determine the degree of deacetylation is based on the infrared (IR) spectrum, specifically the absorbance ratio between the amide and hydroxyl groups.

In this study, the Domszy and Robert method was applied to calculate the degree of deacetylation, as shown in Equation (1). This method utilizes the absorbance ratio of the amide (A_{1655}) and hydroxyl (A_{3450}) groups in the FTIR spectrum:

$$\text{Degree of Deacetylation} = 100 \left[\frac{A_{1655}}{A_{3450}} \times 100 \right] \frac{1}{1.33} \quad (1)$$

By counting:

$$(A_{1655}) \text{ amides} = \log \left(\frac{10^{D_{A1}}}{DE} \right) \quad (2)$$

$$(A_{3450}) \text{ hydroxyl} = \log \left(\frac{10^{A1}}{AB} \right) \quad (3)$$

Equation (2) presents the calculation for the amide group absorbance (A_{1655}), which correlates with the presence of acetyl groups in chitin. This absorbance is influenced by the degree of deacetylation, as the reduction of acetyl groups leads to a lower A_{1655} value. Similarly, Equation (3) shows the calculation for the hydroxyl group absorbance (A_{3450}), which reflects the presence of hydroxyl groups formed during the deacetylation process.

These equations highlight the relationship between the absorbance of specific functional groups and the degree of deacetylation, providing a quantitative means to assess the extent of chitosan conversion from chitin. By applying these formulas, we can accurately determine the quality of the chitosan produced, ensuring that it meets the desired specifications for industrial applications.

3.6. Baseline by Baxter

Another widely recognized method for calculating the degree of deacetylation is the Baxter method. This method, similar to the Domszy and Robert approach, relies on the ratio of the absorbance of the amide (A_{1655}) and hydroxyl (A_{3450}) groups obtained from the FTIR spectra. However, the Baxter method applies a different constant multiplier (115), as shown in Equation (4), to account for differences in the calibration of the amide and hydroxyl groups:

$$\text{Degree of Deacetylation} = 100 \left[\frac{A_{1655}}{A_{3450}} \times 115 \right] \quad (4)$$

By counting:

$$(A_{1655}) \text{ amides} = \log \left(\frac{10^{B2}}{DE} \right) \quad (5)$$

$$(A_{3450}) \text{ hydroxyl} = \log \left(\frac{10^{C2}}{AB} \right) \quad (6)$$

In Equation (5), the absorbance of the amide group (A_{1655}) is calculated to determine the amount of residual acetyl groups present in the sample. This calculation is crucial for understanding the extent to which the chitin has been deacetylated. Similarly, equation (6) calculates the absorbance of the hydroxyl group (A_{3450}), which increases as deacetylation progresses, indicating the formation of more hydroxyl groups in the structure.

These equations from the Baxter method provide an alternative way of determining the degree of deacetylation, which may result in slightly different values compared to the Domszy and Robert method due to the use of different constants and formula structures. The comparison of these two methods allows for a more comprehensive understanding of the chitosan quality and the efficiency of the deacetylation process. By applying both methods, we can ensure the reliability and accuracy of the results, as discrepancies between the methods can highlight areas for optimization in the production process.

3.7. Characteristics of Shrimp Pond Waste Water

The results of research on the potential of chitosan for water purification are presented in Table 4. Various doses of chitosan were used to determine the quality of the parameter test results.

Table 4. Parameter Test Results in the Effect of Adding Various Doses of Chitosan

Parameter	Quality Standards	Chitosan Dosage (mg/L)				
		0	20	40	60	80
Waste Water Parameters						
pH	6-9	7.32	7.20	6.85	6.54	6.31
Turbidity (NTU)	≤ 50	23.5	18.0	8.06	8.39	3.55
Nitrit (mg/L)	<2.5	0.0543	0.7247	0.0415	0.0468	0.0455
TSS (mg/L)	≤ 200	282.0	56.3	33.4	28.5	14.6
BOD (mg/L)	<45	25.62	8.52	8.33	8.40	4.62
Clean Water Parameters						
pH	6.5-8.5	7.32	7.20	6.85	6.54	6.31
Turbidity (NTU)	25	23.5	18.0	8.06	8.39	3.55
Nitrite (mg/L)	1	0.0543	0.7247	0.0415	0.0468	0.0455
Temperature (o C)	Air temperature ± 3	32.10	30.70	30.20	30.00	31.40
TDS (mg/L)	1000	16064	8038	6419	5914	2974

Several parameters of the quality standard of shrimp pond wastewater were tested to determine whether the wastewater was appropriate or not before the study was carried out without re-processing in its sustainability. As shown in Table 4, clean water parameters were also tested to assess the success of treating shrimp pond wastewater with various doses of chitosan, aiming to process the purification into clean water [53]. The control dose (0 mg/L) or no treatment of the overall parameter test results for TSS and TDS did not meet the ideal quality standards, while other parameters remained within acceptable limits that did not exceed the quality standard values for wastewater and clean water.

