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Transforming Coconut-Coir Waste *(Cocos Nucifera. L)* into Tissue Towels: Advancing Sustainable Development Goals towards Circular Economy Practices

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ABSTRACT

The increasing demand for pulp as a raw material for tissue towel manufacturing has significant environmental consequences, particularly due to its reliance on wood. Waste from the pulping process contains hazardous compounds, such as lignin and chlorine, which cause riverbed sedimentation, odor, and pollution. These issues align with Sustainable Development Goals (SDGs), particularly Goal 12, which emphasizes responsible consumption and production to minimize waste and its impacts. This research explores the use of coconut coir *(Cocos nucifera L.)*, a sustainable alternative to wood, in tissue towel production. The organosolv process, employing organic solvents like ethanol (50%, 60%,70%) and cooking time (90 min, 120 min), offers an eco-friendly pulping method by eliminating sulfur and enabling black liquor recyclability. Experimental results revealed that increasing ethanol concentration and cooking duration reduced lignin and moisture content while enhancing cellulose yield. The optimal treatment involved a 60% ethanol solution and a 90-minute cooking time, producing tissue with 81.09% cellulose, 24.98% lignin, and desirable physical properties. This study supports SDGs by advancing green technology, promoting a circular economy, and fostering sustainable, environmentally friendly tissue towels.

1. INTRODUCTION

The increasing demand for pulp as a raw material for tissue towel manufacturing has a negative impact on the environment, especially since the main raw material used today is wood. The pulp and paper industry, as a large-scale sector, utilizes large tracts of land, wood raw materials, and endless hours of production. This has led to a variety of environmental problems, including land degradation and forest fires. The clearing of forests not only disrupts biodiversity but also contributes to climate change by reducing carbon sequestration capacity and altering local ecosystems [1].

Waste generated from the cooking process of tissue raw materials has the potential to cause serious impacts on the environment. Based on research by Dahlan [2], pulp and paper industry wastewater contains residual lignin, extractive compounds, chlorine, and wash water from the kraft process. This waste can cause sediment in the riverbed, unpleasant odors, and color pollution due to the oxidation reaction of lignin during the delignification process. In addition, chemical compounds such as sulfuric acid, used in the sulfite process, are slow to degrade naturally, with the rate of degradation influenced by environmental conditions and concentration [3]. The cumulative impact of these environmental issues underscores the need for the pulp and paper industry to adopt more sustainable practices. Alternative raw materials, such as agricultural residues or recycled fibers, could reduce the reliance on wood and mitigate deforestation. Additionally, the development of cleaner production technologies and more efficient waste management systems is essential to minimize the industry's ecological footprint. By addressing these challenges, the pulp and paper industry can contribute to environmental conservation while meeting the growing demand for tissue products.

This issue is directly related to the Sustainable Development Goals (SDGs) targets, particularly goal 12 on responsible consumption and production. One of the main focuses is reducing the amount of waste generated and optimizing waste treatment to realize the concept of zero waste. With effective and efficient waste treatment, it can not only reduce the amount of waste that pollutes the environment, but also minimize its negative impact on the environment and human health. In addition, proper waste treatment can support the recovery and reuse of resources, thereby encouraging more sustainable and responsible management of natural resources. This effort is in line with the vision of creating an environmentally friendly and sustainable production system as per the principles of the SDGs [4].

This highlights the need for a fully integrated supply chain approach to reduce food loss and waste substantially [5]. Thus, alternative raw materials are needed to replace wood and harmful chemical compounds such as sulfur and chlorine in

the pulping process. The use of alternative raw materials is expected to reduce environmental damage due to pulp waste [6]. One potential alternative raw material is coconut coir, which comes from the coconut plant *(Cocos nucifera L.),* a tropical plant that is widespread in Indonesia. Coconut production in West Sumatra reaches 78,902 tons per year, with a planting area of 87,298 hectares spread across 19 districts and cities [7].

