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Dried Nata de Coco with Water Absorptivity Competing Silica Gel

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Abstract

Nata de Coco (NDC) is a network of cellulose fibers that traps abundant of water. If a freshly made NDC is dried to remove nearly all trapped water, we will get a very hygroscopic material. This material is potential for making water adsorber that might compete the well known silica gel. NDC was prepared using standard methods and its water absorption was investigated. Dried NDC was used in this study. For comparison, we also investigated the water absorption of several commercial NDC. To determine its business prospects, the water absorption of silica gel was also investigated. The results showed that dried NDC could absorb water vapor comparable to the absorption of commercial silica gel. This suggests that dry NDC has the potential as an alternative water vapor absorber in food packaging. The advantages of the NDC compared to silica gel are safer and environmentally benign, and easily decomposed.

Introduction

Today, packaged foods are available in increasing quantities, both in terms of quantity and type. The main problem of food in packaging is how it can be stored for a long time without causing significant changes in physical and chemical properties or avoiding harmful effects such as toxicity. Packaged food producers take various steps to extend their shelf life, such as the use of preservatives, the implementation of special processes before packaging, such as pasteurization, the use of packaging technology highly sterile and sophisticated or the insertion of other materials into the packaging. Silica gel is an ingredient that is often inserted into the packaging of food to prolong its life. Solid chemicals that are widely used as moisture absorber is silica gel. Silika gel is often application as a moisture absorber in packaging products such as medicine and food [1]. Silika gel has attracted a lot of attention because of its superiority, so intensive study of silica gel continues to grow rapidly so far [2-8]. Various advances have been made concerning the study of the synthesis, properties and application of silica gel [9-11].

Silika gel is usually non-toxic, but it is a choking hazard, especially for small children. However, silica gel can cause neuromuscular disorders if accidentally swallowed [12]. Another danger of silica gel is that it contains cobalt chloride which can cause effects of nausea and vomiting [13]. Cobalt chloride is an ingredient that makes silica wet (hydrated) in dark blue when dry (anhydrous) in gel and, if consumed in large quantities, can be carcinogenic (a cancer-triggering substance) [14]. This is the reason why most silica gels are labeled as dangerous or toxic [15,16]. This is certainly a problem if the silica gel used as a water absorber in packaged foods is eaten accidentally. This may occur especially in children. Therefore, it is very important to find alternative materials to absorb foods without danger even if consumed. Non-chemical food driers, where no chemical changes occur after the material has absorbed moisture, so it does not change its chemical properties, are one of the good choices.

On the market, non-chemical moisture absorbers are not widely available. Several studies related to moisture absorbers as substitutes for silica gel were carried out, such as Handayani et al (2015) which used rice husk waste., but there are still additional chemical compounds such as sodium hydroxide, hydrochloric acid, and acetic acid [17]. Another organic material that is often used as a water absorber is bacterial cellulose [18]. Another example of research is the application of moisture absorbers in packaging products from the use of bacterial cellulose and eggshells [19,20]. Coconut water is the basic ingredient for Nata de Coco (NDC), which is a bacterial cellulose product resulting from the Acetobacter xylinum fermentation process. Coconut water is a source of micronutrients, often referred to as bacterial cellulose [21,22]. NDC is a material that is very easy to process and obtain with low production costs. Several applications of NDC other than as a food ingredient have also been studied by several researchers, including as an absorber of dyes in artificial wastewater [23], an absorber of heavy metals for water treatment [24], an ultrafiltration membrane [25], and a material for air masks [26]. On the other hand, no there a study that reported NDC as a water-absorbing material as an application of packaged food dryers. So, in this study, the development of water-absorbing material as an application of packaged food dryers based NDC was carried out. The application is quite potential remembering of NDC has a fiber strength less of than 10 nm [27]. According to the latest findings of researchers at Kyoto University, the size of the bacterial cellulose fiber at the nanoscale allows it to transmit light without bending. Its superior properties, such as superior glass, are heat resistant and even softer than plastic. This makes cellulose a dream material with various advantages [28].

Experimental Method

NDC preparation

NDC is the raw material in this study obtained from fermented coconut water. Fermentation is done by leaving the coconut water that has been opened from the fruit for several days (minimum 4 days) to increase its acidity level. Furthermore, coconut water is mixed with sugar, urea and acetic acid with a composition of 900 ml of coconut water; 4.5 g of sugar; 4.5 g of urea and 4.5 ml of acetic acid to adjust the pH to 3-4 then all the mixed ingredients are boiled until boiling at a temperature of 70^{o}C. After boiling, let it cool down and then add 9 ml of Acetobacter xylinum [11]. Acetobacter xylinum is a bacteria that grows during the fermentation of coconut water. The mixture of ingredients is stored in a closed container and stored for 7 days. After 7 days, a gel will grow, which is called NDC.

