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Comparative Evaluation of Chitosan Extraction from Mud Crab (*Scylla paramamosain*) Shells: Yield, FTIR Characterization, and Degree of Deacetylation

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ABSTRACT

Crab shell waste is a potential source of chitin and chitosan that can be converted into value-added biopolymers for food applications. This study aimed to compare two extraction methods for producing chitosan from mud crab (*Scylla paramamosain*) shells and to evaluate the resulting chitosan based on yield, Fourier Transform Infrared (FTIR) characteristics, and degree of deacetylation (DD). Crab shells were subjected to extraction methods modified from Narudin *et al.* (2020) and Pambudi *et al.* (2018), involving deproteinization, demineralization, deacetylation, filtration, washing, and drying under different treatment conditions. The chemical composition of the crab shell showed 6.71 ± 0.02% moisture, 9.48 ± 0.08% protein, 0.19 ± 0.00% fat, 70.11 ± 0.01% ash, and 10.40 ± 0.09% dietary fiber. Pambudi *et al.,* 2018 method produced higher chitin and chitosan yields of 94.50 ± 4.10% and 80.20 ± 8.49%, respectively, compared with 87.50 ± 1.41% and 32.30 ± 15.42% obtained using Narudin *et al.,* 2020 method. However, Narudin *et al.,* 2020 method resulted in a higher mean DD of 57.96 ± 15.07%, compared with 29.66 ± 8.04% for Pambudi *et al.,* 2018 method. FTIR spectra showed characteristic hydroxyl, amine, amide, and C–O–C/C–O functional groups in the extracted products. Overall, Pambudi *et al.,* 2018method was more effective for chitosan recovery, whereas Narudin *et al.,* 2020 method produced chitosan with a higher degree of deacetylation. Further optimization is needed to improve DD while maintaining high chitosan recovery.

INTRODUCTION

Mud crab (*Scylla* spp.), particularly *Scylla paramamosain*, is one of the most commercially valuable marine species across the Indo-Pacific region, with extensive aquaculture development reported in China, Indonesia, Vietnam, Singapore, and neighbouring countries (Li *et al.,* 2018; Feng *et al.,* 2025). As sustainability and circular bioeconomy principles gain increasing attention in fisheries and aquaculture, the utilization of processing by-products has emerged as a promising strategy to mitigate environmental impacts while simultaneously producing value-added bioproducts for food, biomedical, and industrial applications (Ma *et al.,* 2020; Arvanitoyannis and Kassaveti, 2008; Nisticò, 2017). Among various applications, the extraction of chitin and its derivative chitosan from mud crab shells has gained particular attention due to the biodegradability, biocompatibility, and antimicrobial properties of these materials (Romainor *et al.,* 2014; Yusof *et al.,* 2019).

Crustacean shell waste is an underutilized by-product of seafood processing and represents an important source of chitin and other valuable components. The recovery of chitin

and its derivatives from these residues has gained increasing attention because it provides an opportunity to convert an underutilized waste stream into value-added biopolymers while reducing the environmental burden associated with shell disposal (Amiri *et al.,* 2022; Nirmal *et al.,* 2024). Crustacean shells are particularly suitable as raw materials for chitin production because chitin is one of their major structural components, together with proteins and inorganic minerals. The valorization of crustacean waste into chitin and chitosan has consequently become an important research area within marine biomass utilization and circular bioeconomy strategies.

Conventional chitosan production from crustacean shells generally involves sequential demineralization, deproteinization, and alkaline deacetylation. Demineralization removes inorganic minerals, predominantly calcium carbonate, while deproteinization removes proteinaceous components from the shell matrix. The resulting chitin is subsequently converted into chitosan through alkaline deacetylation. Although conventional chemical extraction remains widely used because of its relatively simple processing requirements, the efficiency of each extraction stage depends on factors such as acid and alkali concentration, temperature, reaction time, and solid-to-liquid ratio. Consequently, variations in extraction conditions can affect both material recovery and the physicochemical characteristics of the resulting chitosan (Mohan *et al.,* 2022; Hosney *et al.,* 2022).