Coconut coir contains 44.2% cellulose and 32.8% lignin [8]. Although the cellulose contents meet the requirements for pulp raw materials (at least 40%), the lignin content is still too high to produce optimal-quality pulp. Therefore, a process is needed to reduce the lignin content in coconut coir in order to produce tissues that meet quality standard [9].

The organosolv process is one method of chemical pulping using organic chemicals such as methanol, ethanol, acetone, or acetic acid. This process offers advantages, including high pulp yields, black liquor recyclability, and the absence of elemental sulfur, which makes it more environmentally friendly. The process can also produce lignin and hemicellulose by products of high purity [10]. according to Haroen et al [11], the ethanol black liquor produced from this process can be recycled through distillation to be reused as a pulp cooking solution.

Based on the negative impact that the tissue manufacturing process has on the environment, this study offers the solution of utilizing coconut coir waste as an alternative raw material. By applying green technology in the production process, this research contributes to the implementation of circular economy and sustainability (SDGs) while encouraging more environmentally friendly production innovations.

2. MATERIALS AND METHODS

2.1 Material

The equipment used in this research are scissors, tampering, beaker, measuring cup, Erlenmeyer, stirrer, hot plate, oven, desiccator, hotplate, analytical balance, sieve, 50 mesh fiber mold, and blender. The main materials used in this study are coconut coir taken directly from the coir cooperative in Pauh Kamba sub-district, Padang Pariaman, ethanol from Novalindo, hydrogen peroxide (H_2O_2), chitosan, tapioca starch, virgin coconut oil (VCO), aquadest.

2.2 Methods

In this study, the manufacture of tissue from coconut coir waste using the organosolvv method was carried out, starting with cleaning the raw materials and then drying them with tampering, then analyzing the raw materials, including analysis of water content, analysis of ash content, analysis of lignin content, and analysis of cellulose content, after which the cooking process was carried out using the organosolv method using ethanol solvents with variations in concentration of 50%, 60%, 70%. Then, the solution would be heated on a hotplate for 90 minutes and 120 minutes (ethanol content and cooking time were determined based on previous literature). The resulting pulp will then be bleached with 20% H_2O_2 solution and added additives (chitosan, tapioca starch, virgin coconut oil) and then print the pulp with a 50-mesh fiber mold with an area of 20x30 cm. The resulting tissue is then tested in accordance with the quality requirements of SNI 0103: 2008. The design used in this study was a factorial complete randomized design with 3 treatments on factor A (ethanol concentration), 2 treatments on factor B (cooking time) and 3 replications, the data from the observations were analyzed using Analysis of Variance (ANOVA) if the results obtained were significantly different, the Least Significant Different (LSD) further test was carried out at the 5% level.

Sample Code Description

A1B1: 50% ethanol concentration, 90 minutes cooking time

A2B1: 60% ethanol concentration, 90 minutes cooking time

A3B1: 70% ethanol concentration, 90 minutes cooking time

A1B2: 50% ethanol concentration, 120 minutes cooking time

A2B2: 60% ethanol concentration, 120 minutes cooking time

A3B2: 70% ethanol concentration, 120 minutes cooking time

2.2.1 Pulp making stage

The dried coconut coir was weighed as much as 24 grams. Then put it into an Erlenmeyer. Ethanol solution was added to the Erlenmeyer with a concentration variation of 50%, 60%, and 70% with the ratio of raw materials to solvent 1: 10. Then the solution was heated using a Hotplate with a cooking temperature of 118ºC. The cooking process of raw materials and ethanol solution was carried out with a variation of cooking time of 90 minutes to 120 minutes. The results of cooking are then filtered to separate the solvent (black liquor) from the pulp. Then, the pulp is washed with distilled water until the phosphate is clear. The clean pulp is then dried in an oven at 105ºC until constant weight [12].

2.2.2 Bleaching process

The pulp in sheet form is put into a glass beaker and then mixed with 240 ml of 2% H_2O_2 solution and then heated using a water bath for 1 hour at 60ºC. Next, the pulp is filtered and then washed until clean. The clean pulp is put into a blender and then chitosan is added as much as 2 grams (as an additive so that the tissue is softer). Then add tapioca flour as much as 1 g (as an additive so that the tissue is more adhesive) and 200 ml of distilled water. Furthermore, 3 ml of VCO is added (to soften or as soft tissue), and then all the mixtures are blended until smooth [12].

