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Characteristics of Chitosan from Chitin Deacetylation Using Different NaOH Concentration and Evaluation of Its Solubility in Liquid Smoke

Karakteristik Kitosan Hasil Deasetilasi Kitin Cangkang Rajungan Menggunakan Konsentrasi NaOH Bervariasi Dan Uji Kelarutannya dalam Asap Cair

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ABSTRACT

This research aimed to determine the effect of chitosan characteristics produced from the deacetylation of chitin with various concentrations of NaOH on its solubility in liquid smoke. Chitin produced from rajungan shell raw materials was deacetylated using 40% NaOH (K40%), 50% (K50%), and 60% (K60%). The resulting chitosan was then measured of its degree of deacetylation (DD) with FTIR method, molecular weight (MW) with viscometry method, and solubility in liquid smoke was conducted qualitatively. The results showed that K40% had a DD of 56.99%, K50% had a DD of 72.86% and a BM of 149.1 kDa, also K60% had a DD of 82.87% and a BM of 102.6 kDa. The solubility of chitosan in 10% liquid smoke indicated that K40% was not dissolved, K50% was almost completely dissolved, and K60% was completely dissolved.

Keywords: Chitin deacetylation; chitosan; liquid smoke; solubility.

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1. INTRODUCTION

The primary sources of chitin and chitosan that have been widely utilized to date are the skins/shells of crustaceans (Saravanan, et al. 2023). Chitin is the second most abundant biopolymer in nature after cellulose. Despite its abundance, the utilization of chitin remains limited. One of the main reasons for this limited use is its insolubility in water, diluted acids, alkalis, and organic solvents. Therefore, the chemical structure of chitin is typically modified to obtain derivatives with improved chemical properties. One such derivative is chitosan. The modification of chitin into chitosan is achieved by converting the acetamide groups (–$NHCOCH_3$) in chitin into amine groups (–NH_2) through the removal of acetyl groups, a process known as

deacetylation (Aberoumand & Hoseinian, 2025).

The deacetylation of chitin to produce chitosan can be carried out using highly concentrated strong bases, with sodium hydroxide (NaOH) being the most used. According to Zuwanna, et al. (2025), the extent of acetyl group removal increases with increasing NaOH concentration; in other words, higher NaOH concentrations during the deacetylation process result in a higher degree of deacetylation. This increase is accompanied by a decrease in yield and molecular weight (Ghanem, et al., 2025).

Chitosan exhibits low solubility in neutral or alkaline water but readily dissolves in dilute weak acids with pH < 6, such as acetic acid, formic acid, and citric acid, due to its structural richness in amine groups ($–NH_2$). When chitosan is dissolved in weakly acidic media, the amine groups become protonated to form positively charged $–NH_3^+$ groups, rendering chitosan a cationic polyelectrolyte that is stably dispersed in aqueous media (Vo et al., 2025).

Liquid smoke contains organic acids, one of which is acetic acid. The presence of acetic acid makes liquid smoke a potential solvent for chitosan. This has been demonstrated by Junaidi et al. (2019) , who reported that liquid smoke at concentrations of 5–15% was capable of dissolving chitosan at concentrations exceeding 50 g/L. According to Wang and Roman (2023), the solubility of chitosan is strongly influenced by its characteristics, particularly the degree of deacetylation (DD) and molecular weight (MW). Chitosan characteristics such as DD, MW, antibacterial activity, and antioxidant properties are affected by the source of raw materials (shrimp shells, crab shells, fungi) and the preparation method (Niu & Hu, 2024). This study was conducted to determine the DD and MW characteristics of chitosan produced from the deacetylation of crab shell chitin using varying NaOH concentrations. In addition, the effect of the resulting chitosan characteristics on its solubility in liquid smoke was also investigated. This study aims to prove how much influence the concentration of NaOH used in the deacetylation process of crab shell chitin has on the DD and MW values and the solubility level of chitosan produced in liquid smoke.

2. MATERIALS AND METHODS

2.1. Materials

This study was conducted at the Biomaterials Laboratory, Faculty of Mathematics and Natural Sciences, Universitas Lambung Mangkurat, Banjarbaru, and at the Organic Chemistry Laboratory, Faculty of Mathematics and Natural Sciences, Universitas Gadjah Mada. The materials used in this study included crab shells obtained from Sekandis Village, South Pamukan Subdistrict, Kotabaru Regency, liquid smoke derived from coconut shells with a phenol content of 2.22% GAE g/L and a total acid content of 14.52% AAE g/L, HCl, NaOH pellets, acetone, NaOCl, distilled water, 98% CH_3COOH, and NaCl.