Sample preparation

In this experiment, several brands of NDC that are available in the market were also used as a comparison. All NDC were sterilized to remove sugar content. Furthermore, pressing was carried out with a load of 5 tons at a temperature of 120°C for 5-10 minutes, then dried. The temperature and pressure are the optimum values obtained from several experiments that have been carried out to produce a thin layer without damaging the structure of the NDC. We have also published this value from previous research [26,29]. The dried NDC was cut into pieces of the same size. In this study, the absorption of NDC will be compared with the absorption of silica gel as a comparison.

Experiment

In this study, dry NDC was wrapped using polyethylene (PE) coated litho paper. This paper is a paper commonly used to wrap silica gel. In order to test the absorption capacity, dry NDC samples were stored together with packaged food in one container (simulated like silica gel stored in packaged food). Measurement of absorption capacity was carried out by directly weighing the mass of dry NDC before storage and after storage together with packaged food in a container. A Fourier Transform InfraRed Spectrometer type FTIR Alpha Platinum ATR A220 was used to check the water content.

Result and Discussion

The main ingredient used as food dryer is NDC, which is pressed with a press when heated. The temperature optimization is done in such a way that the water from the coconut can easily come out but the physical properties of the coconut are not affected. After this process, thin NDC sheets with very low or almost zero water content are obtained.
To compare, we also used several brands on the market in this study as shown in Figure 1(a). A square test object measuring 1 cm long x 1 cm wide was cut from a pressed NDC sample (Figure 1(b)). To hold more water vapor, small sizes are preferred because they have a very large surface area. The total surface area of a material in contact with air divided by the mass of the material is defined as the surface area expressed in square meters per kilogram or equivalent units when expressed in another system of units.

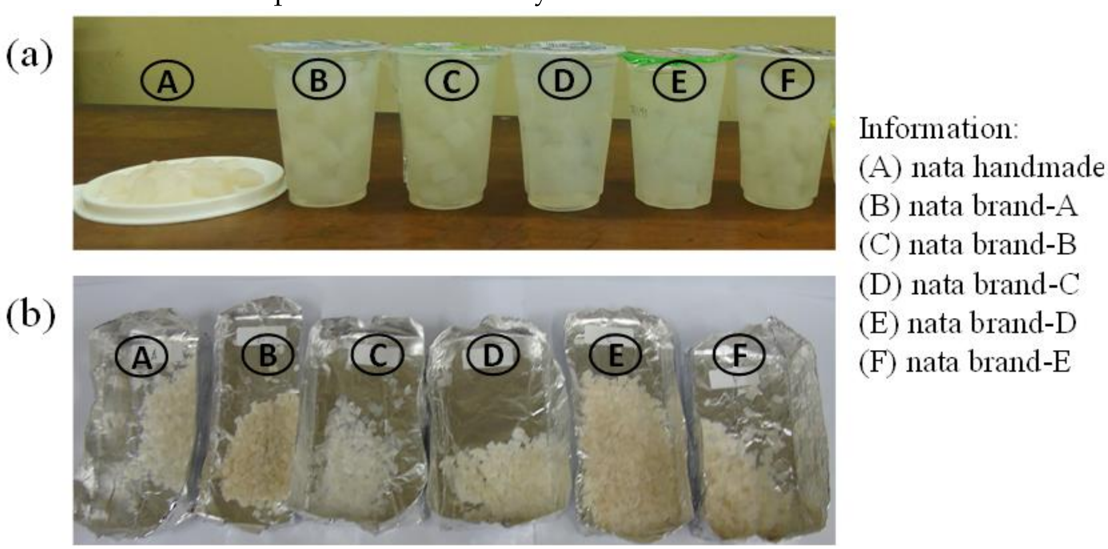


Figure 1. (a) NDC as base material; (b) nata after hot press and cut into small pieces.

All NDC were heated in the oven for 15 minutes at temperature T=500C to equalize the initial condition before vapor absorption test. The equation of the initial conditions must be done before comparing the absorption properties of all NDC. Furthermore, FTIR was used to see the initial condition of the water content of all NDC, are shown in Figure 2.

