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Characterization and Adsorption Efficiency of Cellulose and Nanocellulose From Kepok Banana Peel

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Abstract
The adsorption method is a highly effective technique for adsorbing methylene blue from dye waste. Adsorbents from natural materials have a high absorption capacity, such as banana peel waste, which contains very fine fibers with a hemicellulose (6-8%), cellulose (60-65%), and lignin (5-10%). The effectiveness of adsorbent from Kepok banana peel for methylene blue dye was studied in this research. The parameters tested include the characterization of cellulose and nanocellulose using FTIR, SEM and XRD instruments, determination of the optimum weight, efficiency of cellulose adsorption, and adsorption capacity of the adsorben. The results show that cellulose and nanocellulose isolated from banana peel indicate functional groups in the characteristic absorption regions of cellulose, such as O-H stretching, C-H, C-O, and C=O functional groups in the FTIR characterization. SEM analyses confirmed the fibrillar and porous structure of the nanocellulose, highlighting its suitability for adsorption applications. XRD analysis showed that the nanocellulose possesses a crystalline structure typical of Cellulose Type I, with a crystallinity index of ~59.6%. The optimum weight for cellulose and nanocellulose is 60 mg. The adsorption efficiency of methylene blue ranged from 41.66% -67.38%. Maximum adsorption capacities of cellulose and nanocellulose were 6.943 mg/g and 9.673 mg/g respectively. These results indicate that cellulose and nanocellulose are effective adsorbents for methylene blue under the tested conditions.

Keywords: Adsorben, adsorption capacities, kepok banana peel, nanoselulose, selulose

Introduction

The waste of methylene blue dye entering water bodies can inhibit the transmission of sunlight. The color produced obstructs light from entering the water body, thereby reducing the photosynthesis processes of the plant in the water and the process of supplying oxygen to the water (Varjani *et al*., 2018) [21]. Methylene blue has negative effects on humans upon direct contact, such as eye irritation and digestive system irritation. If methylene blue ingested, it can cause side effects such as nausea, vomiting, and diarrhea (Mulyana *et al*., 2024; Salazar *et al*., 2017) [9, 15]. Waste containing methylene blue needs to be processed before being taken out into the environment.

Several methods have been developed to control and remove dye waste in water bodies, such as coagulation (Mcyotto *et al*., 2021) [8], ultrafiltration (Parakala *et al*., 2019) [11], electrocoagulation (Carvalho *et al*., 2015) [1], and adsorption (Parastar *et al*., 2025) [12].The adsorption method is considered the most advantageous because of its simple process, high effectiveness and adsorption capacity, selectivity, low operational cost, and absence of side effects such as toxic substances (Volesky and Naja, 2005) [22]. The adsorption method has the disadvantage of requiring periodic replacement of the adsorbent. Development of adsorbents from natural materials continues to address this limitation. Natural material adsorbents have high absorption capacity, are easy to obtain at a low cost, and are abundantly available. In addition, they are non-toxic and environmentally friendly. Some natural material adsorbents that have been studied include coconut shell waste (Susmanto *et al*., 2020) [16], corn husk (Desianna *et al*., 2017), and banana peel (Fitriani *et al*., 2015) [6].

Banana peel waste is composed of fine fibers and consists of approximately 6-8% hemicellulose, 5-10% lignin and high cellulose of 60-65% (Tjahyono, 1998) [19]. Banana peel waste possesses strong mechanical characteristics, including a high tensile modulus, superior purity, excellent capacity of water binding, and a well-structured network, making it a potential adsorbent (Pankaj *et al*., 2012) [10].

Previous research using Kepok banana peel waste as an adsorbent, conducted by Dyah *et al*. (2015) [5], found the adsorption capacity of Kepok banana peel for methylene blue to be 2.85 mg/g. The use of banana peel has also been proven effective in removing Basic Blue 9, Basic Violet 10, and Methylene Blue dyes (Crini, 2018) [2]. Pankaj *et al*. (2012) [10] and Fitriani *et al*. (2015) [6] stated that banana peel can be used as an adsorbent for reactive red 141 and methylene blue dyes.