2.2. Methods

The isolation of chitin and chitosan from crab shells was carried out through demineralization, deproteinization, depigmentation, and deacetylation processes. The initial step was demineralization, which referred to a modified method reported by Junaidi et al. (2021). Crab shells were demineralized using a 1.5 M HCl solution at a ratio of 1:15 (w/v) at room temperature for approximately 2 hours. The demineralized product was then deproteinized using a 3.5% (w/v) NaOH solution at a ratio of 1:10 (w/v) at 65°C for 4 hours. Chitin obtained from the demineralization and deproteinization steps was depigmented using a 2% sodium

hypochlorite (NaOCl) solution at a ratio of 1:10 (w/v) at room temperature for 10 minutes.

Chitin resulting from the demineralization, deproteinization, and depigmentation steps was deacetylated using NaOH concentrations of 40% (K40%), 50% (K50%), and 60% (K60%) at a ratio of 1:15 (w/v) at 105°C for 2 hours. Solvent regeneration was performed twice. The residue was separated by decantation and washed until neutral pH was reached, after which it was dried at 80 °C to constant weight and the yield was calculated.

Chitosan characterization included the analysis of the degree of deacetylation (DD) and molecular weight (MW). The DD of chitin and chitosan was determined using Fourier transform infrared spectroscopy based on the method of Junaidi et al. (2021). Chitin and chitosan powders were prepared as pellets with KBr at a ratio of 1:100 (w/w). The pellets were analyzed for functional group absorption in the wavenumber range of 4000–400 cm^{-1}. The degree of deacetylation of chitin and chitosan was calculated using the Baxter equation (1).

$$DD\ (\%) = 100 - \left[\frac{A1655}{A3450} \times 155\right] \quad (1)$$

The molecular weight of chitosan was determined using the viscometry method. Chitosan solutions with concentrations of 0.025%, 0.05%, 0.075%, 0.1%, 0.15%, and 0.2% as reported by Junaidi et al. (2021) were prepared by dissolving chitosan in a mixed solvent consisting of 0.33 M acetic acid and 0.3 M NaCl. The viscosity was measured by placing 10 mL of the chitosan solution into a viscometer. The flow rate of the solution was then converted into kinematic viscosity using Equation (2).

$$\eta_{average\ kinematic} = \frac{(k_1 \times t_1)+(k_2 \times t_2)}{2} \quad (2)$$

The kinematic viscosity of the obtained solution was compared with the kinematic viscosity of the solvent, which is referred to as the relative viscosity (3):

$$\eta_{rel} = \frac{\eta_{average\ kinematic}}{\eta_{solvent}} \quad (3)$$

The relative viscosity (η_{rel}) of the chitosan solution was converted into specific viscosity (η_{sp}) to eliminate the solvent effect (4).

$$\eta_{sp} = \eta_{rel} - 1{,}0 \quad (4)$$

The effect of chitosan concentration on specific viscosity was eliminated and converted into intrinsic viscosity (η) using the Huggins equation (5):

$$\frac{\eta_{sp}}{C} = [\eta] + k'[\eta]^2 \quad (5)$$

Subsequently, the reduced viscosity (η_{red}) was determined using Equation (6):

$$\eta_{red} = \frac{\eta_{sp}}{C} \quad (6)$$

The obtained reduced viscosity (η_{red}) values were then plotted in a linear graph, resulting in the equation $y = ax + b$, where ax represents the slope = $k'[\eta]^2C$ and b represents the intercept = $[\eta]$. Based on the intrinsic viscosity value $[\eta]$, the molecular weight of chitosan was determined using the Mark–Houwink equation as shown in Equation (7).

$$[\eta] = K \times M^{\alpha} \quad (7)$$

The solubility test of chitosan in liquid smoke was conducted following the method reported by Junaidi *et al.* (2019). A mass of 0.1 g of K40%, K50%, and K60% chitosan was dissolved in 10 mL of liquid smoke at concentrations of 10%, 15%, and 20%, followed by stirring at room temperature. In addition, the solubility of chitosan in acetic acid was also evaluated by dissolving 0.1 g of K40%, K50%, and K60% chitosan in 10 mL of 1% and 2% acetic acid solutions. Solubility was qualitatively assessed using the following criteria of completely soluble, almost

completely soluble, partially soluble, slightly soluble, and insoluble.