Biochemical Oxygen Demand or BOD is a measurement of water quality based on the need for the amount of dissolved oxygen in water to break down waste materials [54]. The test results for each additional dose of chitosan that is getting bigger, the BOD value continues to decrease. From the highest control value of 25.62 mg/L decreased to the lowest value at a dose of 80 mg/L of 4.62 mg/L. The higher the BOD value, the greater the degree of water pollution.

Nitrite (NO_2) is part of the nitrogen cycle. Nitrite is a chemical compound whose form is intermediate between ammonia and nitrate. The nitrite content will endanger health if used or consumed in everyday life [55]. The resulting nitrite resulted in an unstable number where at the control dose it was 0.0543 mg/L and it experienced a large increase at the 20 mg/L dose of 0.7247 mg/L, then decreased again to 0.0415 mg/L at 40 mg/L.

Water turbidity is caused by suspended colloidal particles. The water will look dirty, muddy and not clear. Turbidity is not a measure of color or can be called a measure of water clarity [56]. Turbidity from the control dose to the highest dose continued to decrease with the lowest turbidity value at the highest dose of 80 mg/L of 3.55 NTU.

Total Suspended Solid (TSS) as a measure of water quality parameters contained residual suspended solids causing water turbidity with suspended solids in diameter ($> 10^{-3}$ mm) and retained on filter paper with a pore size of 0.45 micrometers in diameter. The higher the TSS value, the worse the water quality. The TSS at the control dose exceeded the applicable quality standards, after administration of doses from 20 mg/L to 80 mg/L the TSS value continued to decrease with the lowest value at a dose of 80 mg/L of 14.6 mg/L.

Total Dissolved Solid (TDS) is a water quality parameter related to the solubility of solids in unfiltered water at a pore size of 0.45 micrometers in filter paper. The higher the TDS value, the higher the turbidity and water pollution. Chitosan dosing is only given as a TDS parameter where all doses exceed the applicable quality standards, however, with larger doses, the TDS value continues to decrease. Chitosan has been proven to possess antimicrobial properties, as supported by research conducted by [57], which demonstrated its ability to inhibit the growth of pathogenic bacteria in wastewater. Moreover, chitosan's ability to chelate heavy metals presents potential for chemical remediation beyond physical purification. This dual action of physical and chemical treatment makes chitosan a versatile solution for comprehensive wastewater management.

There are three types of acidity (pH), namely neutral, acidic and basic. Good water quality has a pH of 7 (neutral). A pH value of less than 7 is acidic and a value of more than 7 is alkaline. The more OH^- ions there are in water, the higher or more alkaline the pH will be. Meanwhile, the more H^+ ions there are, the lower or more acidic the pH will be. The pH value decreased with each dose of chitosan. The pH value is still within the range in accordance with quality standards.

Temperature is a parameter measuring the hotness or coldness of the water being tested. Factors that can affect changes in temperature include season, time of day, cloud cover, water flow and depth, and so on. The resulting temperature corresponds to the air temperature of $\pm 3^\circ\text{C}$ from the test room temperature of 32.10°C .

In addition to the TSS value at the control dose and the TDS parameter at all chitosan doses, the other parameter test results are appropriate and ideal in the quality standards of shrimp pond wastewater and clean water. Various doses of chitosan in the test results for parameter values produced the best value, namely at a dose of 80 mg/L.

3.8. Problem

This study identified several water quality issues in untreated shrimp pond wastewater, specifically high levels of Total Suspended Solids (TSS), Total Dissolved Solids (TDS), and Biochemical Oxygen Demand (BOD). These parameters did not meet the ideal quality standards, indicating significant water pollution. This Study have compared the use of chitosan with other existing solutions in the field of aquaculture wastewater treatment. For instance, while traditional methods such as chemical coagulants (e.g., aluminum sulfate) and biological treatments like activated sludge are effective in reducing some water pollutants, they come with limitations such as high cost, sludge production, and potential toxicity. In contrast, chitosan's natural biopolymer properties offer a biodegradable, non-toxic alternative, which has been shown to be highly effective in reducing suspended solids, turbidity, and even some heavy metals. Additionally, chitosan's flocculation ability complements biological treatments by enhancing solid removal, making it a versatile and more sustainable solution in aquaculture wastewater treatment. The challenge was to determine if treating the wastewater with various doses of chitosan could improve water quality to acceptable levels.

3.9. Research Implementation

To address the identified issues, different doses of chitosan (ranging from 20 mg/L to 80 mg/L) were applied to the wastewater. Results showed significant improvements in water quality. BOD decreased from 25.62 mg/L in the control sample to 4.62 mg/L at 80 mg/L of chitosan. TSS levels also dropped, reaching 14.6 mg/L at 80 mg/L. Turbidity reduced to 3.55 NTU at the highest dose. Although TDS levels remained above

standards, they showed a decreasing trend with higher doses. The pH values remained within acceptable limits, and the temperature stayed stable.

