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THE MESOPOROUS BIOSILICA CATALYST FROM ANDONG BAMBOO LEAF FOR DIRECT-PYROLYSIS REACTION

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ABSTRACT

Silica is a functional material with broad benefits, including as a catalyst. It is essential to substitute synthetic silica with natural silica to support green technology and economic development. The silica extraction process from bamboo leaf waste was carried out using an acid-base solution and a cetyltrimethylammonium bromide (CTAB) template structure to get mesoporous biosilica. This mesoporous biosilica was then applied as a biocatalyst for α-cellulose direct pyrolysis. Biosilica was characterized using various analyses including Fourier Transform Infrared Spectroscopy (FTIR), Surface Area Analyzer (SAA), Scanning Electron Microscope (SEM), gravimetric methods, and applications to the cracking process using Pyrolysis Gas Chromatography Mass Spectrometry (Py-GCMS). The CTAB addition is divided into three variations, namely 0.05:1, 0.1:1, and 0.2:1. The data found that the highest yield was produced in the CTAB biosilica 0.2:1, and the silica content in the bamboo ash and CTAB biosilica sample was 60% and 90.5-93.6%, respectively. The surface acidity of the biosilica ranged from 1.97 and 2.1 mmol/g. The essential groups in the biosilica formed are hydroxyl, silanol, and siloxane groups, with the morphology of the silica being observed to be irregular in shape, forming aggregates like coral. The surface area of biosilica with the ratio of 0.05:1, 0.1:1, and 0.2:1 was 177.068 m^2/g, 661.166 m^2/g, and 684.852 m^2/g, respectively, with a pore size distribution following the mesoporous class. The α-cellulose cracking using py-GCMS with a biosilica catalyst at CTAB variations of 0.05:1, 0.1:1, and 0.2:1 yielded a hydrocarbon content of 44.88%; 61.6%; and 30.4%.

Keywords: α-cellulose, Catalytic Cracking, Mesoporous Silica.

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INTRODUCTION

Indonesia's natural resources, especially biomass, have high biodiversity and abundance. Bamboo is one of the most common types of plants, with hundreds of species spread across the entire area. Bamboo is still limited and produces quite a lot of leaf waste without appropriately being used and polluting the environment.[1] Effort are needed to convert this waste into more sophisticated biomaterials to provide added value while reducing the environmental pollution. Bamboo leaves contain silica components that can be used as biosilica raw materials. Silica is an abundant, cheap material, has stable surface properties in acidic media, can be developed on a surface, has good thermal stability, is resistant to microbial attack, and has a lower cost.[2,3] Silica is a compound widely used in various fields, including as raw material for glass, adsorbents, catalysts, and composites.[4–9] Mostly, silica is obtained from chemical raw materials, namely Tetraethyl Orthosilicate (TEOS), a source of silica. TEOS has many disadvantages, including being expensive, flammable, and difficult to store.[10] Therefore, looking for alternative materials that can be used

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as silica raw materials is essential. Several methods to obtain silica from natural raw materials include hydrothermal, alkaline fusion using KOH reagents, furnace tools assisted, and sol-gel.[11–13] These methods have their respective advantages and disadvantages, but the sol-gel method can be carried out under stable conditions with low temperature and pressure. The silica catalyst was developed recently by researchers. The application of silica as a catalyst can be an accelerating reaction agent, such as cracking reactions to break large molecules into small molecules. Therefore, from this reaction, hydrocarbon or valuable chemical products are obtained. Using microporous silica catalysts can cause limited diffusion of large molecules in the pores and become easily deactivated due to coke formation, so this catalysis process requires mesoporous silica material. Mesoporous silica has been widely developed because of its high surface area and adaptable heteroatom composition characteristics for heterogeneous catalysts and catalyst carriers. Mesoporous molecules have large pores, which can be used for polymers and other large-sized compounds and produce better particle dispersion.[14] The various silica applications depend on the silica's modification, such as using the CTAB surfactant so that the pore structure of the silica can be controlled.[15] Silica extracted from rice husk waste and modified its pores using CTAB to obtain a pore size of 3.13-3.58nm of mesoporous silica.[10] Meanwhile, the pore size of 2.5-2.8nm was also accepted from TEOS sol-gel extraction using CTAB.[16] The mesoporous biosilica as a catalyst is interesting; therefore, in this study, silica was extracted from the raw material of bamboo leaf waste to obtain biosilica, which was then modified using cationic surfactant CTAB with various concentrations to see its effect on the silica formed. Then the silica was applied to the α-cellulose cracking process using the py-GCMS instrument to make the product compound more specific than the reactants.