2.2.3 Tissue forming process

The fine pulp is then molded. The pulp is printed on a mold made of fiber with a size of 50 mesh with an area of 20 x 30 cm. Pulp that has been printed is then dried so that tissue products are obtained [12].

2.2.4 Tissue test parameters

a. Gravimetric Method Moisture Content Analysis

Clean empty cups are heated in the oven at 105ºC for 30 minutes and then transferred into a desiccator and biarka cool for 15 minutes. The weight of the empty cup is recorded, the test material is added to the cup (3-5 grams), then the weight of the sample is recorded. The cup and the test material are baked for about 3 to 4 hours, observed for the naming of the test material; if it still contains water, continue heating; if it is dry, the cup can be cooled and moved into a desiccator for 30 minutes and weighed the weight of the cup and material. Weighed the weight of the cup and material (if the weight difference is obtained 0.2 grams of weight can be said to be constant) then calculated using the formula for water content

[13].

b. Extractive Substance Content Testing (TAPPI T 204 om-88)

Testing was carried out using the TAPPI T 204 om-88 standard with stages, weighed coconut coir powder in a cup of 10 grams, and put into a filter paper lead that has a known weight. The lead was put into the extraction tube and set until the cup was submerged in the solvent. Extraction was carried out for 6-8 hours, and after completion, the lead was removed. Then washed with 50 ml of ethanol to remove benzene and dried in an oven at 105 ± 3°C for 2 hours. After that, it was cooled in a desiccator and weighed to obtain dry weight coconut fiber powder after extraction.

c. Lignin Content Testing (TAPPI T 13 os-54, 1990)

Weighed 2 g of extracted sample into a 100 ml glass cup added 25 ml of 72% H_2SO_4 and left for 2 hours at room temperature while occasionally stirring. Diluted with 500 ml of distilled water heated to boiling and left for ± 4 hours. After cooling, the precipitate was filtered with filter paper and washed with distilled water until acid-free. The precipitate on filter paper was dried in an oven at 105°C until constant weight.

d. Holocellulose Content Testing (TAPPI T9 m-54, 1990)

A 5-gram sample of previously extracted powder was placed in a 200 ml Erlenmeyer. The sample was added 160 ml distillate water, 1.5 g$NaClO_2$ and 10 drops of CH_3COOH (acetic acid). Erlenmeyer containing the sample was covered with a small Erlenmeyer which was turned upside down and heated in a water bath for 4 hours at 70-80°C, occasionally shaken, and every 1 hour 10 drops of acetic acid followed by 1.5g $NaClO_2$. After completion, it was cooled in ice water and then filtered. The sample was washed with ice water and then with acetone. Then, the samples were dried in a vacuum oven at 40°C until constant weight.

e. Cellulose Content Testing (TAPPI m-55, 1990)

A total of 2 grams of holocellulose was weighed, then heated in a 500 ml beaker with 200 ml of 1.3% H_2SO_4 for 2 hours over boiling water in a water bath. After 2 hours, the mixture was filtered and washed with 150 ml of distilled water until neutral. When it was neutral, it was washed with ethanol and dried in an oven at 105°C until constant weight.

f. Calculation of Hemicellulose Content

Holocellulose is hemicellulose and cellulose in plants. Determination of the hemicellulose content of the plant is determined by subtracting the sum of the weights of holocellulose obtained from the weight of cellulose analyzed.

g. Microscopic

An optical microscope, often referred to as a "light microscope", is a type of microscope that uses visible light and a lens system to magnify small specimen images.

h. Sheet State

The sheet state procedure is observed through several parameters. The appearance of the sheet by looking, feeling and looking at the paper sheet, then observing resistance in water by putting the tissue in water, then shaking or stirring for less than 60 seconds; if it decomposes, it means it is easily destroyed. Color by soaking the tissue in water for approximately 60 seconds, if the soaking water is colored, it means it does not fade [14].