Recent studies have demonstrated that modification of individual extraction stages can substantially influence chitin and chitosan recovery. In crab-shell processing, optimization of demineralization conditions has been shown to affect the recovery and characteristics of the extracted chitosan, including ash content, FTIR characteristics, and degree of deacetylation (Luthfiyana *et al.,* 2022). Similarly, Gîjiu *et al.* (2022) demonstrated that optimization of chitin extraction from crab shells could be used to control the properties of the resulting chitosan, including its degree of deacetylation and molecular characteristics. These findings indicate that the extraction procedure is not merely a means of recovering chitinous material but is also an important determinant of the characteristics of the final chitosan product.

The deacetylation stage is particularly important because the removal of acetyl groups determines the degree of deacetylation (DD) of chitosan. DD is affected by processing variables such as NaOH concentration, temperature, and reaction time. In a study using mud crab shells, Narudin *et al.* (2022) demonstrated that the DD of chitosan increased nonlinearly with deacetylation time and that the deacetylation process was influenced by temperature and NaOH concentration. These findings highlight the importance of controlling deacetylation conditions when producing chitosan with specific chemical characteristics. In addition, chemical extraction studies on different crab species have shown that differences in raw material and processing conditions can result in variation in chitin yield, chitosan yield, solubility, and DD (Narudin *et al.,* 2022; Wahab *et al.,* 2023).

Along with yield, structural characterization is necessary to evaluate the products obtained from different extraction procedures. Fourier Transform Infrared (FTIR) spectroscopy is commonly used to identify characteristic functional groups of chitin and chitosan and to evaluate structural changes associated with deacetylation. Recent studies on crab-derived chitosan have used FTIR together with yield and DD measurements to characterize the extracted polymers, demonstrating that FTIR can confirm the presence of characteristic hydroxyl, amino, and amide-related functional groups (Luthfiyana *et al.,* 2022; Wahab *et al.,* 2023). Therefore, evaluating extraction performance through yield alone may not sufficiently describe the characteristics of the resulting chitosan, and structural characterization should be considered together with recovery and DD.

Although recent research has explored optimization and alternative approaches for chitin and chitosan extraction, conventional chemical extraction remains relevant because it provides a practical route for laboratory-scale production using commonly available reagents and equipment. At the same time, recent studies have attempted to simplify chemical extraction procedures and reduce chemical consumption while maintaining the physicochemical characteristics of the resulting chitosan (Liyanage *et al.,* 2023). These developments

demonstrate that differences in extraction sequence and processing severity can influence the balance between material recovery and product characteristics. Consequently, comparison of established extraction procedures remains useful for determining which procedure provides a more favorable outcome for a particular raw material and intended chitosan characteristic.

For *S. paramamosain*, the shell represents a potential source of chitin and chitosan, but the performance of an extraction procedure cannot be evaluated solely from the amount of material recovered. A method producing higher chitosan recovery may not necessarily provide a higher degree of deacetylation, while conditions that promote greater deacetylation may also result in greater material loss. This consideration is particularly relevant when comparing extraction procedures that differ in acid and alkali concentration, treatment temperature, reaction time, and solid-to-liquid ratio. Therefore, evaluating chitin yield, chitosan yield, chitosan recovery, FTIR characteristics, and DD together provides a more comprehensive basis for assessing extraction performance.

In this study, two conventional extraction procedures modified from Narudin *et al.* (2020) and Pambudi *et al.* (2018) were comparatively evaluated for the production of chitin and chitosan from *S. paramamosain* shells. The study first characterized the raw shell material through proximate composition analysis and subsequently compared the two extraction procedures based on chitin yield, chitosan yield, chitosan recovery from chitin, FTIR characteristics, and degree of deacetylation. The objective was to determine the differences in extraction performance between the two procedures and to identify the relative advantages of each method in terms of material recovery and degree of deacetylation.

METHOD

Raw Material and Sample Preparation

Mud crab (*Scylla paramamosain*) shells were collected from a local fish market in Pattani, Thailand, with approximately 1–2 kg of shells obtained. The shells were thoroughly washed with water to remove mud, dust, residual meat, and other impurities, and then dried in an oven at 50 °C for 48 h. The dried shells were crushed and ground using a mortar and pestle and then sieved through a No. 60 stainless-steel sieve (250 μm aperture). The resulting shell powder was collected and used for subsequent analyses and chitin extraction. For preliminary analyses and method optimization, approximately 10 g of shell powder was used for each experimental procedure.