EXPERIMENTAL

Materials and Equipment

The materials used were andong bamboo leaf obtained from Bogor-Indonesia, distilled water, NaOH p.a (Merck, Germany), pyridine p.a (Merck, Germany), HCl p.a (Merck, Germany), CTAB (Himedia), α-cellulose (Sigma-Aldrich). The biosilica was characterized with Surface Area Analyzer (BET JWGB Meso 112, China), Scanning Electron Microscope (SEM-ZEISS), Fourier Transform Infra-Red (FTIR), pyrolysis-Gas Chromatography-Mass Spectroscopy (py-GCMS-Shimadzu).

Silica Extraction from Andong Bamboo Leaf

The first step is collecting the bamboo leaf waste, then washing it from impurities and air-dried. The bamboo leaf samples were then burned in a conventional drum for 5-6 hours to turn the leaves into ash. The ash becomes a precursor in the silica extraction process using the primary NaOH reagent. Bamboo leaf ash was reacted with NaOH with ash: NaOH ratio of 5:4 (w/w) dissolved in 80 mL of distilled water. Subsequently, reflux was carried out at 80° C for 2 hours while stirring. The resulting mixture was cooled and centrifuged for 10 minutes at 3500 rpm, and the Na_2SiO_3 filtrate was taken.

Biosilica Mesopore Synthesis

CTAB surfactant is weighed based on the CTAB mole ratio: SiO_2 (0.5:1; 0.1:1; 0.2:1). For the stirring process, the distilled water is added into CTAB and then mixed for 15 minutes. The Na_2SiO_3 filtrate was dropped into the CTAB solution and stirred for 30 minutes. This solution was added with HCl 1M, and the pH was controlled to 10 while stirring for 2 hours. The aging process was conducted at 25°C for 24 hours to increase the condensation time. The gel was washed and pH adjusted to the neutral condition, then dried in an oven at a temperature of 60°C. The solid was calcined using a furnace to remove CTAB at a temperature of 550°C for 6 hours (noted as biosilica 0.5:1, 0.1:1, and 0.2:1).

Biosilica Application

The biosilica was applied as a catalyst in the cracking process of α-cellulose using py-GCMS. The cracking/pyrolysis of α-cellulose using this device was carried out at a temperature of 500°C, with a ratio sample weight: catalyst of 5:1 w/w-the injection temperature, interface temperature, and detector temperature range of 280°C. The carrier gas is helium, with a total flow of 46.5 mL/min.

Analysis and Characterization of Biosilica

In this study, several analyses were carried out to support information regarding the extraction and modification of biosilica from bamboo leaf ash.

Analysis of Silica Content Using the Gravimetric Method

The best ash and silica samples (0.1:1) were weighed as much as 2 grams, added 37% concentrated HCl, and heated on a hotplate until the HCl had evaporated. Then, the sample was washed using hot distilled water until neutral and filtered using filter paper. The residue was heated in a furnace at 700°C for 4 hours. After heating, the residual weight was weighed, and the silica content was calculated using the equation:

Silica content: $\frac{b}{a}\ x\ 100\%$

a: sample weight of silica before treatment(g)
b: sample weight after treatment (g)

Analysis of Adsorption of Biosilica on Pyridine Bases

As much as 0.4 g of silica sample was placed in a crucible, and the adsorption process was carried out in a desiccator saturated with pyridine vapor. Then, the adsorption process was carried out for 24 hours, after which the samples were weighed until they were constant. The calculation of silica adsorption to pyridine follows the equation.