The application of nanotechnology in wastewater treatment offers high removal efficiency and can be tailored to specific needs. This depends on the charge, optical, electrical, or magnetic properties of the nanomaterial, allowing it to achieve a high ratio of surface area to particle size on the nanoscale (Kyzas and Matis, 2015) [7]. Nanocellulose possesses several superior properties, such as the mechanical properties of its crystals compared to cellulose, making it useful for various applications.

This research aims to determine the adsorption capacity of cellulose and nanocellulose from banana peel (Musa acuminata L.) in reducing the methylene blue dye content, as well as the efficiency of cellulose and nanocellulose from Kepok banana peel waste (Musa acuminata L.) in reducing the methylene blue dye content.

Methodology

1. Materials

The materials used in this study include banana peel waste, ethanol, NaOH, H_2O_2, H_2SO_4, methylene blue, and distilled water. Formic acid (HCOOH, 90%), sodium hydroxide (NaOH, 96%), hydrogen peroxide (H_2O_2, 30%), sulfuric acid (H_2SO_4, 98%), distilled water, and ethanol. All chemicals used are pro-analysis grade.

2. Adsorben Preparation

This research was conducted in the Integrated Laboratory of Udayana University. The Kepok banana peels that were obtained were cleaned and Chopped into tiny pieces. The small pieces of banana peels dried in the oven at 80-90°C for ± 24 hours. After drying, the peels were grind using a blender and sieved until finely powdered. A total of 5 grams of banana peel powder was isolated by adding 5 mL of 10% NaOH solution and stirring with a magnetic stirrer. After 24 hours, the banana peel powder was separated from the NaOH solution using a filter. Next, a bleaching process was carried out by soaking the banana peel powder in H_2O_2 solution for 24 hours. After soaking, the banana peel powder was washed with distilled water (aquades) and then the isolation process was continued. H_2SO_4 solution was added to a container containing the banana peel powder, with varying concentrations of 5%, 10%, 15%, and 20%. The solution was heated in a water bath for 3.5 hours at 50°C. The solution was then neutralized by centrifugation until the pH became neutral. The sample was then placed in an ultrasonic cleaner and oven-dried at temperatures between 20-40°C until dry. Afterward, the sample was ground until finely powdered using a mortar.

3. Characterization

The powder of cellulose and nanocelullose was used for characterization using FTIR, SEM and XRD. The cellulose characterization was carried out using FTIR to identify functional group absorptions. Infrared absorbance was measured in the wavelength range of 4000-400 cm^{-1}

4. Measurement of Adsorption Efficiency

The optimum weight was determined by varying the weight of cellulose and nanocellulose to 20, 35, and 50 mg/L, which were added to 20 mL of 10 mg/L methylene blue solution. The solution was agitated for 1 hour. Afterward, the sample solution was centrifuged at 3000 rpm speed for 15 minutes. The various solution was used for measured the absorbance using a UV-Vis spectrophotometer (λ 663.2 nm). Optimum weight obtained was used to measure the adsorption capacity. 20 mL of methylene blue solution was added to the optimum weight. The various concentrations of methylene blue were 20, 35, and 50 mg/L. Mixed solution were shaken for a specified time at pH 7.5. The solution was at 3000 rpm speed centrifuged for 15 minutes. The absorbance of sample solution was determined using a UV-Vis spectrophotometer at (λ 663.2 nm). The adsorption capacity was determined using Equation 1:

$$q = \frac{V\,(C_0 - C_e)}{m} \quad (1)$$

The adsorption efficiency is determined using Equation 2:

$$R = \frac{C_0 - C_e}{C_0} \times 100\,\% \quad (2)$$

q represents the adsorption capacity (mg/g), V denotes the solution volume (L), C_0 refers to the initial dye concentration (mg/L), C_e indicates the final dye concentration (mg/L), m corresponds to the mass of cellulose or nanocellulose (g), and R signifies the adsorption efficiency.

Results and Discussion

Exposition and discussion of the results of the study were written with the regular Verdana 9 font.