i. Grams per Square Meter (GSM) testing

Preparation of the test piece is done by ensuring that the test piece is free from folds, dirt, or visible damage. Test cuts shall be taken from tissue specimens or tissue products, either in cut or whole product form. In the cutting process, the test sheet or stack of test sheets may be placed between two sheets of backing paper, such as office copy paper, to ensure clean cut edges and accurate dimensions. The dimensions of the test specimens need to be adjusted due to variations in the size of the tissue or tissue product, with a minimum area of individual test specimens of 100 cm². If required, one test piece may consist of several smaller parts. For testing purposes, at least 10 test pieces should be prepared, with a minimum area mass of 1000 cm² determined in accordance with the provisions. Next, the mass of the test specimen is measured using an analytical balance, while the area is calculated using a ruler with an accuracy of at least 0.5 mm. Once the mass and area data are obtained, a grammage calculation is performed to determine the complete characteristics of the specimen [15].

j. Water Absorbency

A tissue strip with a width of 15 mm and a length of at least 200 mm is prepared. Hang the tissue strip perpendicular to the surface of the distilled water with one end dipped 10 mm deep. After 10 minutes, read the height of the water rise that permeates the tissue in millimeters [14].

3. RESULT

3.1 Coconut coir raw material analysis

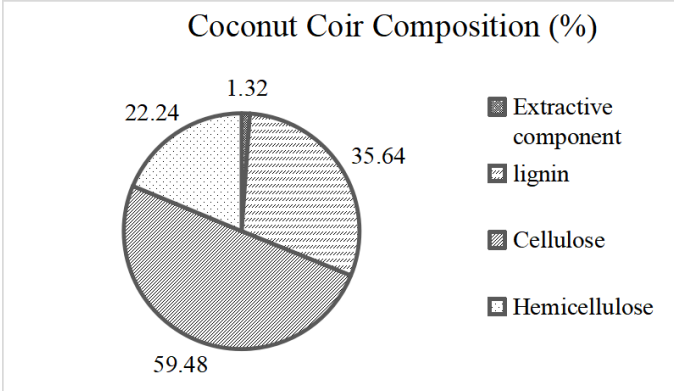


Figure 1. Coconut coir composition

Based on the analysis results in Figure 1, it can be seen that several compounds contained in coconut coir are extractive substances such as (tannins, waxes, resins, fats) of 1.32%, lignin 35.64%, cellulose 58.48% and hemicellulose of 22.24%.

3.2 Chemical analysis of tissue towel with ethanol concentration treatment and cooking time

Based on Table 1, it is known that the moisture content of coconut coir pulp is obtained between 6.32% and 6.95%, the highest moisture content value is found in the A1B1 treatment (50% ethanol concentration and 90 minutes cooking time) which is 6.95% and the lowest moisture content value is found in the A1B2 treatment (70% ethanol concentration and 120

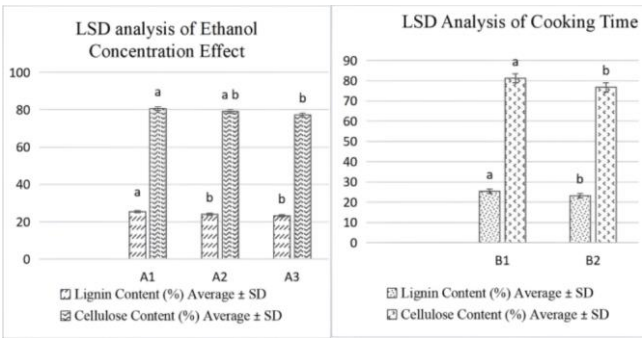
minutes cooking time) which is 6.32%. The lignin content of tissue made from coconut coir is obtained between 22.19% to 26.53%. The cellulose content obtained is between 74.01% to 82.14%.