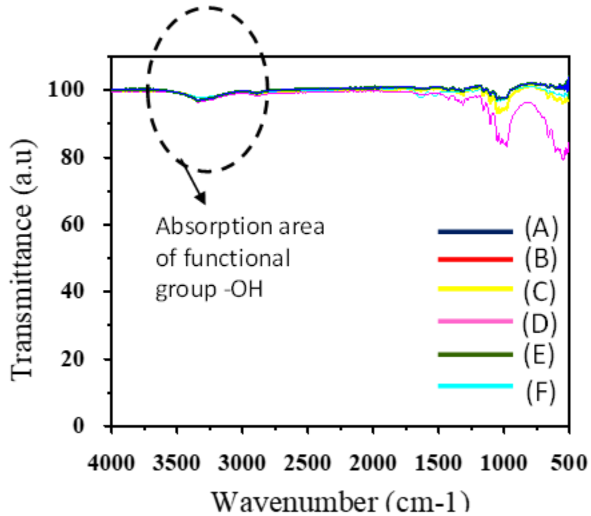


Figure 2. The FTIR spectra of various NDC samples after drying in oven for (A) nata handmade, (B) nata brand A, (C) nata brand B, (D) nata brand C, (E) nata brand D and (F) nata brand E.

A stretch band in the region of 3400-3500 cm-1 indicating the presence of a hydroxyl functional group O-H [30]. This is can be used as an indicator of the water content in sample. Based on Figure 2, we can conclude that all NDC has been in a condition have not absorbed water. Designing NDC as a water absorber to be applied to food dryers as shown in Figure 3(a). The design is similar to the design of silica gel which is used as a food dryer in packaging, where the material is wrapped in strong mesh paper which consists of a plastic layer, a waterproof layer and a fiber layer so that it can be used safely [9].

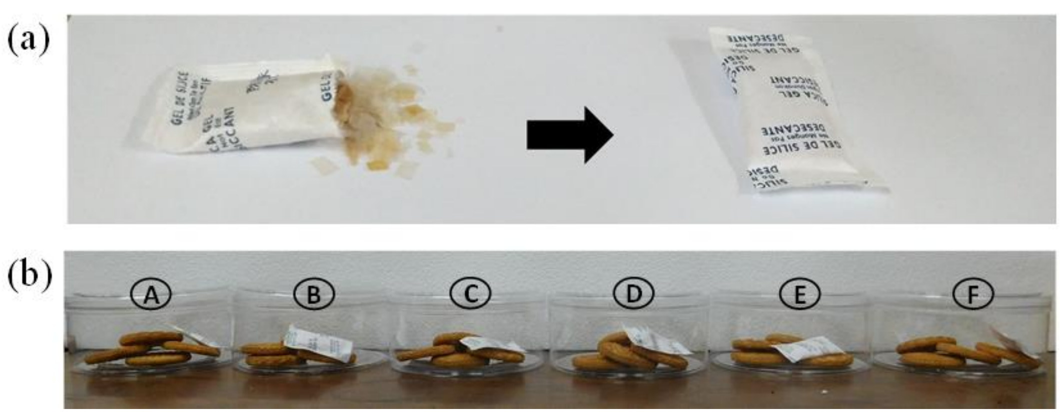


Figure 3. (a)The design of NDC as a water absorber; (b) NDC and biscuits are placed in the same closed container: (A) nata handmade, (B) nata brand A, (C) nata brand B, (D) nata brand C, (E) nata brand D and (F) nata brand E.

Then the sample and the cookies are kept in the same closed container. Storage lasts several days and absorption measurements are taken every day, keeping temperature, dew point and humidity constant. The water content is measured by directly weighing the mass of all the NDC. The result is that the total mass of the NDC increases every day. The increase in mass indicates the amount of water vapor absorbed.

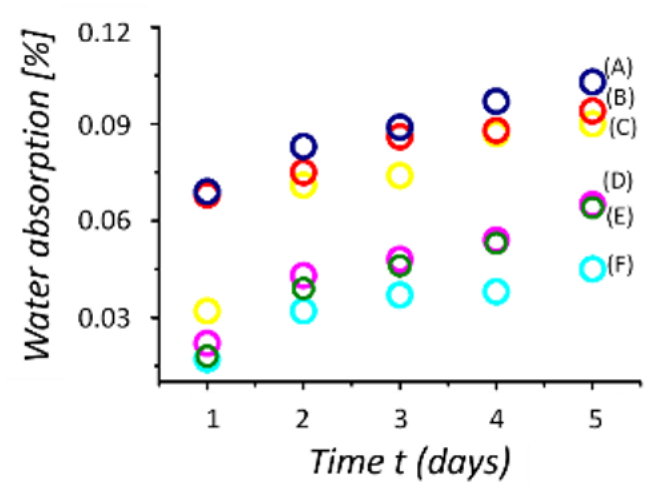


Figure 4. Graph of water absorption by the sample NDC for several days on cake:(A) nata handmade, (B) nata brand A, (C) nata brand B, (D) nata brand C, (E) nata brand D and (F) nata brand E.