3. RESULTS AND DISCUSSION

3.1. Chitin and Chitosan Isolation

The demineralization process involves the removal of minerals contained in the raw material. The most dominant minerals present in crustacean shells are $CaCO_3$ and a small amount of $Ca_3(PO_4)_2$. The HCl solution reacts with these minerals to form salts and CO_2 gas (Aberoumand & Hoseinian, 2025). The reaction occurring in this process is as follows:

$$CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(aq)} + H_2O_{(l)} + CO_{2(g)}$$

$$Ca_3(PO_4)_{2(s)} + 4HCl_{(aq)} \rightarrow 2CaCl_{2(aq)} + Ca(H_2PO_4)_{2(aq)}$$

The resulting yield was 62.65%. This value is consistent with the statement by Rochima (2014) that crab shells contain 40–60% mineral content.

The deproteinization process involves the removal of proteins present in the raw material. During this process, cleavage of protein bonds occurs, in which Na^+ ions derived from NaOH bind to the negatively charged ends of protein chains. The protein bonds are released to form sodium proteinate, which is soluble in water and is therefore removed during the washing of the residue. The reaction occurring in the deproteinization process is illustrated in **Figure 1.**

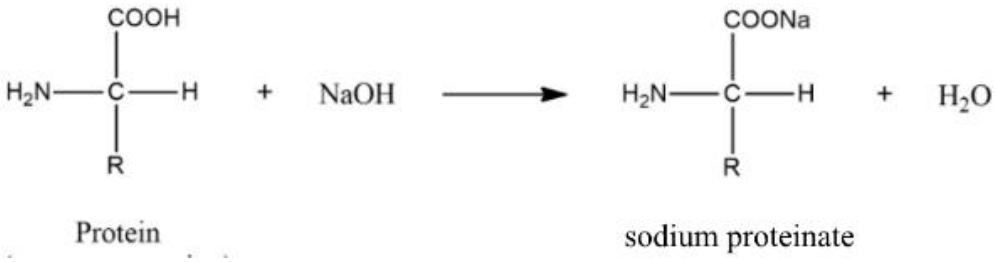

Figure 1. Deproteinization process

The resulting yield was 50.94%. This value differs considerably from the typical yield of the deproteinization process, in which the protein content of crustaceans generally ranges from 20–40%.

This substantial difference is likely due to the presence of residual meat and internal organs that remained attached to the outer surface of the crab shells and were removed during the deproteinization process. In addition, fine powdered residues may have been lost during the washing step and passed through during the decantation process (Korampattu, et al., 2024).

The depigmentation process involves the removal of pigments present in the raw material. In general, pigments in crab shells are dominated by astaxanthin, canthaxanthin, lutein, and β-carotene, which are carotenoid compounds (Fearghail et al., 2019; Korampattu, et al., 2024). Residual pigments present in chitin or chitosan may cause adverse effects when applied in biomedical fields. Therefore, chitin and chitosan intended for such applications must possess a high degree of purity. The yield obtained from the depigmentation process was 97.69%.

The deacetylation process involves the cleavage of acetyl groups originally present in chitin. Initially, an addition reaction occurs in which the –OH group enters the $–NH–COCH_3$ group, resulting in the elimination of the CH_3COO^- group and the formation of amine groups, which are the principal functional groups of chitosan (Novikov et al., 2023).

The yields obtained for K40%, K50%, and K60% were 71.30%, 62.05%, and 56.50%, respectively. The deacetylation yield data

indicate that higher NaOH concentrations lead to lower yields.

This decrease is attributed to polymer degradation and the increased removal of acetyl groups as a result of higher alkali concentrations and elevated reaction temperatures (Fadli et al., 2017).