1. Isolation and Synthesis of Cellulose and Nanocellulose

Cellulose isolation from banana peels is carried out through alkalization and bleaching processes. During the alkalization stage, lignin undergoes degradation due to its reaction with NaOH solution. Hydroxide ions (OH^-) play a role in breaking the lignin structure bonds, while sodium ions (Na^+) bind to lignin, forming polar sodium phenolate, which dissolves easily in water (Rahmidar *et al*., 2018) [13]. Dry cellulose has a very hard texture due to the strong intermolecular forces. The isolation of dry cellulose yielded 28.3222 g from an initial mass of 40 g, resulting in a yield of 70.81%. According to Sutiya *et al*. (2012) [17], the obtained yield is linier to the cellulose in the sample. A higher yield indicates a greater cellulose in the sample. Additionally, a high yield may indicate the presence of residual hemicellulose and phenolate salts, necessitating a bleaching stage for further purification (Walsh, 1991) [23].

The bleaching process aims to enhance the brightness and purity of cellulose while removing non-cellulose compounds that have not dissolved during alkalization. In this stage, H_2O_2 is used as an oxidizing agent to help eliminate remaining impurities (Tutus, 2004) [20]. The final result is a white, odorless cellulose powder.

Nanocellulose synthesis is performed using an acid hydrolysis method. A 64% H_2SO4 solution is added to the cellulose, dissolving it to form nanoscale particles through a top-down chemical method. In this process, larger cellulose particles break down into nano-sized particles, resulting in nanocellulose in colloidal form.

2. Characterization of Cellulose and Nanocellulose using FTIR

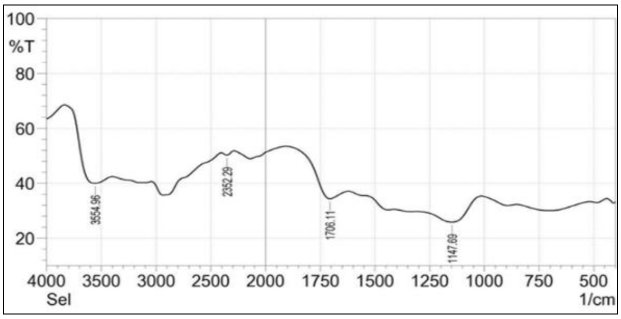

Fig 1: FTIR Spectrum of Cellulose

Table 1: Absorption Region, Bonds, and Types of Functional Groups in Cellulose

Absorption Region (cm^{-1})	Bond and Functional Group Type
1147.69	C-O-C Asymetric
1706.11	Carbonyl Stretch with Aromatic Ring
2352.29	C=O Streching
3554.9	O-H Streching

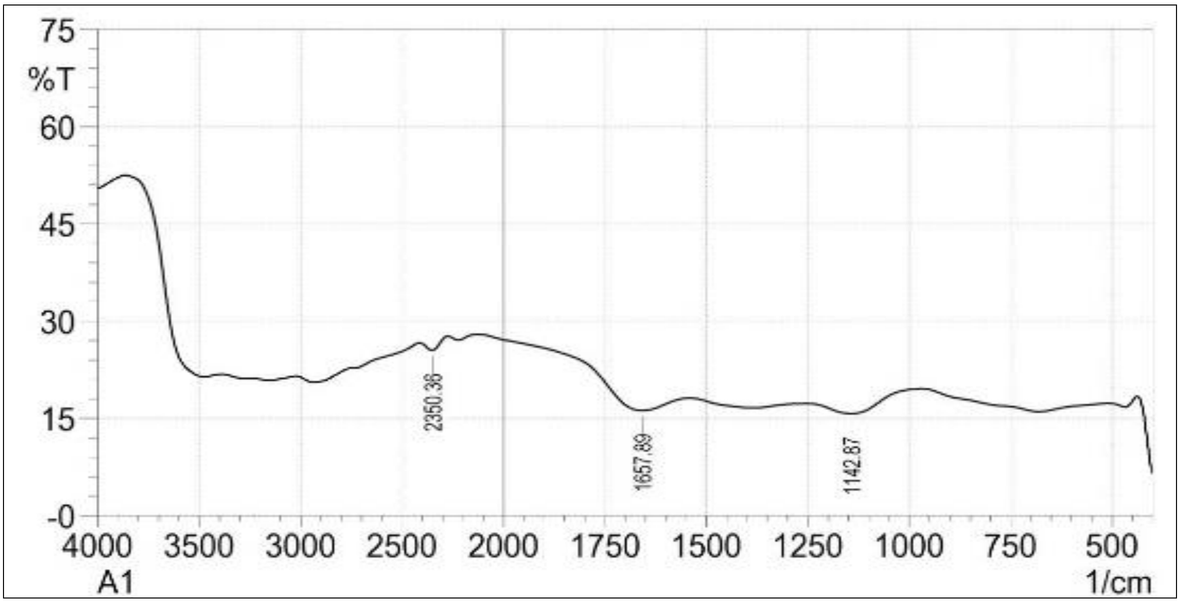

Fig 2: FTIR Spectrum of Nanocellulose

Table 2: Absorption Region, Bonds, and Types of Functional Groups in Nanocellulose