Figure 4 shows the weight of water absorbed by dry NDC on different days. The figure shows that the absorption rate initially increases rapidly over time and only reaches a saturation value after a very long time. This behavior is simply explained by the presence of maximum absorption capacity. Suppose the maximum weight of water that can be absorbed by a certain sample as W_0. The absorption occurs if there weight of water is still less than the maximum capacity. The rate of absorption can be approximated to be proportional to the available room in the material, i.e., the difference between maximum capacity with the current capacity. This approximation can explain why initially the absorption rate increases rapidly since the room for absorption is maximum. Therefore, we can propose a simple equation for the absorption rate as

$$\frac{dW}{dt} = \kappa(W_0 - W) \quad (1)$$

with W is the weight of water absorbed at time t and κ are a constant that may differ for different samples. Eq. (1) can be solved simply to give

$$W(t) = W_0(1 - e^{-\kappa t}) \quad (2)$$

Parameters of W_0 and κ for different samples are shown in Table 1.

Table 1. Parameters of W_0 and κ for different samples.

	W_0	κ
Nata handmade	0.09791	1.09
Nata brand A	0.089091	1.26
Nata brand B	0.099602	0.495561
Nata brand C	0.083293	0.275991
Nata brand D	0.073254	0.381514
Nata brand E	0.047412	0.49523

Furthermore, to prove the absorption of water by NDC, we measured the weight of biscuits at different days. Figure 5 shows the bread mass. By assuming the initial mass of the biscuits is and since the water absorbed by NDC satisfies Eq. (2), we conclude the bread mass at time t will satisfy

$$B(t) = B_0 - W(t) = (B_0 - W) + W_0 e^{-\kappa t} \tag{3}$$

Figure 5 is the measured biscuits mass and the fitting curve using Eq. (3).

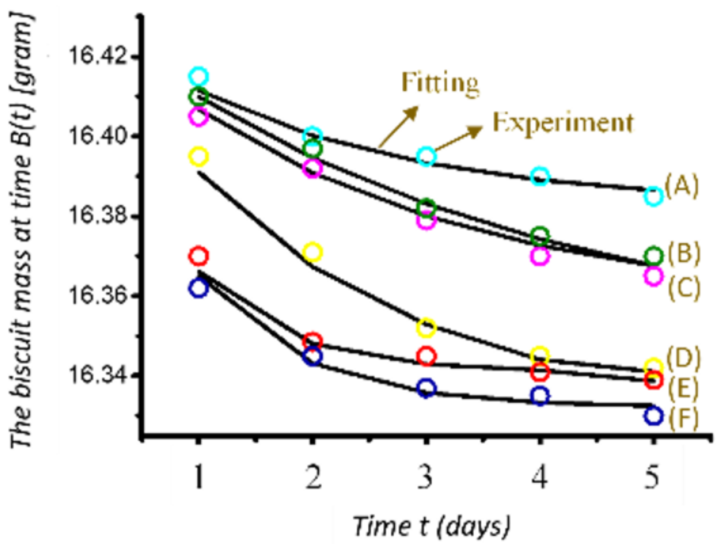


Figure 5. The measured biscuits mass and the fitting curve(A) nata E (B) nata brand D (C) nata brand C (D) nata brand B (E) nata brand A and (F) nata handmade

According to the measurement results, the handmade NDC sample achieved the highest water absorption, which was consistent with the lowest mass value of the cookies stored with NDC. Meanwhile, the lowest water absorption value was found for the E brand NDC sample. This is also consistent with the FTIR measurement curve, which shows that the absorption area of the handmade NDC sample has the largest value (ranging from 3,400 to 3,500 cm-1) compared to other NDC samples, as shown in Figure 6. ImageJ TM software was used to calculate the absorption area. ImageJ TM is a Java-based image processing program [31] for predicting the area absorption curve. The results are shown in Table 2.