Figure 1. (a) crab shell powder, (b) residue after demineralization, (c) chitin after deproteinization, (d) chitin after depigmentation, (e) chitosan after deacetylation

Visually, the chitosan produced through the demineralization to deacetylation stages is shown in **Figure 2**. Figure 2 shows a gradual color change from image (a) to image (e). The removal of minerals from the raw material caused the residue to appear reddish brown. Chitin obtained after the deproteinization process exhibited a slightly lighter reddish color, which can be attributed to the corrosive nature of NaOH that is capable of damaging pigments in the sample. Chitin obtained after the depigmentation process appeared white, indicating that the pigments previously bound to chitin after deproteinization were effectively removed. The chitosan produced after the deacetylation process exhibited a cream or slightly yellowish color.

Chitosan is a glucose-based polymer containing reducing sugar units, in which its structure includes aldehyde groups (CH_2OH) and primary amine groups (NH_2). When chitosan is heated at temperatures above 100°C, a Maillard reaction occurs. The Maillard reaction is a non-enzymatic browning reaction between carbohydrates, particularly those containing reducing sugars, and amine groups present in the material, resulting in a brownish coloration (Ridhani et al., 2021).

3.2. Chitosan Characterization

The FTIR spectra of chitin, K40%, K50%, and K60% shown in **Figure 3** indicate differences in functional groups before and after the deacetylation process. The spectral regions observed in Figure 2 include absorption peaks corresponding to O–H stretching vibrations, C–H stretching, C=O stretching, N–H bending, C–H bending, and C–O–C stretching, which are presented in **Table 1**.

The spectral regions of chitin and K40% show similar wavenumber absorptions for each observed functional group. This indicates that K40% possesses properties similar to those of chitin. The O–H stretching vibrations of K50% and K60% are observed in the absorption region at 3441 cm^{-1}. The absorption bands at 3109.25 cm^{-1}, 3263.56 cm^{-1}, and 3271.27 cm^{-1} observed in chitin and K40% are absent in K50% and K60%,

indicating the removal of acetyl groups. The absorption band at 2885.51 cm^{-1} indicates the presence of alkane C–H groups corresponding to the stretching vibration of $–CH_2–$ groups (Cakasana et al., 2014).

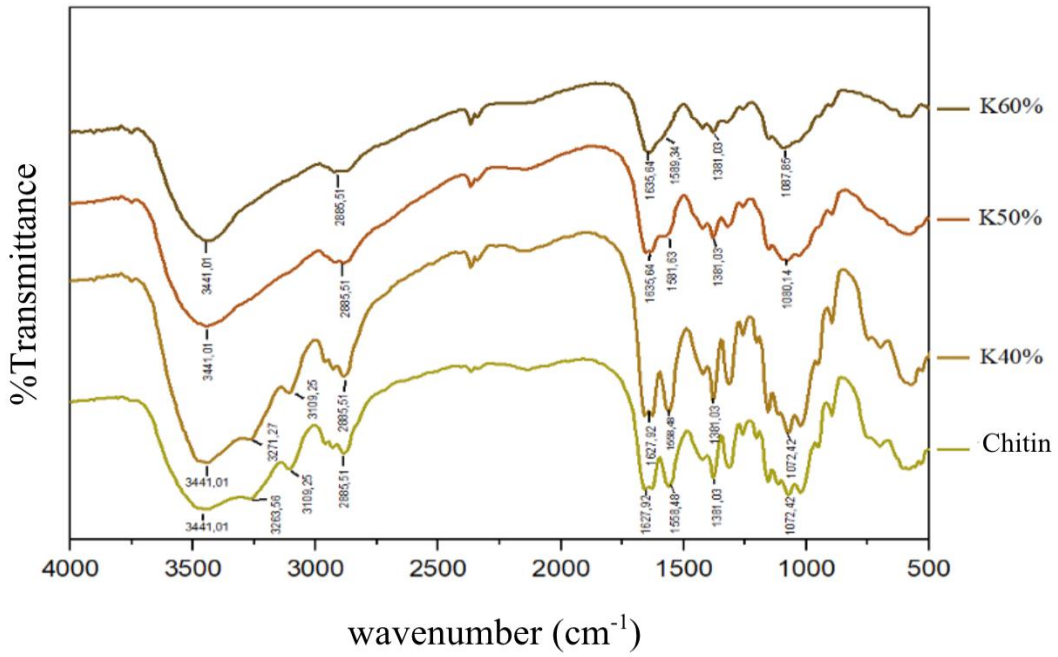

Figure 2. FTIR spectra of chitin and chitosan

Table 1. FTIR absorption functional groups of chitin and chitosan K40%, K50%, and K60%