In addition to its effects on physical parameters, chitosan treatment offers promising chemical and microbiological benefits for wastewater management. Research has shown that chitosan can act as a chelating agent, binding to heavy metals and reducing their presence in water, which is crucial for chemical pollutant mitigation in aquaculture environments [43]. Chitosan also has inherent antimicrobial properties that can inhibit the growth of pathogenic bacteria and other harmful microorganisms commonly found in aquaculture wastewater, thereby potentially lowering disease risks among aquatic species [57]. Incorporating chitosan's chemical and microbial impact into wastewater treatment could enhance its overall effectiveness, providing an integrated solution to physical, chemical, and biological water quality concerns.

4. MANAGERIAL IMPLICATIONS

The findings suggest practical applications for the aquaculture industry. Implementing chitosan treatment can significantly improve water quality, promoting healthier shrimp farming environments. Beyond its application in water treatment, chitosan production from shrimp shell waste exemplifies a sustainable approach to waste recycling, significantly reducing organic waste in the aquaculture industry. By converting shrimp shells into a valuable biopolymer, this process not only mitigates the environmental burden of shell waste but also supports circular economy principles by transforming by-products into commercially viable resources. Additionally, this method aligns with broader environmental goals by reducing landfill use and decreasing the demand for synthetic polymers, which are often less biodegradable. Therefore, chitosan serves as an environmentally friendly alternative that promotes overall sustainability and resource efficiency in aquaculture and beyond.

This process can also be scaled up for industrial wastewater treatment, particularly in sectors dealing with high levels of organic waste, such as food processing and agriculture. In aquaculture, this approach could be adapted to other forms of waste, such as fish farming, where managing solid and liquid waste is a challenge. The scalability of this method will depend on optimizing chitosan production processes to ensure cost-effectiveness and feasibility at industrial levels. The scalability of chitosan-based wastewater treatment extends beyond shrimp aquaculture, holding potential for application in other forms of aquaculture, such as fish farming, where solid and liquid waste management remains a challenge. In fish farming, for instance, chitosan's effectiveness in reducing organic matter, pathogens, and heavy metals could help improve water quality and support more sustainable practices. Furthermore, this process could be adapted to industrial sectors with high levels of organic waste, including food processing, agriculture, and dairy production, by modifying the chitosan dose or combining it with other treatment agents specific to each industry's waste profile. This adaptability makes chitosan treatment a promising solution not only for aquaculture but also for industries aiming to implement environmentally friendly waste management solutions. This approach supports sustainable practices, helps comply with environmental regulations, and provides a cost-effective alternative to synthetic chemicals.

To enhance the practical relevance of this research, a thorough cost-benefit analysis should be included to evaluate the economic feasibility of chitosan production from shrimp shell waste. This analysis could detail the production costs, including raw materials, labor, equipment, and energy consumption, against potential profits from selling chitosan for various applications in water treatment, agriculture, and pharmaceuticals. Furthermore, examining the long-term financial sustainability, such as the break-even point and profit margins, would provide insight into the scalability of chitosan production for industries seeking both environmental and economic benefits. Such an analysis could offer valuable information to stakeholders considering chitosan as an alternative to more expensive or less sustainable treatment options.

5. CONCLUSION

The attributes of chitosan, including its water content, ash content, and degree of deacetylation, play a pivotal role in determining its suitability and quality for specific applications. Ensuring that these values align with appropriate chitosan quality requirements is imperative, as it has a direct impact on the efficiency of recycling shrimp pond wastewater. Optimal chitosan quality is paramount for maximizing the recycling process, particularly in the context of shrimp pond wastewater treatment. The most effective recycling process was observed at a chitosan dose of 80 mg/L. Despite notable improvements in various water quality parameters, such as Biochemical Oxygen Demand (BOD), nitrite, turbidity, Total Suspended Solids (TSS), pH, and tempera-

ture, it's noteworthy that certain parameter values did not meet the quality standard regulations. Specifically, the Total Dissolved Solids (TDS) test results did not align with the quality standards, and values exceeding the stipulated standards were observed in tests conducted with various chitosan doses. This outcome suggests that while chitosan effectively reduces many water quality parameters, it may need to be combined with other treatment agents, such as activated carbon or ion exchange resins, to address high TDS levels.

Although chitosan treatment proved effective in reducing many pollutants, its limitations in lowering TDS levels to acceptable standards suggest that a combined treatment approach may be necessary for comprehensive wastewater purification. For instance, combining chitosan with activated carbon could enhance TDS reduction through adsorption processes, as activated carbon is highly effective in trapping dissolved organic and inorganic particles. Similarly, incorporating ion exchange resins or membrane filtration might be valuable in selectively removing specific ions contributing to TDS. Future research could focus on optimizing these combined treatments to create a more efficient and sustainable solution tailored to the aquaculture industry's wastewater needs.

6. DECLARATIONS

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Conceptualization: LS; Methodology: MS; Software: MV; Validation: LS and MS; Formal Analysis: EK and NP; Investigation: LS; Resources: MS; Data Curation: MS; Writing Original Draft Preparation: MV and EK; Writing Review and Editing: MV and NK; Visualization: MS; All authors, LS, MS, MV, NP, NA, EK, and NK, have read and agreed to the published version of the manuscript.

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The data presented in this study are available on request from the corresponding author.

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6.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

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