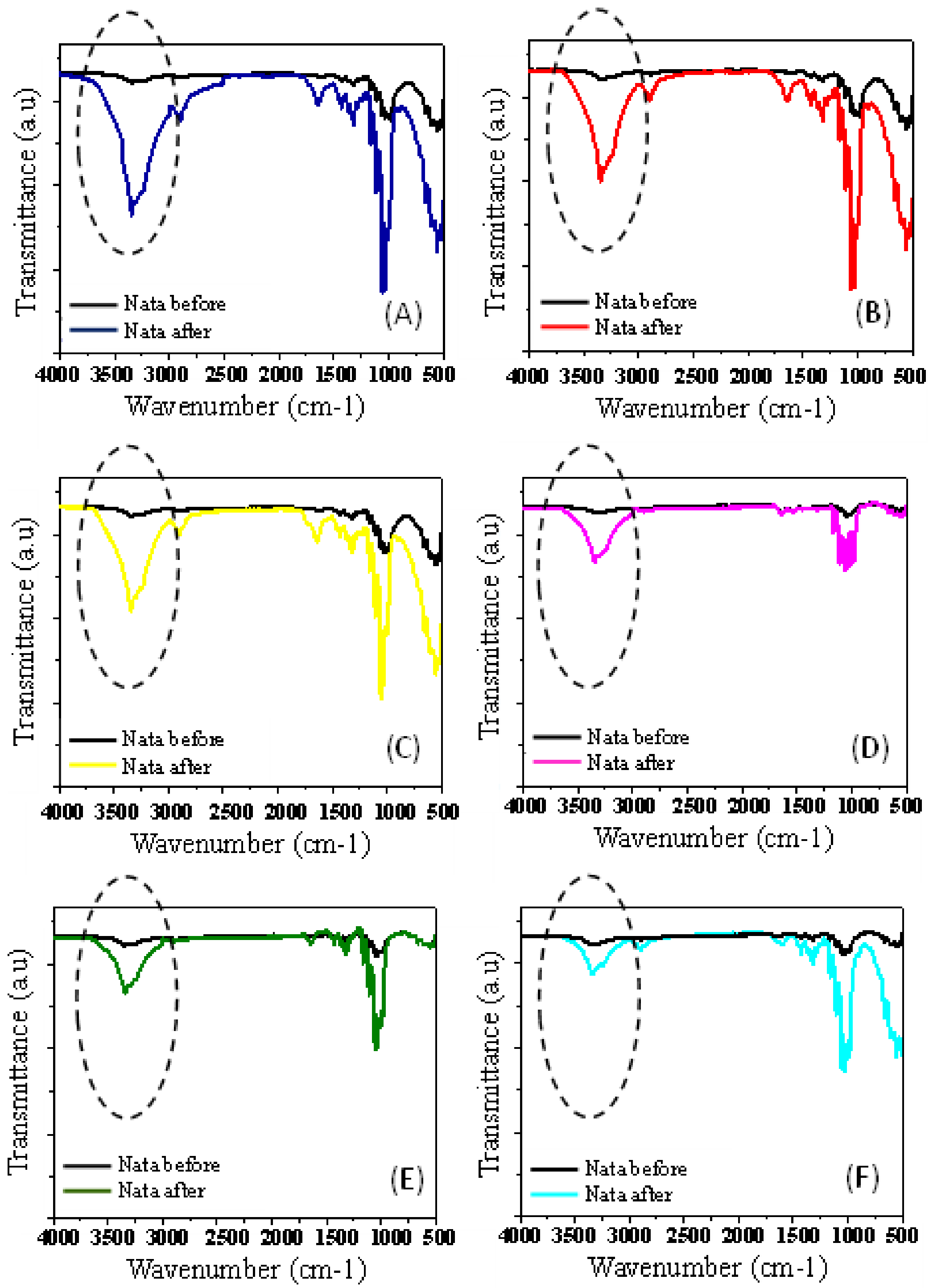


Figure 6. The FTIR spectra of (A) nata handmade, (B) nata brand A, (C) nata brand B, (D) nata brand C, (E) nata brand D and (F) nata brand E.

Table 2. The amount of absorption area.