Proximate Composition of Crab Shell

The proximate composition of *S. paramamosain* shell powder was determined by analyzing the moisture, protein, fat, ash, and dietary fiber contents. The results were expressed as percentages on a dry-weight basis. Protein content was calculated using a nitrogen-to-protein conversion factor of 6.25. The proximate composition was determined to characterize the raw material prior to chitin and chitosan extraction.

Extraction of Chitin and Chitosan

Two chemical extraction procedures were evaluated to compare their effectiveness in producing chitin and chitosan from *S. paramamosain* shells. The procedures were modified from Narudin *et al.* (2020) and Pambudi *et al.* (2018). Both procedures consisted of chemical treatments to remove non-chitin components followed by alkaline deacetylation to produce chitosan.

Extraction Method Based on Narudin *et al.* (2020)

The chitin extraction procedure was modified from Narudin *et al.* (2020). In the original method, demineralization was performed before deproteinization, whereas in the modified method, deproteinization was carried out first, followed by demineralization. In both methods, deproteinization was conducted using 5% NaOH at a solid-to-liquid ratio of 1:10 (w/v), with continuous stirring at 90–95 °C for 6 h. Demineralization was performed using 1 N HCl at a solid-to-liquid ratio of 1:10 (w/v) for 3 h.

Several procedural changes were also introduced. In the original method, the solid fractions were filtered under vacuum and washed with distilled water until pH 7. In the modified method, Whatman® filter paper was used for filtration, followed by repeated washing with distilled water until a neutral pH was reached. An additional acetone treatment was included in the modified method for decolorization. The material was treated with acetone for 10 min, washed with distilled water, and then dried at 60 °C for 24 h.

For deacetylation, the original and modified methods used the same conditions: 40% NaOH at a chitin-to-solution ratio of 1:15 (w/v), with continuous stirring at 105 °C for 2 h. However, the modified method used Whatman® filter paper for filtration and repeated washing with water until a neutral pH was reached. The resulting chitosan was dried at 40 °C for 48 h.

Extraction Method Based on Pambudi *et al.* (2018)

The extraction procedure was modified from Pambudi *et al.* (2018). In the original method, 50 g of crab shell powder was demineralized using 500 mL of 7% HCl (v/v) for 24 h, followed by deproteinization with 10% NaOH (w/v) at a solid-to-liquid ratio of 1:10 (w/v) for 24 h at 60 °C. In the modified method, the sample size was reduced to 10 g of crab shell powder, and the volume of 7% HCl was reduced proportionally to 100 mL, maintaining the original solid-to-liquid ratio of 1:10 (w/v). The deproteinization conditions were kept the same as those of the original method.

The deacetylation procedure was also modified. The original method used 50% NaOH at a solid-to-liquid ratio of 1:10 (w/v), with stirring at 500 rpm for 10 h at temperatures of 60, 70, 80, 90, and 100 °C. In the modified method, deacetylation was carried out at 90 °C for 10 h with continuous stirring at 500 rpm. Thus, 90 °C was selected as the deacetylation temperature instead of testing the five temperatures used in the original method. The filtration, neutralization, and drying procedures were performed as described in the modified method.

Determination of Chitin and Chitosan Yield

The yield of chitin was determined based on the weight of dried chitin obtained relative to the initial weight of crab shell powder. Chitosan yield was calculated based on the weight of dried chitosan relative to the initial weight of crab shell powder. Chitosan recovery from chitin was calculated based on the weight of chitosan obtained relative to the weight of extracted chitin.

The yield and recovery were calculated using the following equations:

1. Chitin Yield (%) :

$$Chitin\ Yield\ (\%) = \frac{Weight\ of\ dried\ chitin\ (g)}{Initial\ weight\ of\ crab\ shell\ powder\ (g)}\ X\ 100$$

2. Chitosan Yield (%) :

$$Chitosan\ Yield\ (\%) = \frac{Weight\ of\ dried\ chitosan\ (g)}{Initial\ weight\ of\ crab\ shell\ powder\ (g)}\ X\ 100$$

3. Chitosan Recovery from Chitin(%) :

$$Chitosan\ Recovery\ (\%) = \frac{Weight\ of\ dried\ chitosan\ (g)}{Weight\ of\ extracted\ chitin\ (g)}\ X\ 100$$

Fourier Transform Infrared Spectroscopy Analysis

The chemical functional groups of the extracted chitosan were characterized using Fourier Transform Infrared (FTIR) spectroscopy following the method described by Varan (2017), with modifications. FTIR analysis was performed using a Bruker Tensor 27 FTIR spectrometer equipped with an attenuated total reflectance (ATR) accessory. The samples were directly placed onto a germanium (Ge) crystal. Spectra were recorded over the wavenumber

range of 1000–4000 cm^{-1} at a resolution of 4 cm^{-1}, with 16 scans accumulated for each sample. The spectra were processed using OPUS (OPtical User Software).