Table 1. Tissue chemical analysis results

Samples	Moisture Content (%) ± SD	Lignin Content (%) ± SD	Cellulose Content (%) ± SD
A1B1	6.95 ± 0.5	26.53 ± 1.20	82.14 ± 2.58
A2B1	6.89 ± 0.06	24.98 ± 0.89	81.09 ± 1.84
A3B1	6.84 ± 0.11	24.35 ± 0.66	80.36 ± 1.73
A1B2	6.48 ± 0.06	24.20 ± 1.08	79.19 ± 2.11
A2B2	6.46 ± 0.04	23.07 ± 0.51	76.95 ± 2.16
A3B2	6.32 ± 0.04	22.19 ± 1.10	74.01 ± 2.05

Description: SD = Standard Deviation

Based on the results of the analysis of variance (Figure 2.) show that cooking time has a significant effect on the moisture content of coconut coir pulp. In contrast, the ethanol concentration and the interaction produced by cooking time and ethanol concentration on the analysis of coconut coir pulp moisture content are not significantly different. Cooking time and ethanol concentration had a significant effect on the lignin content of tissue made from coconut coir. In contrast, the interaction between cooking time and ethanol concentration on the analysis of lignin content was not significantly different. Cooking time and ethanol concentration significantly affect the cellulose content of coconut coir tissue. In contrast, the interaction produced by cooking time and ethanol concentration on the analysis of cellulose content is not significantly different.



(a) (b)

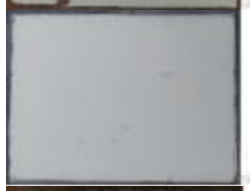
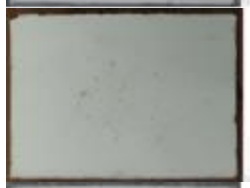
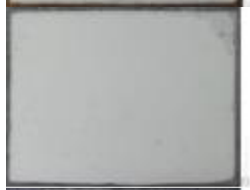
Figure 2. (a) Least Significant Different (LSD); (b) Test results on chemical analysis of tissue towel

3.3 Physical analysis of tissue products with ethanol concentration treatment and cooking time

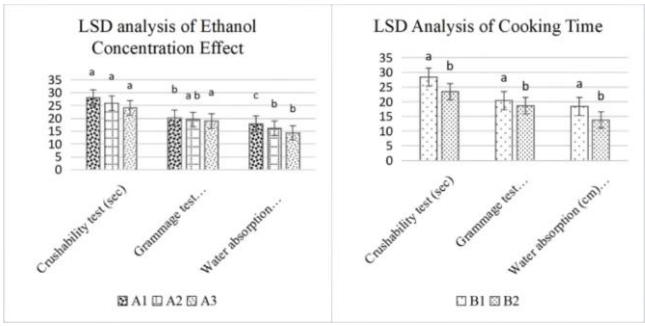
Based on the results of sheet analysis that has been done (Table 2), the average tissue has a slightly smooth texture, tissue that has a rough texture in the A1B1 treatment (50% ethanol concentration and 90 minutes cooking time).

Table 3 shows the average value of the test easily destroyed in water tissue made from coconut coir, based on the results of the data obtained, the time required for the destruction of tissue in water ranges from 21.33 seconds to 31.33 seconds. Based on the data obtained from the gramature test, the data obtained is 18.23-21.18 grams/m^2 from the results of the analysis carried out by the A1B1 treatment (50% ethanol concentration and 90 minutes cooking time), getting the highest gramature data of 21.18 grams/m^2, and A3B2 treatment (70% ethanol concentration and 120 minutes cooking time) getting the lowest gramature data of 18.23 grams/m^2. Based on the data obtained from the water absorption test, the data obtained has increased, namely 11.33-19.83 cm.