Absorption Region (cm^{-1})	Bond and Functional Group Type
1142.87	C-O-C Asymetric
1657.89	Carbonyl Stretch with Aromatic Ring
2350.36	C=O Streching

Based on Figures 1 and 2, the isolation of cellulose and nanocellulose from kepok banana peels exhibits functional groups consistent with those reported in the literature for cellulose. This is indicated by the disappearance of lignin and hemicellulose functional groups at wavenumbers 1706.11 cm^{-1} (C=O group) and 1147.69 cm^{-1} (C-O group) in cellulose, and at 1657.89 cm^{-1} (C=O group) and 1142.87 cm^{-1} (C-O group) in nanocellulose. The characteristic O-H stretching absorption at 3554.9 cm^{-1} confirms the presence of hydroxyl group vibrations in the isolated cellulose. The characterization results of cellulose from banana blossoms by Salama *et al.* (2023) show similar functional groups at 1740 cm^{-1} (C=O group), 1515 cm^{-1} (C=C group), 1240 cm^{-1} (C-O group), and a characteristic OH stretching absorption at 3417 cm^{-1}. These findings confirm the successful removal of lignin and hemicellulose, supporting the effectiveness of the isolation process in obtaining pure cellulose and nanocellulose.

3. Determination of Optimum Weight

Table 3. Optimum Weight Analysis Results

Adorben weight	Percentage of Weight Loss (%)	
(mg)	Selulose	Nanoselulose
10	17.30	18.23
20	28.30	29.30
30	46.58	47.98
40	40.91	41.82
50	56.98	57.96
60	65.35	66.39
70	65.34	66.31

The adsorption process of methylene blue using cellulose and nanocellulose was visually observed based on the percentage change in sample weight (Dewi *et al.*, 2020) [4].
The determination of the optimum adsorbent weight aims to identify the most effective weight of cellulose and nanocellulose for adsorbing methylene blue at the same concentration. The increasing percentage of adsorption loss within the adsorbent weight range of 10–60 mg indicates that cellulose and nanocellulose exhibit greater adsorption capacity as their weight increases. However, a decline in adsorption at 70 mg is observed, which may be due to incomplete adsorption processes, as the available time was insufficient for all active sites on the adsorbent to bind to the adsorbate (Syafiranda *et al.*, 2017) [18]. Additionally, adsorption reduction can also occur if the adsorbent amount is excessive, leading to insufficient adsorbate molecules to occupy all active sites (Reyra *et al.*, 2017) [14]. The highest adsorption was achieved at a cellulose and nanocellulose

weight of 60 mg, making it the optimal adsorbent weight for efficient methylene blue adsorption.