The characteristic absorption bands were identified based on their corresponding functional groups, including O–H/N–H stretching, C–H stretching, amide I, amide II, and C–O–C/C–O stretching. The resulting spectra were compared between the two extraction methods to evaluate similarities and differences in the chemical structure of the extracted chitosan.

Determination of Degree of Deacetylation

The degree of deacetylation (DD) of the extracted chitosan was determined from the FTIR spectra according to the method described by Varan (2017), with modifications, using the absorbance ratio between the amide I band at 1665 cm^{-1} and the hydroxyl band at 3450 cm^{-1}. The calculation was based on the equation adapted from Baxter *et al.* (1992).

The degree of deacetylation was calculated using:

$$\%DD = 100 - [(\frac{A1655}{A3450})x100/1.33)]$$

where (A_1665) represents the absorbance at 1665 cm^{-1} and (A_3450) represents the absorbance at 3450 cm^{-1}. DD was determined for each replicate and expressed as mean ± standard deviation.

Statistical Analysis

The experimental results were expressed as mean ± standard deviation. Chitin yield, chitosan yield, chitosan recovery from chitin, and degree of deacetylation obtained from the two extraction procedures were compared. Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 26 (IBM Corporation, New York, NY, USA). Differences between the extraction procedures were analyzed using one-way analysis of variance (ANOVA). When significant differences were detected, means were separated using the Least Significant Difference (LSD) test. Differences were considered statistically significant at $p < 0.05$.

RESULT AND DISCUSSION

Proximate Analysis

The proximate analysis showed that the shell of *Scylla paramamosain* contained 6.71 ± 0.02% moisture, 9.48 ± 0.08% protein, 0.19 ± 0.00% fat, 70.11 ± 0.01% ash, and 10.40 ± 0.09% dietary fiber. As shown in Table 1, the high ash content indicates that the crab shell is predominantly composed of inorganic minerals, particularly calcium carbonate, which is a major mineral component of crustacean exoskeletons. Therefore, demineralization is an essential step in the extraction of chitin from crab shell.

Table 1 Proximate Analysis

Analysis Parameters	*S. paramamosain*
Moisture content (%)	6.71 ± 0.02
Protein content (%) (CF = 6.25)	9.48 ± 0.08
Fat content (%)	0.19 ± 0.00
Ash content (%)	70.11 ± 0.01
Dietary fiber (%)	10.40 ± 0.09

The relatively low fat content (0.19 ± 0.00%) indicates that lipid components were present only in a small proportion of the raw material. Meanwhile, the protein content of 9.48 ± 0.08% demonstrates that crab shell contains a considerable amount of protein that needs to be removed during the deproteinization process. In chitin extraction, the removal of mineral and protein components is important because residual inorganic and protein materials can affect the purity and physicochemical properties of the resulting chitin and chitosan.

The high ash content obtained in this study is consistent with the general composition of crustacean shells, which contain substantial amounts of mineral components. Therefore, the relatively high ash content observed in the raw *S. paramamosain* shell supports the need for an effective demineralization treatment before further conversion of chitin into chitosan.

Yield of Different Extractions

The extraction method significantly affected the amount of chitin and chitosan recovered from the crab shell in Table 2, Pambudi *et al.* (2018) method produced a higher mean chitin yield of 94.50 ± 4.10%, compared with 87.50 ± 1.41% obtained using Narudin *et al.* (2020) method. A greater difference was observed in the chitosan yield, where Pambudi *et al.* (2018) method produced 80.20 ± 8.49%, whereas Narudin *et al.* (2020) method produced only 32.30 ± 15.42%.