Functional Group	Wavenumber (cm^{-1})			
	Chitin	K40%	K50%	K60%
O-H stretching	3441.01	3441.01	3441.01	3441.01
N-H stretching	3109.25	3109.25	-	-
C-H stretching	2885.51	2885.51	2885.51	2885.51
C=O stretching	1627.92	1627.92	1635.64	1635.64
N-H bending	1558.48	1558.48	1581.63	1589.34
C-H bending	1381.03	1381.03	1381.03	1381.03
C-O-C bending	1072.42	1072.42	1080.14	1087.85

The peak at 1627.92 cm^{-1} in chitin and K40% corresponds to the C=O stretching vibration of amide groups and shows a decrease in intensity in K50% and K60% with a shift to 1635.64 cm^{-1}. This indicates a reduction in secondary amide N–H groups in chitin due to the removal of acetyl groups (Azizati, 2019). The absorption band of chitin and K40% at 1558.48 cm^{-1} indicates N–H bending vibrations of $R–NH_2$ and shows a decrease in intensity with shifts to 1581.63 cm^{-1} for K50% and 1589.34 cm^{-1} for K60%, which indicates an increase in the degree of deacetylation. According to Azizati (2019), the formation of chitosan can be identified by a decrease in the intensity of the C=O stretching and N–H bending absorption peaks that were initially sharp. The decrease in peak intensity indicates a reduction in acetyl groups in chitin. The absorption band at 1381.01 cm^{-1}

corresponds to C–H bending vibrations, while absorption bands at 1072.42 cm^{-1}, 1080.14 cm^{-1}, and 1080.85 cm^{-1} correspond to asymmetric C–O–C stretching vibrations of the glucosamine ring (Etminanrezaeieh, et al., 2025).

The degree of deacetylation represents the percentage of acetyl group removal following the deacetylation process of chitin. The principle of DD determination using the FTIR method is based on the ratio of absorbance values of the amide group at a wavenumber of 1655 cm^{-1} and the hydroxyl group at 3650 cm^{-1} (Junaidi et al., 2021). According to Ghanem, et al. (2025), deacetylated chitin can be classified as chitosan when it has a degree of deacetylation of at least 70%.

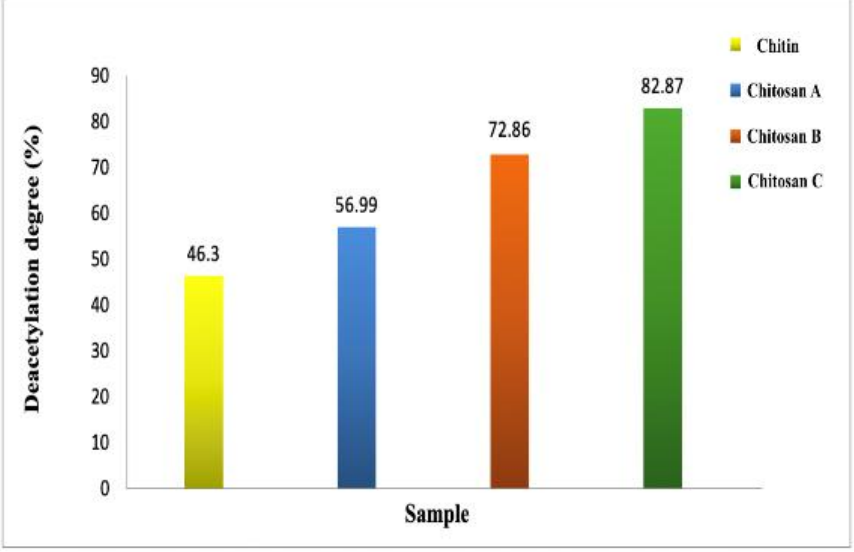

Figure 3. Results of DD analysis of chitin and chitosan: A (K40%), B (K50%), and C (K60%)