Table 2. Results of sheet state analysis

Samples	Sheet Appearance	Color	Image
A1B1	Slightly rough Perforated Less clean	Bright yellow Does not fade	
A2B1	Soft perforated with holes Less clean	Yellowish white Does not fade	
A3B1	Soft slightly spacey Less clean	Yellowish white Does not fade	
A1B2	Slightly rough Perforated Less clean	Bright yellow Does not fade	
A2B2	Soft slightly spacey Less clean	Yellowish white Does not fade	
A3B2	Soft No holes Less clean	Yellowish white Does not fade	

Cooking time and ethanol concentration have a significant effect on the test of easily destroyed water tissue made from coconut coir. In contrast, the interaction produced by cooking time and ethanol concentration in the analysis of easily destroyed water is not significantly different. Based on the results of the analysis of variance, it shows that cooking time and ethanol concentration have a significant effect on the grammage of tissue water made from coconut coir. In contrast, the interaction produced by cooking time and ethanol concentration on grammage analysis is not significantly different. Based on the results of the analysis of variance, it shows that cooking time and ethanol concentration have a significant effect on the water absorption of tissue water made from coconut coir. In contrast, the interaction produced by cooking time and ethanol concentration on the analysis of water absorption is not significantly different (Figure 3).



(a) (b)

Figure 3. (a) Least Significant Different (LSD); (b) Test results on physical analysis of tissue towel

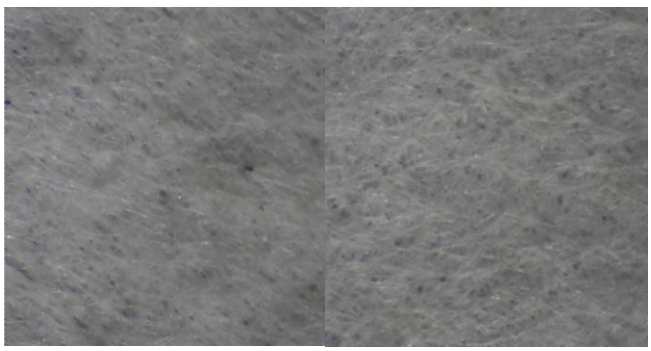
Table 3. Results of physical analysis of tissue towel

Samples	Mean Value of Water Disintegrability Test (Sec) ± SD	Mean Value of Grammature Test ± SD	Mean VALUE WATER Absorption ± SD
A1B1	31.33 ± 0.57	21.16 ± 0.76	11.33 ± 1.52
A2B1	28.33 ± 1.52	20.33 ± 0.57	14.16 ± 1.04
A3B1	25.66 ± 0.57	19.66 ± 0.57	15.83 ± 1.25
A1B2	24.66 ± 1.15	19.16 ± 0.76	17.33 ± 1.52
A2B2	23.33 ± 1.52	18.66 ± 0.28	18.16 ±1.25
A3B2	22.33 ± 1.15	18.23 ± 0.40	19.83 ±1.75

Description: SD = Standard Deviation

3.4 Microscopic analysis

Based on the microscopic tests that have been carried out, it can be seen that there are still many holes on the surface of the tissue and the uneven surface makes the texture of the tissue still feel slightly rough. Cellulose fiber fibers in Figure 4. (a) are more regular than cellulose fiber fibers in Figure (b).



(a) (b)

Figure 4. Microscopic images of tissue towel (a) surface of tissue made from coconut coir treated A2B1 (b) surface of tissue made from coconut coir treated A2B2

4. DISCUSSION

The result showed that the analysis of coconut coir raw materials produced high values compared to Kondo's [16] research, where lignin was recorded at 33.5%, cellulose at 37.9%, and hemicellulose at 15.5%. this difference may be due to variations in the location of the materials or type of coconut coir used. The content of lignin, cellulose, and hemicellulose in a plant is influenced by the type of plant, growing location, and age of the plant [16]. Even plants of the same type can have different compositions if they grow in different locations.

The moisture content of the test material, which is measured based on the amount of water lost during heating at 105°C [13], decreased as the temperature and cooking duration increased. This decrease is consistent with previous study [11], which noted that the moisture content of coconut coir pulp was in the range of 6.1%-6.9%. This occurs because water molecules in the pulp are released during cooking, so the longer the cooking process, the lower the moisture content.