Sample	Area [-]
Nata handmade	6725
Nata brand A	4359
Nata brand B	4143
Nata brand C	1966
Nata brand D	1846
Nata brand E	1107

With the same method, water absorption also testing was carried out of other types of food packaging. This aims to determine whether NDC also can be applied to other food packaging, not limited to just one type of food packaging. Therefore, absorption tests were carried out on 3 other types of packaging food namely cracker, wafer and bread. We used NDC handmade. The result is shown in Figure 7 (a). Furthermore to prove the absorption of water by NDC, we measured the weight of bread at different days and fitted curve using Eq. (2). The measured mass of all samples and the fitting curve using Eq. (2) are shown in Figure 7(b).

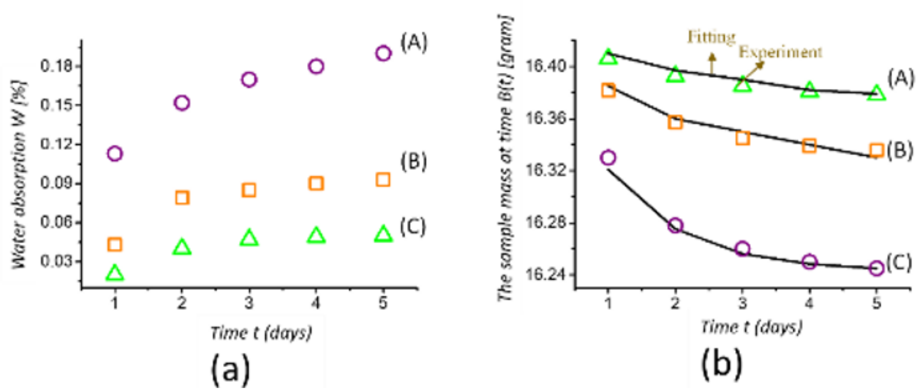


Figure 7. (a)Graph of water absorption by the sample natahandmade for several days on (A) bread, (B) wafer and (C) crackers; and (b) The measured biscuits mass and the fitting curve: (A) bread, (B) wafer and (C) cracker.

Silica gel also used as the comparison for the absorption water test. Generally, silica gel is widely used as an absorber of moisture in the storage of various hygroscopic materials [6]. Therefore, in this study silica gel was used as a comparison. Silica gel and NDC were heated together in the oven at the same temperature and during the same time interval to equalize the initial conditions. The matching of the initial conditions must be done before comparing the absorption properties of the two materials as shown in Figure 8**.**

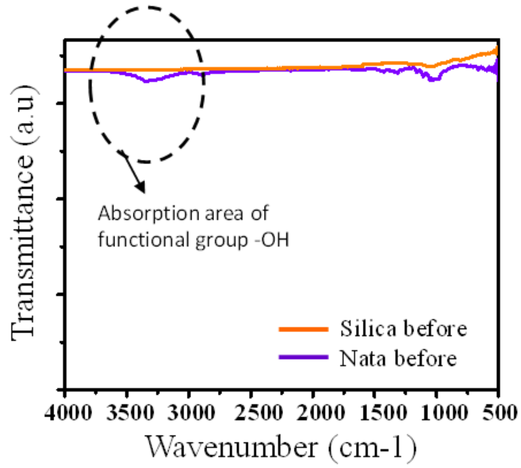


Figure 8. The FTIR spectra after drying in oven.

Figure 8 shows the FTIR spectra of NDC samples and a silica gel sample that shows the initial condition of both samples prior to using as an absorber. Especially looking in the region of 3400-3500 cm-1 indicating the presence of a hydroxyl functional group O-H. This peak related to water or other –OH bond in the material. It is clear that for silica gel we did not obtain any peak to indicate that the silica gel sample did not contain any water or related compounds containing –OH bonds. To the contrary, the NDC samples show the presence of –OH peak. We suspect that the peak did not originate from water molecules, instead it originated from cellulose forming the NDC fibers.

NDC is composed of three stages of reaction based on the mechanism of bacterial cellulose formation. Hydrolysis of sucrose that produces fructose and glucose is the first stage. Sucrose is the main sugar content. In the acidic medium, cellulose can undergo hydrolysis reaction, either totally or partially. The hydrolysis reaction involves the breaking of ties glycosides so that can produce glucose units. In the early stages of this reaction, H+ ions (protons) will attack the oxygen atom on glycoside bond. This step is followed by breaking the C-O bond that lasts a slow. Next will form substance between cyclic carbocations and react with water molecules to form a stable final product with the discharge of a proton. In alkaline media, cellulose can also experience a variety of reactions. The degradation process will lead to termination of the glycoside bond like hydrolysis reaction in acidic media. Glycoside bond solving process in an alkaline medium tends to be on a slower pace when compared with the process of solving in acidic media [7].