AS: $\frac{W3-W2}{(W2-W1)M}\ x\ 1000$

AS: silica adsorption
W1: the empty crucible (g)
W2: sample and crucible before pyridine adsorption (g)
W3: sample and crucible after pyridine adsorption (g)
M : molecule weight of pyridine (79.1 g/mol)

Silica Characterization with Instrumental Analyzer

The functional groups of silica were determined using FTIR and morphological features using SEM, while the size pore, distribution pore, and surface area using SAA with BET and BJH methods. The application of silica as a biocatalyst was analyzed using py-GCMS to obtain chemical components produced from the pyrolysis reaction.

RESULTS AND DISCUSSION

Extraction and Modification of Silica from Bamboo Leaf Waste using CTAB

The silica extraction process generally begins with the reaction of bamboo leaf ash using essential reagents such as NaOH to bind silica to sodium to form sodium silicate. Then, hydrolysis is carried out with an acid solution so that the silica can be bound to the hydroxyl group to form Si-OH and condensed into Si-O-Si. Then when the sol-gel reaction is achieved perfectly, it will form SiO_2, which we know as silica. Silica will dissolve in the NaOH base and bind with Na ions to form sodium silicate.[17] The following process synthesizes mesopore silica from the previously obtained sodium silicate filtrate. The mesoporous silica synthesis process was carried out by adding the surfactant CTAB and HCl gradually. With the addition of HCl, an ion exchange occurs between Na^+ and H^+ to produce silicic acid. In other words, the siloxy group (Si-O-) becomes silanol (Si-OH) through the protonation route.[18] The high concentration of protons (H^+) affected by acid addition and the Si-OH groups obtained from Si-O- in sodium silicate solution. The Si-OH groups then attacked with O-Si-O to form Si-O-Si. This process occurs rapidly and continuously to form amorphous silica. CTAB is a cationic surfactant used in many industrial processes, disinfectants, antiseptic agents, drug formulations, biocides, emulsifiers, and corrosion inhibitors.[19] CTAB includes cationic surfactants, where cationic surfactants are good emulsifying agents.[20] The solution pH was adjusted to 10 because there was a strong electrostatic interaction between the surfactant and silica and the faster condensation rate, which caused the simultaneous growth of the surfactant-silicate assembly. According to [21], when the pH > 12, the mixture becomes transparent, which indicates that the solids formed are all dissolved. The silica yield was determined from silica weight before and after the extraction and modification process, as shown in Table-1.

Table-1 shows that each extraction and modification process produces different yield values, especially when the product is treated with calcination to remove residual CTAB and aims to open silica pores. The variation of the CTAB produced the highest yield: SiO_2 ratio of 0.2:1, as much as 62.82%.

Table-1: The Yield of Each Extracted and Modified Biosilica Using CTAB

Mol ratio of CTAB: SiO_2	Silica before calcination (gr)	Silica after calcination (gr)	Yield (%)
0.05:1	14.6577	8.6761	59.19
0.1:1	12.8292	3.9146	30.51
0.2:1	15.4401	9.6995	62.82

Analysis of Silica Content and Silica Adsorption on Pyridine Bases

In this study, the silica content and surface acidity levels obtained from CTAB-modified biosilica were also carried out (shown in Fig.-1).