The decrease in lignin content as ethanol concentration increases occurs due to the breaking of ether bonds in the delignification process [17]. According to Hamzah et al. [18], the combination of water and ethanol creates an effective solvent to break down lignin with maximum efficiency at 70% ethanol concentration. The longer the cooking, the more lignin is broken down and separated from the raw material [19]. In addition, increasing the temperature and duration of heating accelerates the delignification reaction so that the lignin content decreases [10]. Kraft pulp is particularly well-suited for the production of soft and absorbent tissue towels due to its low lignin content, which contributes to a smoother texture and better absorbency. In contrast, higher lignin levels may lead to rougher textures and reduced absorbency [20, 21]. Research indicates that optimizing production conditions can effectively lower lignin content, thereby enhancing the physical properties of tissue paper [22].

Cellulose serves as the primary structural component of plant cell walls, consisting of long, unbranched chains of d-anhydroglucose units linked by β-(1,4) glycosidic bonds [23]. Cellulose content is calculated from the ratio of the weight of cellulose precipitate to the initial weight of the material [24]. The addition of excessive cooking solution in the delignification process can damage cellulose, turning it from polysaccharides into soluble monosaccharides [25]. Too long cooking time also causes cellulose degradation, so cellulose content decreases. This decrease is in line with the high degradation of lignin during the cooking process [26].

Physical testing of the tissue shows that the tissue sheets tend to be smooth with a yellowish-white color and some small holes. High levels of lignin cause rough texture, dark color, and less cleanness due to the less-than-optimal bleaching process [9]. The decrease in lignin increases water absorption, where all samples meet the SNI 0103: 2008 standard, which is a minimum absorption of 30 mm in 10 minutes [27]. The paper grammage in this study also meets the standard, with a minimum value of 13 grams/m². Observation of the tissue texture using an optical microscope showed that longer pulp milling time increased the fineness of the texture. This demonstrates the control of fiber processing techniques that affect the quality of the final product.

The use of coconut coir has significant environmental benefits. Coir as a by-product of coconut utilization is abundantly available especially in the tropics. The utilization of coir into tissue towels not only reduces agricultural waste but can also improve sustainability by reducing dependence on no-renewable synthetic materials. This is in line with the global trend towards the use of eco-friendly materials and waste utilization in industrial applications. While the uses of

coir have many advantages, it also has limitations. One of the challenges in the utilization of coir is the variability in fiber quality which can affect the consistency of the product. As a natural material, coir has variation in size, water retention capacity and strength that depend on factors such as processing techniques and geographical origin. In addition, the bonding between coir and the polymer matrix can be a limiting factor due to poor interfacial adhesion, which can lead to a decrease in mechanical properties [28]. the utilization of coconut coir, which was previously considered waste, into high-value product can significantly enhance economies value. By transforming coir waste. Local communities have the opportunity to create a waste-free environment while boosting the economic potential of their region. Proper management of this resource by specific community groups not only promotes environmental sustainability but also drives local economic growth [29, 30].

5. CONCLUSION

Based on the results of the research on coconut coir-based tissue towels, it can be concluded that the interaction between cooking time and ethanol concentration did not have a significant effect on all analytical parameters. However, increasing ethanol concentration and cooking duration tends to reduce moisture, lignin, and cellulose content, and vice versa. Individually, cooking duration and ethanol concentration had a significant influence on the characteristics of the tissue produced, where the analytical value decreased as one of these variables increased. The optimum treatment in this study was pulp composition with 60% ethanol concentration and 90 minutes of cooking time. This treatment produced tissue with chemical properties in the form of high cellulose content (81.09%), low lignin content (24.98%), and a moisture content of 6.89%. Physically, the tissue has a smooth sheet, slightly perforated, yellowish-white color, does not fade, water absorption of 150 mm, easily destroyed in water within 29 seconds, and a gramature of 20 grams / m². This study supports SDGs by advancing green technology, promoting a circular economy, and fostering sustainable, environmentally friendly tissue manufacturing.

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