Based on the description mechanisms above, either in acidic or alkaline conditions, bacterial cellulose does have functional groups -OH including also in NDC. It is also evident from the various FTIR testing by other researchers shows that pure cellulose, bacterial cellulose and the NDC have characteristics containing -OH groups [8,32]. NDC is made from coconut water+acetic acid+sugar+bacterial cellulose, coconut water has a high content of OH, acetic acid has a chemical formula CH_3COOH also has a content of OH and sugar and bacteria-containing proteins that contain CHO group so it is possible to also contain OH bonds. NDC have hydroxyl groups but has various absorption, it has been demonstrated by the wide group absorption peak that indicated by FTIR. Hence, any kind of NDC has the characteristic absorption of -OH functional groups are different. NDC containing cellulose with characteristics having free -OH functional group so that the appearance of an absorption band of the -OH functional groups can'tbe used as the main indicator whether or not the water content in NDC. But transmittance value of absorption band -OH functional groups showed almost the same as silica gel(Figure 8), which means in NDC there are no water content so that NDC and silica gel already be in the same condition.

Absorption testing is done by placing of NDC and silica gel in a chamber containing a bread with a mass of 16.43 grams. NDC and silica gel will then absorb the water content in the bread after that measured the percentage of their water absorption for several days are shown in Figure 9(a). In the graph above shows that the sample NDC is higher can absorb water in the bread more than silica gel. And also to further prove the absorption of water by NDC, we measured the weight of bread at different days and fitted curve using Eq. (2). Parameters of W_0 and κfor NDC samples are 0.3338661 and 1.21677 and then for silica gel are 0.207175 and 0.264776. The measured mass of bread and the fitting curve are shown in Figure 9(b).

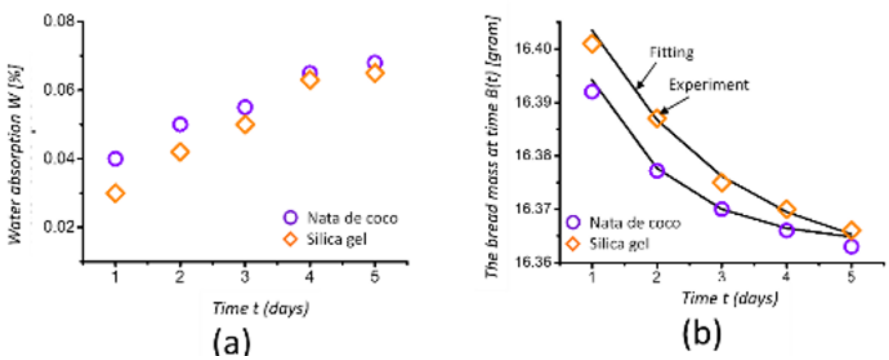


Figure 9. (a) Graph of water absorption by the sample nata and silica gel for several days on and (b) The measured biscuits mass and the fitting curve.

These results of fitting curve are consistent with decreased in a mass of bread. In Figure 9. Decreased of mass of bread caused by reduced water content in bread because it is absorbed by NDC and silica gel. To determine unit structure as well as a large of water absorption, NDC and silica gel characterized by FTIR spectrophotometer again then compared the results with the result of absorbency before absorption testing. The characterization results as shown in Figure 10.