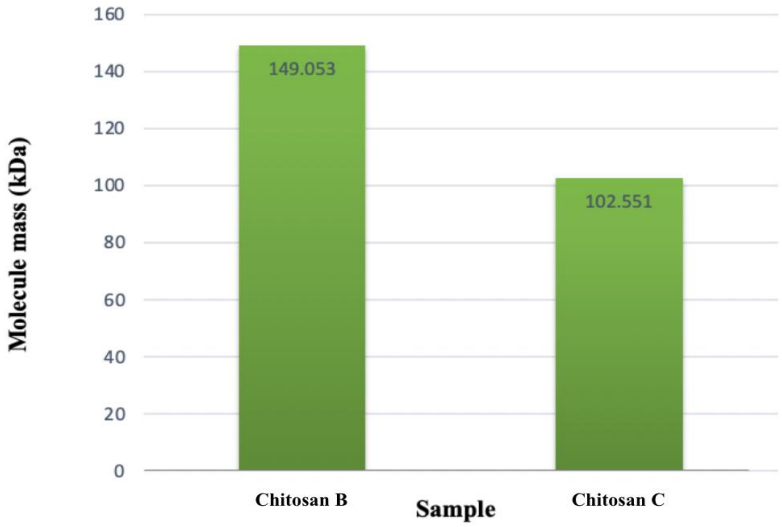

Figure 4. Results of molecular weight analysis of chitosan B (K50%) and chitosan C (K60%)

Based on **Figure 4**, chitin and K40% exhibit DD values of 46.4% and 56.99%, respectively, which are ≤70%. Therefore, K40% is still classified as chitin. In contrast, K50% and K60% are classified as chitosan, as they exhibit DD values of 72.84% and 82.87%, respectively. The differences in DD among K40%, K50%, and K60% are attributed to variations in the NaOH concentration used during the chitin deacetylation process.

Higher NaOH concentrations lead to a greater number of Na^+ and OH^- ions attacking the C=O group of acetamide. This results in increased removal of acetyl groups and their substitution by amine groups, thereby increasing the DD value obtained (Amitaye, et al., 2024).

The NaOH concentration used in the deacetylation process also affects the molecular weight of the resulting chitosan. The molecular weight determination of K50% and K60% was carried out using the viscometry method. The results are presented in **Figure 5**.The molecular weight analysis of chitosan K40%, K50%, and K60% were performed using the viscometry method. However, K40% chitosan did not dissolve in the solvent used, and therefore its molecular weight analysis was not carried out. Based on Figure 5, chitosan K50% exhibited a molecular weight of 149.1 kDa, while K60% exhibited a molecular weight of 102.6 kDa. According to Román-Doval, et al. (2023), chitosan with a molecular weight in the range of 50–150 kDa is classified as having medium molecular weight. The molecular weight of K50% was higher than that of K60% due to differences in the NaOH concentration used during the deacetylation process.

Higher NaOH concentrations result in lower molecular weight. This effect occurs because acetyl groups are removed and replaced by amine groups, which influences the molecular weight of chitosan and leads to a decrease as more acetyl groups are removed. In addition, the use of high NaOH concentrations during deacetylation can cause depolymerization. Increasing NaOH concentration leads to shorter polymer chains as a result of cleavage of glycosidic bonds between chitosan molecules, thereby reducing the molecular weight of the chitosan produced (Periyannan et al., 2023).

3.3. Chitosan Solubility

One of the important parameters influencing the application of chitosan is its solubility. Chitosan solubility was evaluated in acetic acid and in liquid smoke. The observed solubility results of chitosan in these two media are presented in **Table 2**.

Based on **Table 2**, K40% was insoluble in both acetic acid and liquid smoke. This result is attributed to the DD value of K40%, which was 56.99% or less than 70%, indicating that it is still classified as chitin. Chitosan K50% was completely soluble in 2% acetic acid and 20% liquid smoke, while it was partially soluble in 1% acetic acid and almost completely soluble in 10% and 15% liquid smoke. Chitosan K60% exhibited good solubility in acetic acid at concentrations of 1–2% and in liquid smoke at concentrations of 10–20%. These results are consistent with the findings reported by Junaidi et al. (2019) who stated that liquid smoke at concentrations of at least 5% is capable of dissolving more than 50 g/L of chitosan.