Table 2 Yield Different Extraction

Extraction method	Narudin *et al.* (2020)		Mean ± SD	Pambudi *et al.* (2018)		Mean ± SD
Replicate	1	2		1	2	
Initial shell (g)	10	10		10	10	
Chitin (g)	8.85	8.65		9.16	9.74	
Chitin yield (%)	88.5	86.5	87.50 ± 1.41	91.6	97.4	94.50 ± 4.10
Chitosan (g)	4.32	2.14		8.62	7.42	
Chitosan yield (%)	43.2	21.4	32.30 ± 15.42	86.2	74.2	80.20 ± 8.49
Chitosan recovery from chitin (%)	48.81	24.74	36.78 ± 17.02	94.1	76.18	85.14 ± 12.68

The higher chitin yield obtained using Pambudi *et al.* (2018) method suggests that this extraction procedure was more effective in retaining the chitin fraction during the demineralization and deproteinization stages. Differences in acid and alkaline treatment conditions, including reagent concentration, treatment time, temperature, and solid-to-liquid ratio, can influence the removal of non-chitin components as well as the amount of chitin retained after extraction.

The difference became more pronounced during the deacetylation stage. The chitosan recovery from chitin was 85.14 ± 12.68% for Pambudi *et al.* (2018) method, compared with 36.78 ± 17.02% for Narudin *et al.* (2020) method. This indicates that although both methods were able to convert chitin into chitosan, Pambudi *et al.* (2018) method resulted in substantially greater recovery of the initial chitin material.

However, a higher extraction yield does not necessarily indicate that the resulting chitosan has better physicochemical characteristics. Chitosan quality is strongly influenced by parameters such as degree of deacetylation, molecular weight, purity, and solubility. Therefore, yield should be interpreted together with the FTIR and DD results. Chitosan properties are known to vary according to the degree of deacetylation and molecular characteristics of the polymer.

The high variability observed in the chitosan yield of Narudin *et al.* (2020) method (32.30 ± 15.42%) compared with Pambudi *et al.* (2018) method (80.20 ± 8.49%) may indicate that Narudin extraction procedure was more sensitive to experimental variation. Differences between replicates may be associated with variation in shell composition, particle size, washing efficiency, filtration, drying, or material loss during the extraction and deacetylation steps.