4. Characterization of Cellulose and Nanocellulose using SEM

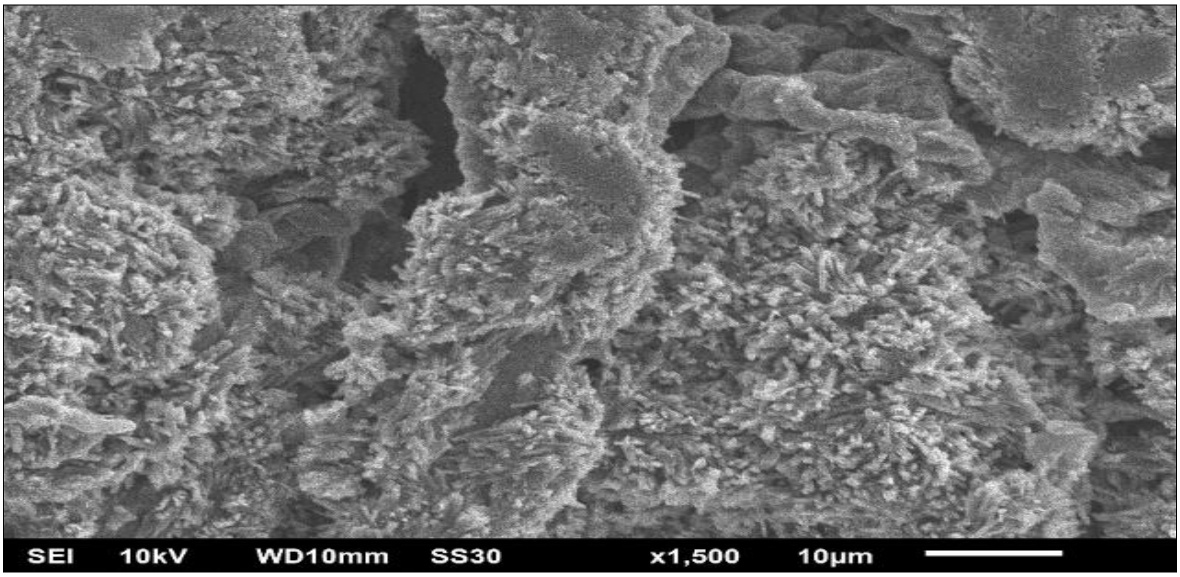

Fig 3: Scanning Electron Microscopy (SEM) image of nanocellulose

Figure 3 shows the SEM micrograph of nanocellulose isolated from kepok banana peel at a magnification of 1500x. The material exhibits a fibrillar morphology with a rough surface and randomly distributed short fibers. The presence of inter-fibril gaps and pores, estimated to range between 1–3 µm, indicates a highly porous structure.

This morphology is consistent with the characteristics of cellulose nanocrystals (CNC), typically obtained through acid hydrolysis. The porous structure and high surface area make this material highly promising for adsorption applications, particularly for methylene blue dye. The fibrillar network facilitates effective interactions between the hydroxyl groups of the nanocellulose and dye molecules, potentially through both electrostatic and physical interactions.