Based on the solubility behavior of K40%, K50%, and K60%, it can be concluded that higher degrees of deacetylation lead to increased chitosan solubility. This is because a higher DD corresponds to a greater abundance of amine groups, which play a key role in the dissolution process. In addition, chitosan solubility is directly proportional to the concentration of liquid smoke used, where

higher liquid smoke concentrations result in greater chitosan solubility. This effect occurs because higher concentrations of liquid smoke contain higher total acid content, which increases the protonation of chitosan amine groups to NH_3^+ due to the abundance of H_3O^+ ions present in the liquid smoke (Junaidi et al., 2019). Following protonation of the amine groups, electrostatic repulsion between NH_3^+ groups occur. This repulsion disrupts attractive interactions between polymer chains such as hydrogen bonding and hydrophobic interactions, leading to the dissolution of chitosan (Saïed & Aider, 2014).

Tabel 2. Solubility test results of chitosan in liquid smoke

Solvent	Solvent Concentration	Solvent pH	K40%	K50%	K60%
Acetic acid	1%	2.8	Insoluble	Partially soluble	Completely soluble
	2%	2.6	Slightly soluble	Completely soluble	Completely soluble
Coconut shell liquid smoke	10%	3.2	Insoluble	Almost completely soluble	Completely soluble
	15%	3.1	Insoluble	Almost completely soluble	Completely soluble
	20%	3.1	Slightly soluble	Completely soluble	Completely soluble

4. CONCLUSIONS

Based on the results of this study, it can be concluded that the NaOH concentration used in the chitin deacetylation process significantly affects the degree of deacetylation and molecular weight of the resulting chitosan. Higher NaOH concentrations produce chitosan with higher degrees of deacetylation and lower molecular weights. Chitosan with a high degree of deacetylation and low molecular weight exhibits greater solubility in liquid smoke. In 10% liquid smoke, K40% was insoluble, K50% was almost completely soluble, and K60% was completely soluble. The results of this study provide scientific support for the potential application of a combination of chitosan and liquid smoke without requiring additional solvents.

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LIST OF REFERENCES

Aberoumand, A., & Hoseinian, M. (2025). Extraction and characterization of chitosan obtained from shells of crab (*Liocarcinus vernalis*). *Applied Food Research, 5*(1), 100964. https://doi.org/10.1016/j.afres.2025.100964

Amitaye, A. N., Elemike, E. E., & Uzah, T. T. (2024). Multifarious techniques for resolving chitosan's degree of deacetylation. *Materials International, 6*(2), 1–24.https://https/doi.org/10.33263/Materials62.016

Azizati, Z. (2019). Pembuatan dan karakterisasi kitosan kulit udang galah. *Walisongo Journal of Chemistry, 2*, 10–16. https://doi.org/10.21580/wjc.v3i1.3878

Cakasana, N., Suprijanto, J., & A. S. (2014). Aktivitas antioksidan kitosan yang diproduksi dari cangkang kerang simpling (*Amusium* sp.) dan kerang darah (*Anadara* sp.). *Journal of Marine Research, 3*, 395–404. https://doi.org/10.14710/jmr.v3i4.8360

Etminanrezaeieh, S., Rezazadeh, K., Jalilnejad, E., & Reza, R. (2025). Preparation and characterization of bio-waste derived chitosan hydroxyapatite pectin green biocomposite. *Scientific Reports, 15*, 24450. https://doi.org/10.1038/s41598-025-07588-0

Fadli, A., Drastinawati, O., Alexander, O., & F. H. (2017). Effect of chitin mass NaOH ratio and reaction time on characteristics of chitosan synthesized from waste of dried shrimp industry. *Jurnal Sains Materi Indonesia, 18*, 61–67. https://doi.org/10.17146/jsmi.2017.18.2.4166

Fearghail, F. O., Giltrap, M., O'Connor, C. O., & P. B. (2019). Improving extraction processes of crustacean chitin using solid state analytical techniques. *International Journal of Applied Chemistry, 6*, 23–30.

Ghanem, S. N., Marzouk, M. I., Tawfik, M. E., & Eskander, S. B. (2025). Spectroscopic approaches for structural analysis of extracted chitosan generated from chitin deacetylated for escalated periods. *BMC Chemistry, 19*, 214. https://doi.org/10.1186/s13065-025-01558-3

Junaidi, A. B., Apriyani, H., Abdullah, A., & Santoso, U. T. (2019). Fraksinasi dan karakterisasi asap cair dari kayu ulin (*Eusideroxylon zwageri* Teijsm. & Binn.) sebagai pelarut kitosan. *Jurnal Riset Industri Hasil Hutan, 11*, 53–64.