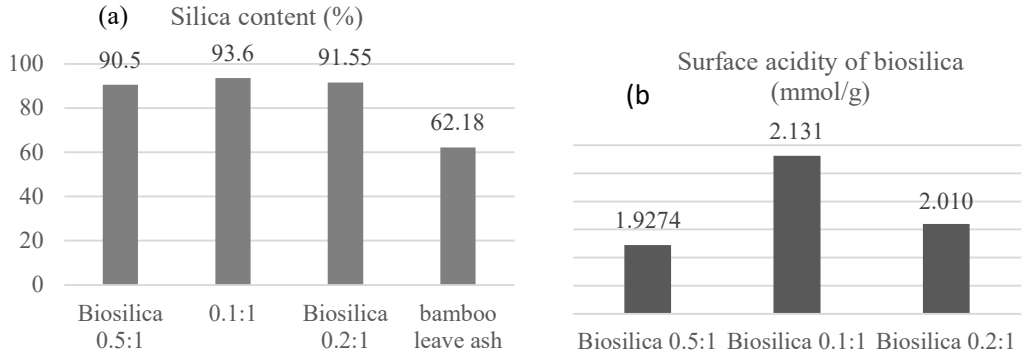

Fig.-1: The Silica Content of Biosilica (a) and Surface Acidity of Biosilica (b)

Figure-1 shows that after undergoing modification using CTAB and calcination, the calculated silica content increased from 62.18% to 93.6% after modification. This high content of silica describes the purity of the silica in the extracted sample. From this result, we can conclude that the silica extraction and modification process has been successfully carried out, increased the purity of the silica, and reduced the impurities from the initial sample. The analysis of the biosilica surface acidity was conducted on the extraction and modification result using CTAB. From the data, it was found that there was an increase in the calculated acidity of the biosilica after modification; this is allegedly going to increase the catalytic performance of the resulting biosilica because the catalytic performance is generally influenced by the acidity of the catalyst itself.[22]

CTAB Modified Silica Functional Group Analysis Using FTIR

FTIR spectra of biosilica material samples with CTAB: SiO_2 ratios of 0.05:1; 0.1:1; and 0.2:1 is shown in Fig.-2. This characterization confirms the biosilica material extracted and modified by CTAB made from andong bamboo leaves using the sol-gel method.

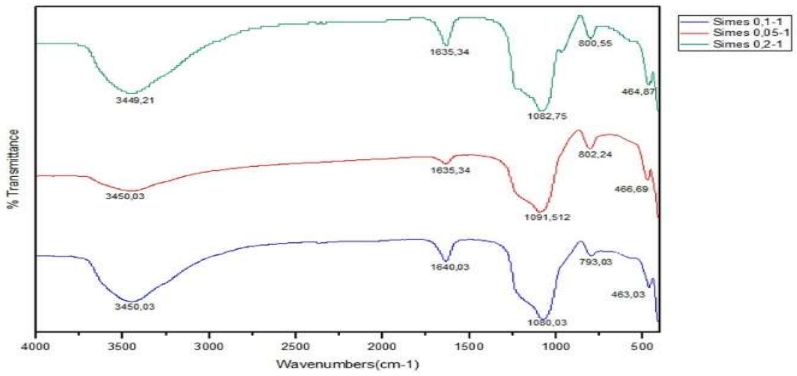

Fig.-2: FTIR Spectra of Biosilica with CTAB Modification

All the biosilica materials showed broadened spectra at a wave number of around 3400 cm^{-1}, related to the presence of water molecules' stretching and bending OH groups (free hydroxyl groups). While the spectra

at wave number 1635-1640 cm^{-1} allegedly indicate the presence of Si-OH groups stretching from the silanol surface that binds to water molecules. Another determining silica group, symmetric and asymmetric Si-O-Si (siloxane groups), is shown at the vibration wave numbers 1080-1090 cm^{-1} and 793-803 cm^{-1} so that all materials are derived from SiO_2 stretching composites of silica. This data is similar to the research of Watthanachai et al.,[23] and Purbaningtias et al.,[14], which also found OH, SiOH, and Si-O-Si groups in mesoporous silica samples with wave numbers of 3000-3700, 1640, and 1090 cm^{-1}, respectively.