5. Characterization of Cellulose and Nanocellulose using XRD

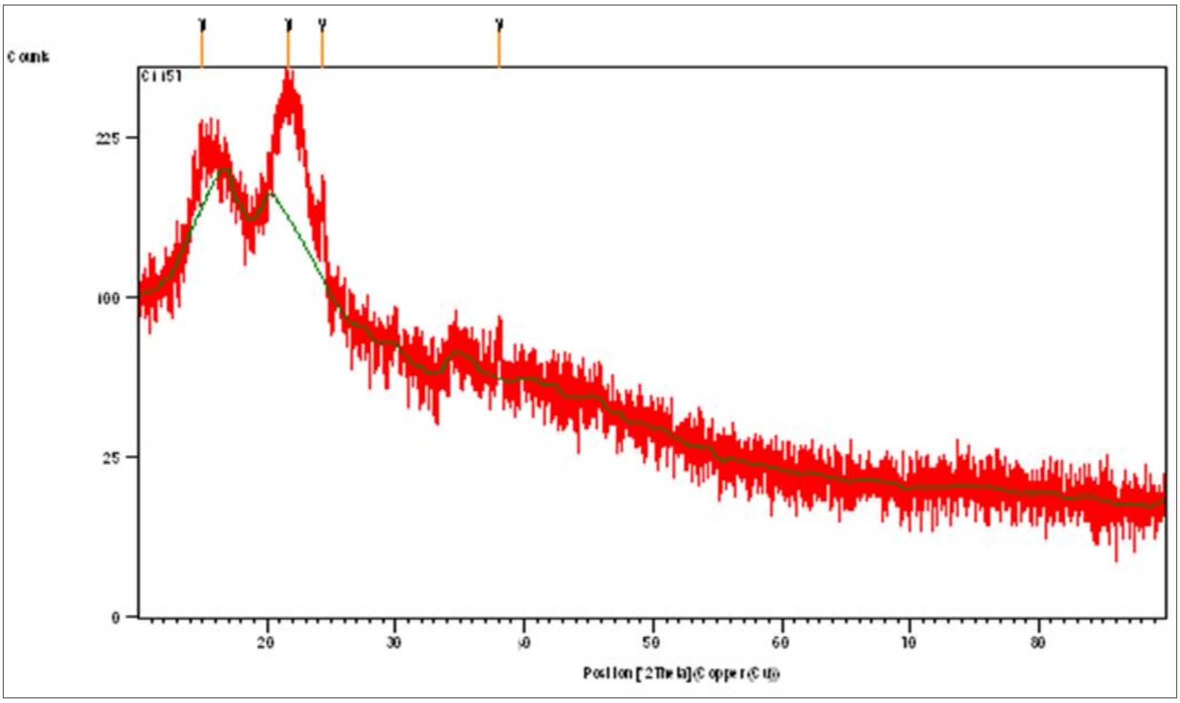

Fig 4: Scanning Electron Microscopy (SEM) image of nanocellulose

Figure 4 presents the XRD analysis of nanocellulose isolated from kepok banana peel through acid hydrolysis. Diffraction peaks observed at approximately 2θ = 15.0° and 22.5° indicate the presence of a crystalline structure characteristic of Cellulose Type I, with the dominant peak corresponding to the (200) crystallographic plane.

In addition, the sloping region between the crystalline peaks represents the amorphous phase of the material. Based on the Segal method, the crystallinity index of the sample is estimated to be around 59.6%, suggesting that the hydrolysis process was effective in increasing the proportion of the crystalline phase.

This result supports the previous SEM findings, which revealed a fibrillar structure with high porosity, thereby further reinforcing the potential of this nanocellulose for adsorption applications, such as the removal of methylene blue dye.

6. Determination of Cellulose Adsorption Capacity and Efficiency

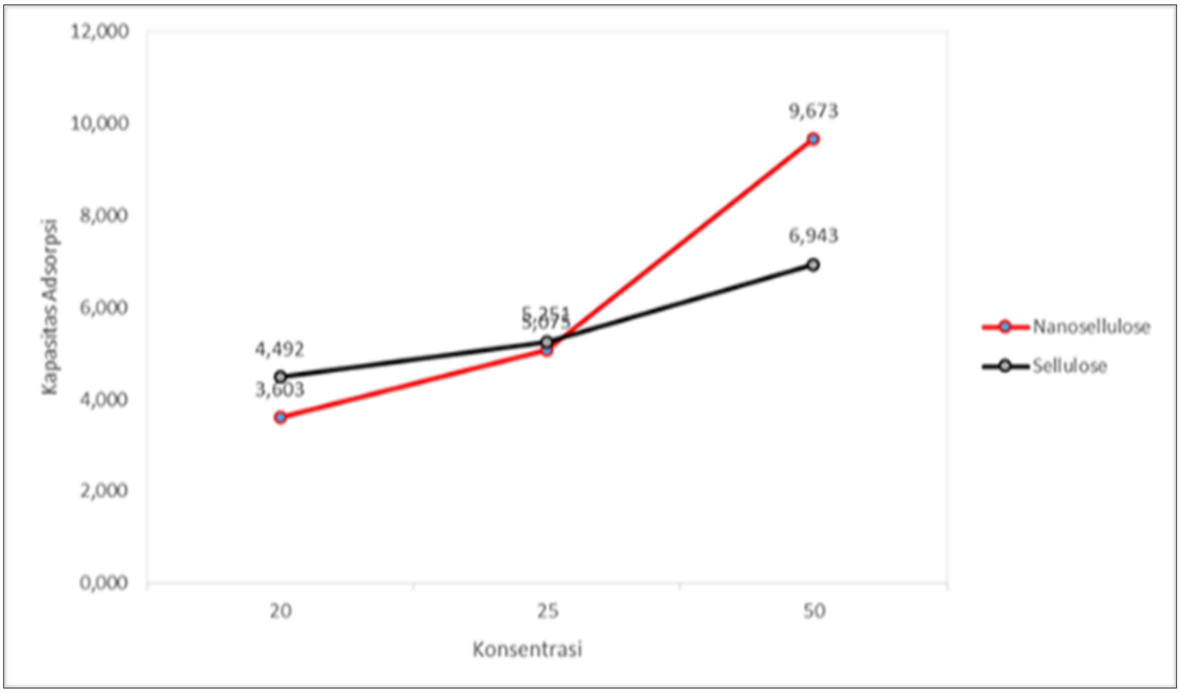

Fig 3: Comparison of Adsorption Capacity of Cellulose and Nanocellulose

The adsorption capacity of cellulose and nanocellulose was evaluated for methylene blue concentrations of 20, 25, and 30 mg/L. The adsorption capacity of nanocellulose increased more significantly compared to cellulose and was directly proportional to the increase in methylene blue concentration. This indicates that nanocellulose has more active sites available to bind adsorbates (Syafiranda *et al.*, 2017) [18]. Nanocellulose's smaller particle size results in a larger surface area, enhancing its adsorption capability. Additionally, nanocellulose has a higher number of hydroxyl (-OH) groups than cellulose, along with physicochemical properties that further support its adsorption efficiency.