FTIR Result

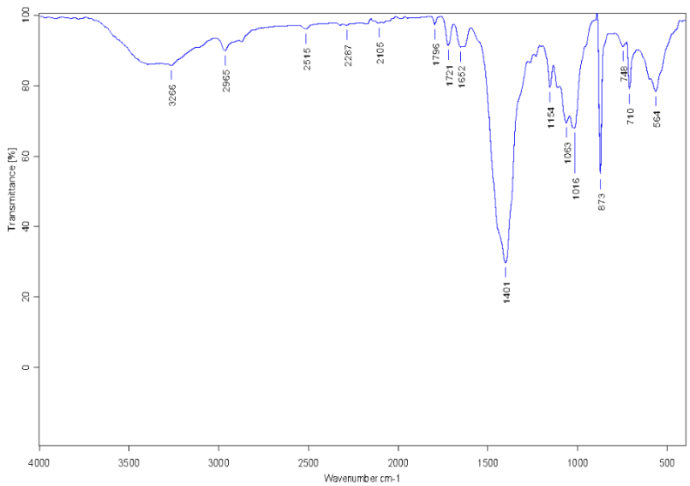


Figure 1 (A) FTIR Narudin *et al.,* 2020 Replicate 1

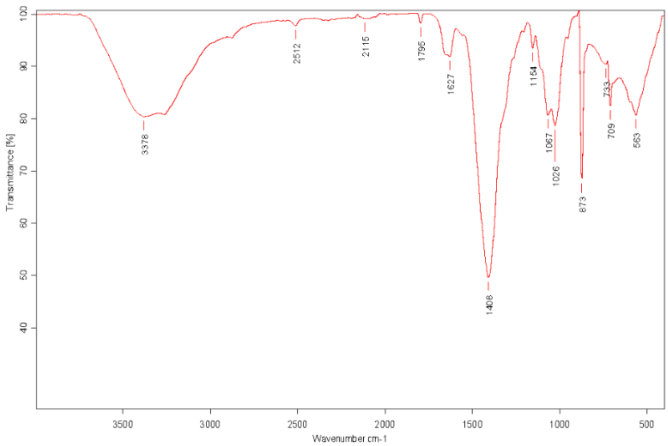


Figure 2 (B) FTIR Narudin *et al.,* 2020 Replicate 2

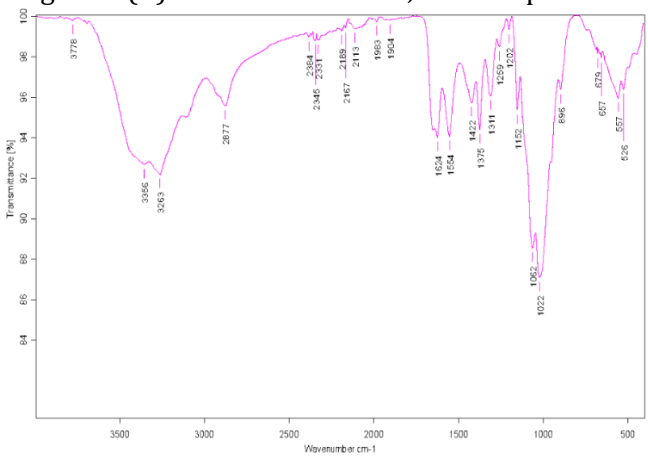


Figure 3 (C) FTIR Pambudi *et al.,* 2018 Replicate 1

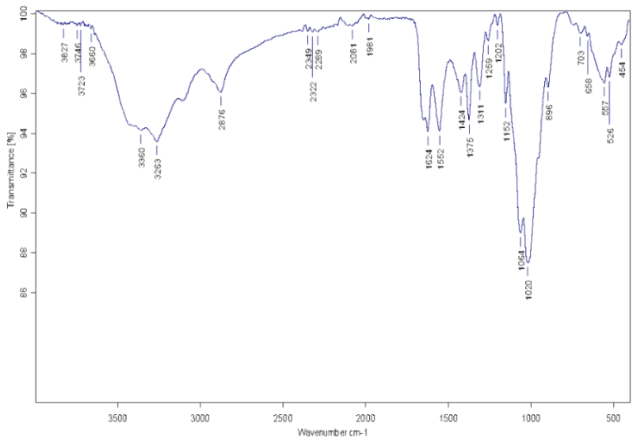


Figure 4 FTIR Pambudi *et al.,* 2018 Replicate 2

Table 3. FTIR Analysis

Functional group	Expected region (cm^{-1})	Narudin *et al.* (2020)		Pambudi *et al.* (2018)	
		r1	r2	r1	r2
O–H / N–H stretching	~3200–3500	3267.17	3377.11	3263.31	3263.31
C–H stretching	~2850–2950	2925.80	2925.80	2925.80	2875.65
Amide I (C=O)	~1650	1650.94	1650.94	1650.94	1650.94
Amide II (N–H bending)	~1550–1600	1554.51	1554.51	1554.51	1550.65
C–O–C / C–O stretching	~1000–1150	1062.70	1066.56	1062.70	1064.63

The FTIR analysis demonstrated that chitosan obtained using both extraction methods exhibited similar characteristic functional groups. The O–H/N–H stretching bands were observed at 3263.31–3377.11 cm^{-1}, while C–H stretching bands occurred at 2875.65–2925.80 cm^{-1}. The amide I band was consistently detected at 1650.94 cm^{-1}, and the amide II band appeared at approximately 1550.65–1554.51 cm^{-1}. In addition, absorption bands associated with C–O–C/C–O stretching were observed at 1062.70–1066.56 cm^{-1}.

The broad absorption band in the region of approximately 3200–3500 cm^{-1} can be attributed to O–H and N–H stretching vibrations, which are characteristic of polysaccharide structures containing hydroxyl and amino groups. The bands observed around 2875–2925 cm^{-1} correspond to C–H stretching vibrations. The absorption around 1650 cm^{-1} is associated with the amide I region, while the band around 1550 cm^{-1} can be associated with amide II/N–H bending.

As shown in Figures 1–4, the recovered materials exhibited absorption bands commonly associated with chitinous polysaccharides. Similar FTIR characteristics between the two methods indicate that both extraction procedures produced materials with comparable fundamental chitosan functional groups, even though their yields and degree of deacetylation differed.