Table-2: FTIR Analysis of Biosilica Samples

Wavenumber	CTAB 0.1:1	CTAB 0.5:1	CTAB 0.2:1	Keterangan
OH stretching	3448.5	3449.90	3449.21	Free hydroxyl groups of water molecules
H-O-H bending vibration/Si-OH stretching	1634.8	1635.42	1634.11	Free hydroxyl groups of water molecules/ surface silanol H bond to the water
Si-O-Si	1080.03	1091.40	1082.75	
Si-O-Si vibration	793.05	803.14	800.55	
Si-O	463.03	467.09	464.87	

Morphological Analysis of CTAB Modified Silica Using SEM

The morphology of the biosilica with various surfactant ratios was revealed by analysis using SEM (shown in Fig.-3.). From Fig.-3, the morphology of the silica looks very irregular and forms an aggregate. This data is similar to previous research that silica from bamboo leaves tends to agglomerate.[24–26]

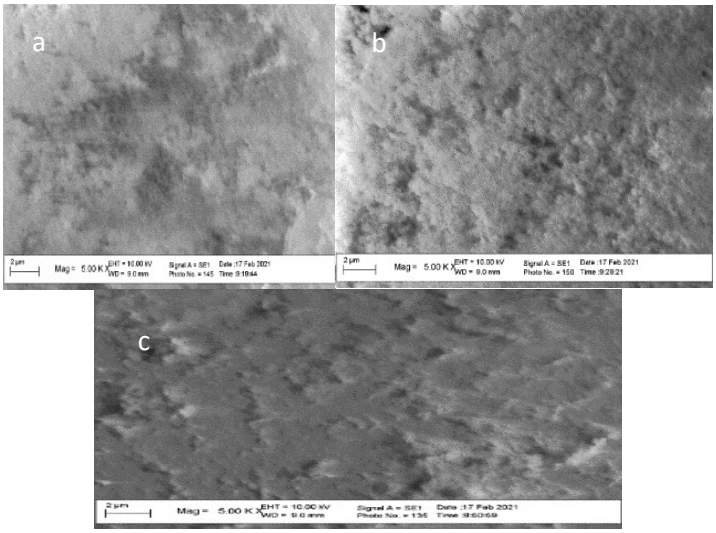

Fig.-3: Morphology of 0.05:1 (a), 0.1:1 (b), and 0.2:1 (c) of Biosilica Using SEM

Silica modification can change the morphological pattern of the silica surface itself, such as forming aggregates and becoming more irregular.[27] Therefore, with increasing surfactant concentration, aggregates' formation becomes more massive.[28-29] The catalyst morphology shape can affect the activity and selectivity of the catalyst because the particles are inversely proportional to the acid site interactions,

Analysis of Pore Size, Surface Area, and Pore Distribution of Biosilica Identified Using SAA With BET and BJH Methods

Analyzing the pore size, surface area, and distribution of silica pores was carried out using the adsorption-desorption nitrogen process on the samples using SAA. All samples were initially degassed at 250°C for 2 hours under vacuum conditions. Then the sample was analyzed by the adsorption-desorption process of N_2 at 77K isotherm, and the specific surface area was calculated using the BET equation. In contrast, the pore volume was calculated from the adsorbed N_2 at a relative pressure of 0.99.

Based on the N_2 adsorption-desorption pattern, it can be seen that the sample shows a type IV isotherm pattern according to the IUPAC classification and has a hysteresis loop with quite sharp desorption

adsorption branches at relatively high pressures. This graph also indicates the presence of a cylindrical mesoporous characteristic.[23]