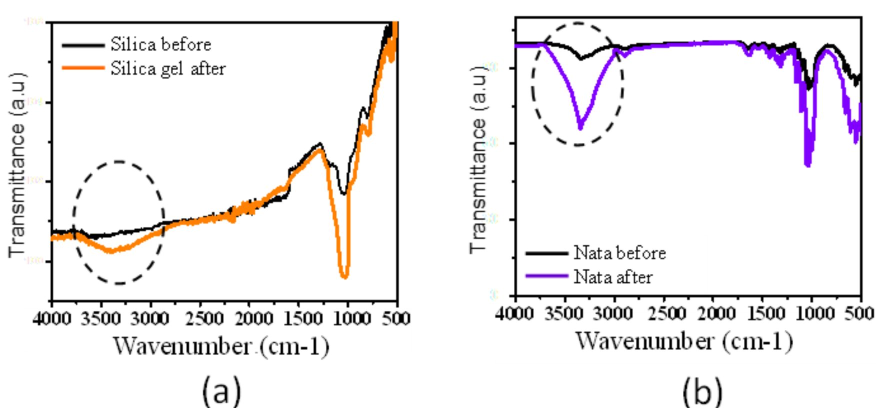
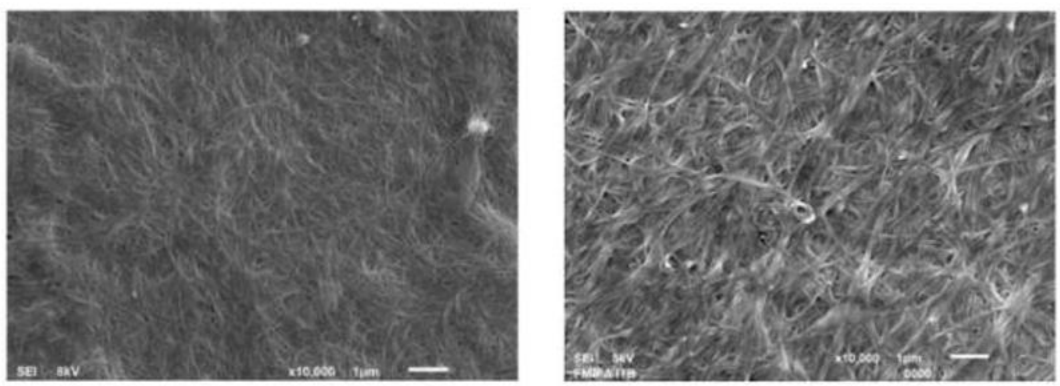


Figure 10. The FTIR spectra of (a) silica gel and (b) NDC.

Results of FTIR characterization the region of 3400-3500 cm-1 shows at NDC and silica gel after absorption testing showed decrease of transmittance. This shows that NDC and silica gel has absorbed water from the bread. Therefore, this outcome accordance with results of water absorption test that NDC has high water absorption, even higher than silica gel. so that it has the potential to be preservative food packaging in the future, substituting for silica gel. It has the potential to be preservative food packaging in the future, substituting for silica gel.

From the measurement results it is clear that nata de coco absorbs higher moisture than silica gel. Next, microscopic structure observations were carried out, the results are shown in Figure 11. It can be seen in the image that the SEM results of the products (each at 10,000x magnification) after the water vapor absorption test were carried out had larger fiber sizes than before the absorption test was carried out. This proves that it is true that the product absorbs water vapor in food ingredients.



(a) (b)

Figure 11. SEM characterization results (a) before the absorption test and (b) after the absorption test

Viewed from several fields, this research has commercial prospects in the fields of materials and technology. The first is that using nata de coco fiber as the main ingredient for food packaging is a new innovation, namely making food packaging from edible and environmentally friendly materials. Secondly, no one has ever reported that nata de coco can be used as active packaging to absorb moisture to extend the shelf life of food, meaning that from the application stage of nata de coco the study of its application becomes wider. Thirdly, in terms of innovative technology, this research offers technology that is simple, easy and cheap so that it is also suitable for application in medium-scale industries and MSMEs. The number of packaged foods currently available is increasing, manufacturers are competing to extend their shelf life by using silica gel, with the presence of dry nata de coco this has become a new alternative for food preservatives whose raw materials are abundantly available. Currently there is not a single piece of food that is not packaged so the prospects for developing this research for food preservation in the future are very large.

Conclusion

We conclude that the water absorption study of Nata de Coco (NDC) has been successfully reported. NDC made from composition of 900 ml of coconut water; 4.5 g of sugar; 4.5 g of urea and 4.5 ml of acetic acid. NDC as the basic material is dried by pressing using a hot press. We design dried NDC as a moisture absorber by wrapping it using litho paper laminated with poly ethylene (PE). This paper is commonly used to wrap silica gel. The measurement of absorption capacity was carried out by weighing dried NDC before and after being stored with food. As a result, the entire mass of NDC increases every day, indicating that NDC absorbs moisture in food. The increase in mass indicates the amount of water vapor absorbed. In this study, we propose a simple equation for the absorption rate. The final results also show that the absorption capacity of NDC is comparable to the absorption capacity of silica gel. Parameters of W_0 and κfor NDC samples are 0.3338661 and 1.21677 and then for silica gel are 0.207175 and 0.264776. To confirmation amount of water that absorbed, we used Fourier Transform InfraRed Spectrometer (FTIR). The absorption area from sample NDC is the largest (in the region of 3400-3500 cm-1) than silica gel. So we conclude if NDC can be used as an alternative as absorbent material for water in food packaging so that food can last longer.

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