However, FTIR peak identification alone cannot be used to conclude that the two products have identical chemical quality. The intensity and relative absorbance of characteristic bands are also influenced by the proportion of acetylated and deacetylated units. Therefore, the DD calculation provides additional information regarding the extent of deacetylation achieved by each extraction method.

Deacetylation Degree Result

The degree of deacetylation (DD) varied between the two extraction methods. Chitosan produced using Narudin *et al.* (2020) method exhibited DD values ranging from 47.31 to 68.62%, with a mean DD of 57.96 ± 15.07%. In comparison, chitosan obtained using Pambudi

et al. (2018) method showed lower DD values, ranging from 23.98 to 35.34%, with a mean of 29.66 ± 8.04%. Therefore, in Table 4, based on the obtained results, Narudin *et al.* (2020) extraction method produced chitosan with a higher degree of deacetylation than Pambudi *et al.* (2018) method.

Table 4 Deacetylation Degree Result

Method	Narudin *et al.* (2020)		Mean ± SD	Pambudi *et al.* (2018)		Mean ± SD
Replicate	1	2		1	2	
A1665/A3450	0.701	0.417		0.86	1.011	
DD (%)	47.31	68.62	57.96 ± 15.07	35.34	23.98	29.66 ± 8.04

Relationship Between Yield, FTIR, and Degree of Deacetylation

When the yield, FTIR spectra, and degree of deacetylation (DD) were considered together, the two extraction methods showed different results. The method of Pambudi *et al.* (2018) produced higher chitin and chitosan recovery, indicating greater material retention during the extraction process. However, the mean DD was relatively low (29.66 ± 8.04%), suggesting that the deacetylation treatment was less effective under the conditions used in this study.

In contrast, the method of Narudin *et al.* (2020) resulted in lower chitin and chitosan yields but a higher mean DD (57.96 ± 15.07%). This indicates that the extraction conditions resulted in greater material loss while promoting more extensive removal of acetyl groups from the remaining chitin. The difference in DD between the two methods indicates that the extraction conditions influenced the extent of deacetylation.

The FTIR spectra supported the formation of chitosan-related polysaccharide structures in both treatments, as both samples showed characteristic O–H/N–H, C–H, amide, and C–O–C/C–O absorption bands. The FTIR results were consistent with the presence of characteristic functional groups in chitosan. However, the DD results showed that the extent of deacetylation differed between the two extraction procedures, with the Narudin *et al.* (2020) method producing a higher DD.

Overall, the Pambudi *et al.* (2018) method provided higher chitin and chitosan yields, whereas the Narudin *et al.* (2020) method resulted in a higher degree of deacetylation. Therefore, the selection of the extraction method depends on the desired characteristics of the final product. Based on the higher DD obtained in this study, the Narudin *et al.* (2020) method was considered more suitable when a greater degree of deacetylation was prioritized. Further optimization of the extraction conditions may be needed to improve DD while reducing material loss.

CONCLUSION

The shell of *Scylla paramamosain* contained 6.71 ± 0.02% moisture, 9.48 ± 0.08% protein, 0.19 ± 0.00% fat, 70.11 ± 0.01% ash, and 10.40 ± 0.09% dietary fiber, indicating its potential as a raw material for chitin extraction. The extraction method influenced chitin and chitosan recovery. Pambudi *et al.* (2018) method resulted in higher chitin yield (94.50 ± 4.10%), chitosan yield (80.20 ± 8.49%), and chitosan recovery from chitin (85.14 ± 12.68%) than Narudin *et al.* (2020) method, which yielded 87.50 ± 1.41%, 32.30 ± 15.42%, and 36.78 ± 17.02%, respectively. FTIR spectra showed similar characteristic functional groups in chitosan obtained by both methods, including O–H/N–H, C–H, amide I, amide II, and C–O–C/C–O groups.

However, Narudin *et al.* (2020) method produced a higher degree of deacetylation (57.96 ± 15.07%) than Pambudi *et al.* (2018) method (29.66 ± 8.04%). Overall, Pambudi *et al.* (2018) method provided higher chitosan recovery, whereas Narudin *et al.* (2020) method produced a higher degree of deacetylation. Further optimization of the deacetylation process is needed to improve DD while maintaining chitosan recovery for subsequent water-soluble chitosan production.

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