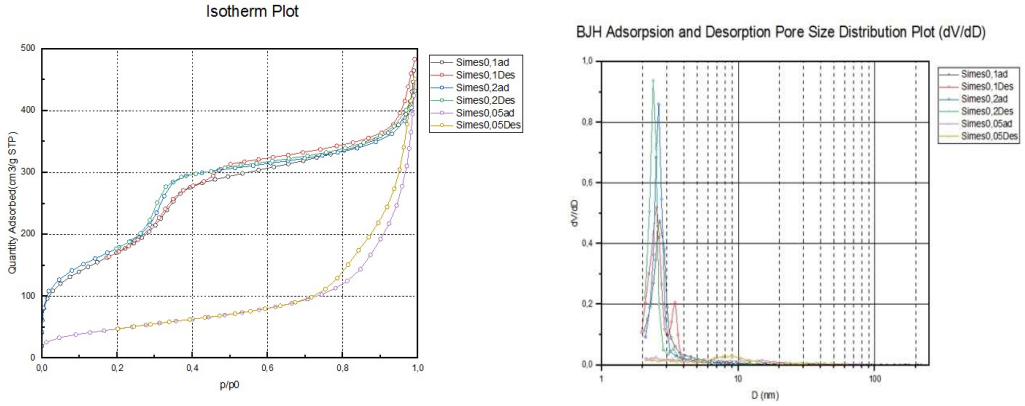

Fig.-4: N_2 Adsorption-Desorption Isotherm Plots and Pore Size Distribution of Biosilica Samples with CTAB Modification Using BET and BJH Methods

In the 0.1:1 biosilica sample, the type IV isotherm shows hysteresis containing one capillary condensation at a relative pressure of $P/P_0 > 0.3$ and gets clearer at P/P_0 pressure > 0.4. In contrast, in the 0.1:2 biosilica sample, the type IV isotherm shows a hysteresis loop pattern with capillary condensation, $P/P_0 > 0.3$. On the other hand, in the 0.05:1 biosilica sample, it was found that loop hysteresis occurred at a pressure of P/P0 > 0.7. Loop hysteresis occurs because of the capillary condensation phenomenon, which is influenced by the presence of pores in the silica solid. The isotherm type of biosilica describes the mesoporous class in the sample; this is confirmed by the N_2 adsorption-desorption pattern for the pore size distribution according to the BJH method (Fig.-4). The pore size distribution graph shows that the diagram's peak is at a point with a diameter of more than 2nm. Moreover, the regularity of pore size is indicated by the distribution pattern of narrowed pore sizes.[30] The nominal surface area, volume, and pore size are shown in Table-3.

Table-3: The Specific Surface Area, Total Pore Volume, And Pore Size of The Biosilica Sample with CTAB Modification

Samples	Specific surface area (m^2/g)	Total pore volume (cm^3/g)	Pore size (nm)
Biosilica 0.05:1	177.068	0.663	14.976
Biosilica 0.1:1	661.166	0.729	4.408
Biosilica 0.2:1	684.852	0.660	3.853

From Table-3, the highest biosilica surface area reached 684.852 m^2/g at a CTAB modification ratio of 0.2:1. The lowest surface area was 177.068 m^2/g, resulting in a CTAB-modified biosilica sample of 0.05:1. This data is still lower than previous research which found that the surface area reached until 915 m^2/g.[31] Several factors that can affect the surface area and pore diameter are aging process time, the CTAB modification process, and its calcination. The use of more CTABs results in a larger surface area.[16] This modification is in line with expectations that the more CTAB, the number of templates that can form the mesopore structure will also be higher so that the surface area increases.[32] In the aging process, hydrolysis occurs, entering the pores and deposition of silica monomers. The longer the aging time, the synthesized silica will cover the template or framework to form bulky material and reduce the surface area.[14] The calcination process removes CTAB from the material so that the surface and pores of the solid are more open and form the desired structure.

The increase in the surface area allegedly improved the catalytic performance because of the presence of more acid sites where the reaction occurred on the catalyst surface.

The pore size shows the mesoporous class (2-50nm), which is supported by the isotherm-type pattern and the previously described pore distribution pattern. This condition indicates that there has been a successful synthesis and modification of mesoporous biosilica from andong bamboo leaf waste with modification of CTAB as a template for silica structure.

The Application of Biosilica as a Catalyst for α-Cellulose Through Direct Pyrolysis Using the py-GCMS.