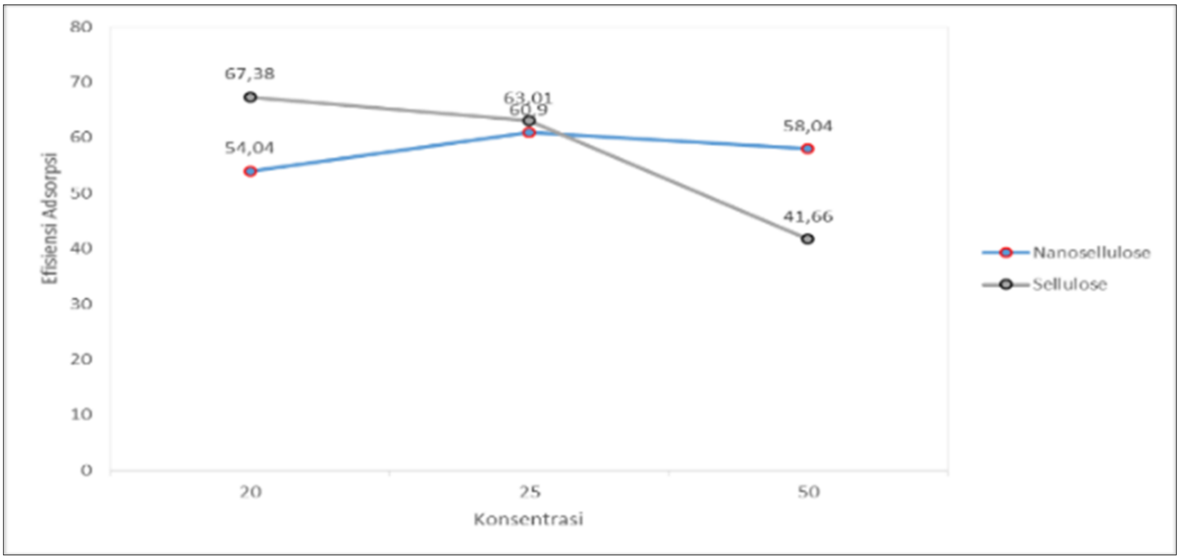

Fig 5: Comparison of Adsorption Efficiency of Cellulose and Nanocellulose

The optimum adsorption efficiency of methylene blue for cellulose that shos in Figure 5 are at 20 mg/L and 25 mg/L. However, the adsorption efficiency of cellulose decreased as the concentration increased. This decline occurs because

cellulose reaches saturation faster than nanocellulose due to its coarser texture, where particles tend to aggregate,
affecting porosity and surface area. In contrast, nanocellulose, with its higher surface area and porosity, maintains greater adsorption capability.
This study demonstrates that cellulose and nanocellulose from kepok banana peels can be used as effective adsorbents for methylene blue, achieving adsorption efficiencies above 40%. The presence of hydroxyl (-OH) groups allows them to form hydrogen bonds, making them promising materials for adsorption applications (Wibowo & Prasetyaningrum, 2015) [24].

Conclusion

Cellulose and nanocellulose can be successfully isolated from kepok banana peels, as confirmed by FTIR characterization, which identified the presence functional groups of C's=O, O-H, and C-H. SEM and XRD analyses revealed that the nanocellulose possesses a fibrillar and highly porous morphology with a crystallinity index of approximately 59.6%, indicating it has high potential for adsorption applications. The adsorption efficiency for methylene blue ranges from 41.66% to 67.38%, demonstrating the effectiveness of cellulose and nanocellulose as adsorbents. The Optimum adsorption capacity of cellulose and nanocellulose were 6.943 mg/g and 9.673 mg/g, respectively, indicating that nanocellulose was potential to be a superior adsorption performance due to its increased surface area and enhanced functional groups.

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