Junaidi, A. B., Irawati, U., & Santoso, U. T. (2021). *Teknologi kitin dan kitosan: Definisi, preparasi dan karakterisasi*. Banyubening Cipta Sejahtera.

Korampattu, L., Neha, G., & Paresh, L. D. (2024). Shell waste valorization to chemicals: Methods and progress. *Green Chemistry, 26*, 5601–5634. https://doi.org/10.1039/D3GC05177C

Niu, Y., & Hu, W. (2024). Preparation, characterization and application in environmental protection of low-molecular-weight chitosan: A review. *Sustainable Environment Research, 34*, 29. https://doi.org/10.1186/s42834-024-00236-8

Nurhikmawati, F., Manurung, M., & Laksmiwati, A. A. I. A. M. (2014). Penggunaan kitosan dari limbah kulit udang sebagai inhibitor keasaman tuak. *Jurnal Kimia, 8*, 191–197. https://doi.org/10.24843/JCHEM.2014.v08.i02.p08

Novikov, V. Y., Derkach, S. R., Konovalova, I. N., Dolgopyatova, N. V., & Kuchina, Y. A. (2023). Mechanism of heterogeneous alkaline deacetylation of chitin: A review. *Polymers, 15*(7), 1729. https://doi.org/10.3390/polym15071729

Periyannan, K., Selvaraj, H., Subbu, B., Pallikondaperumal, M., Karuppiah, P., Rajabathar, J., Al-Lohedan, H., & Thangarasu, S. (2023). Green fabrication of chitosan from marine crustaceans and mushroom waste: Toward sustainable resource utilization. *Green Processing and Synthesis, 12*(1), 20230093. https://doi.org/10.1515/gps-2023-0093

Ridhani, M. A., Vidyaningrum, I. P., Akmala, N. N., Fatihatunisa, R., Azzahro, S., & Aini, N. (2021). Potensi penambahan berbagai jenis gula terhadap sifat sensori dan fisikokimia roti manis: A review. *Pasundan Food Technology Journal, 8*, 61–68. https://doi.org/10.23969/pftj.v8i3.4106

Rochima, E. (2014). Study of utilization of crabs processing wastes and its application for chitosan-based healthy drink. *Akuatika, 5*(1), 71–82. https://jurnal.unpad.ac.id/akuatika/article/view/3707

Román-Doval, R., Torres-Arellanes, S. P., Tenorio-Barajas, A. Y., Gómez-Sánchez, A., & Valencia-Lazcano, A. A. (2023). Chitosan: Properties and its application in agriculture in context of molecular weight. *Polymers, 15*(13), 2867. https://doi.org/10.3390/polym15132867

Saïed, N., & Aïder, M. (2014). Zeta potential and turbidimetry analyses for the evaluation of chitosan phytic acid complex formation. *Journal of Food Research, 3*(2), 71–81. https://doi.org/10.5539/jfr.v3n2p71

Saravanan, A., Kumar, P., Yuvaraj, D., Jeevanantham, S., Aishwaria, P., Gnanasri, P. B., Gopinath, M., & Rangasamy, G. (2023). Polysaccharides from crustacean wastes and their environmental applications. *Environmental Research, 221*, 115330. https://doi.org/10.1016/j.envres.2023.115330

Vo, T. S., Chit, P. P., Hoang, T., Hoang, V. H., Dang, T. T., Vo, T. T. B. C., Park, Y., & Kim, K. (2025). Chitosan solubility in organic acid solutions under ultrasonication: A comparative perspective. *International Journal of Biological Macromolecules, 331*(Pt 1), 148394. https://doi.org/10.1016/j.ijbiomac.2025.148394

Wang, H., & Roman, M. (2023). Effects of chitosan molecular weight and degree of deacetylation on chitosan cellulose nanocrystal complexes and their formation. *Molecules, 28*(3), 1361. https://doi.org/10.3390/molecules28031361

Zuwanna, I., Riza, M., Aprilia, S., Syamsuddin, Y., Said, S., & Dewi, R. (2025). Investigation of characteristics whey protein isolate chitosan with silica addition in biocomposite film. *International Journal of Technology, 16*(1), 359–369. https://doi.org/10.14716/ijtech.v16i1.6335