The pyrolysis/cracking process of biomass involves several reaction steps, namely dehydration, depolymerization, and decomposition, which are generally carried out at high temperatures. Lignocellulosic biomass has several main compositions: lignin, cellulose, and hemicellulose. Cellulose is a potential material to be used as raw material for valuable compounds, such as energy and other chemical compounds. In this study, α-cellulose was used as a model for applying biosilica as a catalyst in the direct cracking process. The α-cellulose pyrolysis process produces a relatively complex mixture of products (Table-4). In general, the results of cracking cellulose usually contain bio-oil with a high content of oxygenated compounds. The yield of pyrolysis products was determined from the percentage of the GCMS peak area, and more than 90 compounds were identified. The data obtained show that the pyrolysis of α-cellulose, either with or without adding silica, produces a hydrocarbon compound. The other compound with a high content is levoglucosan, a depolymerization product of cellulose. Another product formed is acetic acid resulting from the deacetylation reaction. The pyrolysis results are grouped into aromatic, alicyclic, aliphatic hydrocarbons, carboxylic acids, oxygenated compounds (including aldehydes, alcohols, furans, esters, and ketones), nitrogen-containing compounds, and sugars. From Table-1. Aliphatic hydrocarbon products tend to increase with the addition of a mesoporous biosilica catalyst. The α-cellulose pyrolysis process resulted in 11.68 % aliphatic hydrocarbon without a catalyst and 21.03 % using a mesopore silica catalyst 0.05 mol CTAB ratio.

The biosilica with a ratio of 0.1:1 produced 12.49 % aliphatic hydrocarbon and increased in the ratio of 0.2:1 to 16.15 %. If the products of alicyclic, aliphatic, and aromatic hydrocarbons cumulated, the total of hydrocarbons produced in the pyrolysis of α-cellulose, α-cellulose with silica without CTAB, and α-cellulose with mesoporous silica CTAB ratios of 0.05:1, 0.1:1, and 0.2:1 are 42.62%; 25.22%; 44.88%; 61.6%; and 30.4%. This result is higher than previous research that produces 5.59% of hydrocarbon from α-cellulose.[33] Meanwhile, Trisunaryanti *et al.*[34] produce 27.28% of the hydrocarbon from coconut oil found using Co-mesoporous silica as a catalyst. This difference value is probably due to this study's higher surface area of silica.

Table-4: α-cellulose Pyrolysis using py-GCMS

No	Compound	Percentage				
		α-Selulosa	*α*-Selulosa + biosilica without CTAB	*α*-Selulosa+ biosilica (0.1:1)	*α*-Selulosa + biosilica (0.2:1)	*α*-Selulosa + biosilica (0.05:1)
1	Alicyclic hydrocarbon	26.27	15.43	42.54	14.25	23.85
2	Aliphatic hydrocarbon	11.68	9.79	12.49	16.15	21.03
3	Aromatic hydrocarbon	4.67		6.57		
4	Ketones	16.89	16.81	5.94	31.07	15.44
5	Carboxylic acid	5.04		1.8		3.61
6	Furan	2.63		9.9	8.7	1.89
7	Aldehyde	2.75	2.67		3.43	6.52
8	Anhydrous sugars	18.84			14.7	17.18
9	Ester		12	4.6		1.03
10	Alcohol	11.24	13.08	13.21	3.62	8.11
11	N-compound			2.3	8.1	1.03
12	PAHs			0.65		
13	Ether					1.83
14	Long-chain hydrocarbon		30.23			
	Total	100.01	100.01	100	100.02	101.52

If we compare it with other research, the result is still lower because the biosilica is not being impregnated with metal that can contribute to acid sites and maximize the cracking reaction of cellulose compounds into short-chain hydrocarbons, especially aliphatic hydrocarbon.

The result proves that adding silica and structural template (CTAB) to become mesoporous affects the composition of the compounds produced from the pyrolysis process. The increased CTAB concentration in the solution improved the silica structure and regularity. At a ratio of 0.1:1, it was also seen that there were no aldehyde products, then the ketone and acid compounds were much lower than without a mesoporous silica catalyst. However, the addition of the CTAB ratio concentration on silica at 0.2:1 gave a decrease in hydrocarbon yield; this was probably because the pores in the silica became damaged/collapsed and became irregular, so it was not easy to form suitable pore openings for pyrolysis. The CTAB concentrations to the optimum point have a positive effect on the pyrolysis hydrocarbon compounds but can decrease results when the CTAB concentration is continuously increased.[35]

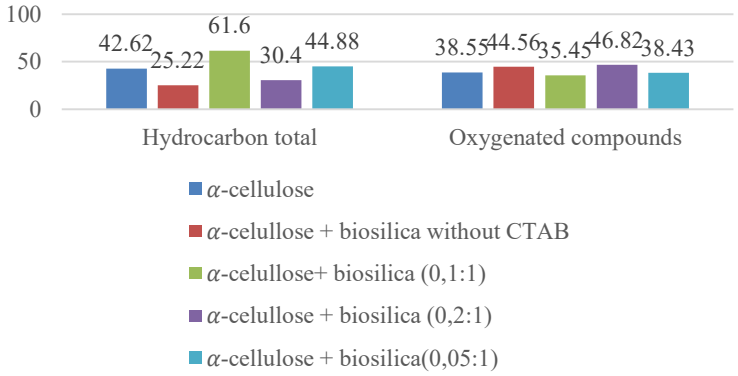

Fig.-5: Hydrocarbon Products and Oxygenated Compounds Resulting from the Pyrolysis of GCMS Alpha Cellulose

From Fig.-5 It is described that there is a decrease in oxygenated compounds with a similar trend to the increase of hydrocarbon. The reduction of oxygen-containing compounds is allegedly through deoxygenation/deoxidation reactions in pyrolysis. In contrast, alcohol compounds are organic constituents for re-pyrolysis. Ketones and aldehydes are also included in undesirable compounds because they cause bio-oil instability. Oxygenated compounds need to be reduced because they will cause a decrease in the quality of the biofuel so that the life of the biofuel will be shorter. The decrease in alcohol compounds (octanol, heptanol, pentanol) indicates the occurrence of these compounds' hydrogenation, deoxidation, and dehydration reactions. On the other hand, alcohol is also a desired product for producing biofuels, apart from hydrocarbons. Hydrocarbon compounds, both aromatic and aliphatic, are desirable products because they contribute to the high heating value and serve as a barometer for biofuels such as gasoline, diesel, and other chemicals. However, phenol compounds are valuable chemical compounds that can also be used as resin materials and other products. Furan is also a high-value product and makes the process more economical, which is formed from the dehydration of carbohydrates. Cellulose is the main compound of biomass and has a linear homopolysaccharide structure of glucopyranose linked by glycosidic bonds. The breakdown of cellulose and hemicellulose chains can produce aromatic compounds with low molecular weights, such as benzene, toluene, and xylene. However, the levels are low (about 2%), especially using a 0.1 CTAB mesopore silica catalyst. This condition can be seen from the decrease in the percentage of sugar compounds after the pyrolysis process using mesoporous silica catalysts. The increase in ester compounds is possible due to the conversion of carboxylic acids to esters. Other compounds that do not give positive results are compounds containing nitrogen because they can produce NOx compounds when heating fuel. Therefore, it needs to be removed when biofuel products from biomass, for example, by denitrogenating reactions. Some unwanted compounds, such as PAHs and furans, are classified as toxic and carcinogenic compounds produced in minimal amounts. This study's PAH and nitrogen compounds results are still much lower than previous studies. They are reaching 4-6% for PAHs and 7-20% for nitrogen compounds.[36] The biosilica application as a catalyst gave positive results that can be developed in the future. This finding is important to support green technology development in creating energy security.

CONCLUSION

The biosilica from andong bamboo leaf was successfully synthesized with a sol-gel method using CTAB as a template resulting in mesoporous biosilica. These material's content and acidity surface ranged from 90.5-93.6% and 1.9-2.1 mmol/g. The surface area for the mesoporous biosilica reached 684.852 m^2/g. The application of this biosilica as a catalyst shows that these materials effectively have a potential for α-cellulose direct pyrolysis. Hydrocarbon as the desirable product produced until 61.6%.

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CONFLICT OF INTERESTS

The author (s) declares that there is no conflict of interest in this research and manuscript.

AUTHOR CONTRIBUTIONS

All the authors contributed significantly to this manuscript, participated in reviewing/editing, and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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