Prepublished copy

Nature Environment & Pollution Technology

This is a peer-reviewed prepublished version of the paper

Original Research

Implementation of Circular Economy Model in White Copra Production

Budy Rahmat*, Iqbal Akmalludin* and Tedi Hartoyo**

*Department of Agrotechnology, Siliwangi University, Tasikmalaya City 46115, Indonesia
**Department of Agrobusiness, Siliwangi University, Tasikmalaya City 46115, Indonesia
Corresponding author: Budy Rahmat; budyrahmat@unsil.ac.id
ORCID ID : *0000-0002-2646-6445*

Abstract: This study implemented a circular economy model in processing coconuts into white copra as the main product, to achieve a zero waste production system. Simultaneously, other fruit components, such as shells, fibers, and coconut water are also processed into products that play a role in supporting the main product directly or indirectly. The processed products obtained were liquid smoke, charcoal briquettes, and tar. The processing of white copra was carried out in the following stages: (i) coconut meat was processed into white copra, while the shell was pyrolyzed into liquid smoke, charcoal, and tar; (ii) liquid smoke was used as a preservative for copra; (iii) charcoal was formed into charcoal briquettes which were used for pyrolysis heating; and (iv) the tar produced was used as a wood preservative. The entire series of research was conducted as a laboratory experiment. The treatment of coconut meat dipping for copra in the concentration of liquid smoke solution was arranged in a randomized block design (RCBD), the data were analyzed by ANOVA and continued with Duncan's multiple differences. Meanwhile, the determination of the components of the results of peeling coconuts and the results of pyrolysis of coconut shells and fibers, as well as the characterization of liquid smoke and charcoal briquettes formed were carried out by observational experiments. The results of this study indicate that the weight of 100 coconuts of the tall variety sample was 175.1 kg or an average weight of 1,751 g per coconut. After peeling all the coconuts, the components of meat, shell, fiber, and fruit water were obtained, each weighing 48.9 kg, 23.2 kg, 70.6 kg, and 32.4 kg. Furthermore, 23.2 kg of shells were pyrolyzed and produced liquid smoke, charcoal and tar of 9,126.70 g, 7,155.52 g and 574.64 g, respectively, which was the average of three pyrolysis repetitions. Coconut shell charcoal briquettes were formed by mixing charcoal flour with tapioca, and water with a ratio of 80:5:10 which formed a homogeneous mixture. The mixture was molded by a hydraulic press with a pressure of 2,000 g/cm^2. Furthermore, the test results of water content, volatile matter, ash, fixed carbon, specific gravity, compressive strength and calorific value were 7.79%, 13.75%, 2.76%, 68.66%, 0.92 g/cm^3, and 64.22 kg/cm^2, 6,521 cal/g, respectively. All the results of the charcoal briquette test parameters met Indonesian and Japanese Standards. In the processing of coconut meat, 25.67 kg of white copra was obtained which was treated with 12.5% liquid smoke with a quality equivalent to the results of sulfur fumigation, namely free from fungal infection and the highest oil yield and copra brightness. The results of this study provide new findings that, from one coconut of the tall variety, 489 g of coconut meat and 232 g of shell were produced. From the shell, 91.13 g of liquid smoke and 82.15 g of charcoal briquettes were produced, and 26.67 g of white copra was produced as the main product. This study provided new findings on the circular economy model and the principle of zero waste in white copra production with the facts that, each tall coconut variety produced 489 g of coconut meat and 232 g of shell. From the shell, 91.13 g of liquid smoke and 82.15 g of charcoal briquettes were produced, and 26.67 g of white copra was produced as the main product. This evidence provided new enthusiasm in the business of producing white copra that is financially profitable and for sustainability. This study opens up many further studies and studies on the circular economy and zero waste, especially in the processing of coconut products, for example in the coconut oil, dessicated coconut, brown sugar, virgin coconut oil industries, etc. In addition, it does not rule out the possibility of research accompanied by financial studies.

Key Words	charchoal briquettes; circular economy; liquid smoke; pyrolysis; white copra

DOI	https://doi.org/10.46488/NEPT.2025.v24i03.D1741 (DOI will be active only after the final publication of the paper)
Citation of the Paper	Budy Rahmat, Iqbal Akmalludin and Tedi Hartoyo, 2025. Implementation of Circular Economy Model in White Copra Production. *Nature Environment and Pollution Technology*, 24(3), D1741. https://doi.org/10.46488/NEPT.2025.v24i03.D1741

Keywords: charchoal briquettes; circular economy; liquid smoke; pyrolysis; white copra

1. INTRODUCTION

Global food demand is being driven by sustained population growth and rising consumption, and agricultural activity is growing to meet this demand. The waste produced by modern agricultural systems is staggering; in Europe alone, agrifood waste amounts to almost 700 million tonnes annually. The circular economy seeks to minimize waste in the agri-food chain while maximizing the utilization of waste produced by employing commercially feasible methods and techniques to raise its value (Toopa *et al*. 2017; Stelte *et al*. 2023). Achi *et al*. (2024) stated that, the rapid increase in global waste production and the urgent demand for sustainable energy alternatives have highlighted the potential of advanced Waste-to-Energy (WtE) technologies. These cutting-edge systems transform waste into a valuable resource, offering a practical approach for sustainable energy recovery while significantly supporting the circular economy framework.

Indonesia has the potential for abundant natural resources in the agricultural sector, especially coconut plantations, which cover an area of 3,728,600 ha, which is equivalent to 18.3 million tons of coconuts per year, making Indonesia the largest coconut producer (Kambey *et al.* 2023). In Indonesia, 15 billion coconuts fruit were harvested per year (Bradley and Conroy, 2019). Based on initial research, each coconut fruit has an average weight of 2.83 kg and the waste obtained is 2.15 kg (75.97%). Based on these two factors, the biomass capacity of coconut fruit waste will be obtained at 32,250,000 tons per year.

Coconut waste management is essential for sustainable environmental practices, especially in countries that produce and consume large amounts of coconut. The reasons behind coconut waste management involve various environmental, economic, and social factors (Rizal *et al*. 2022). Viera *et al.* (2024) stated that, coconut husks, husks, and fibers are often discarded as waste. Without proper management, they contribute to landfills, which not only take up valuable space but also cause long-term pollution. Another consequence as stated by Nordahl *et al.* (2023) is that, organic waste, if not properly decomposed, releases methane, a potent greenhouse gas. Coconut waste management through composting or bioenergy production helps reduce methane emissions. Chen *et al*. (2024) stated that, coconut by-products can be recycled or reused for other purposes, thereby reducing the need for new raw materials, supporting sustainable consumption.

Coconut waste management is in accordance with the concept of a circular economy, where waste materials are not only discarded but also reintroduced into the production cycle in useful ways. This approach reduces environmental impact, minimizes waste, and maximizes resource efficiency (Viera *et al*. 2024).

The product components of the pyrolysis or carbonization process of coconut shells are charcoal and liquid smoke which have benefits as vegetable preservative (Mulyawanti *et al*., 2019). Liquid smoke contains several components that contribute to its preservative qualities. The key components of liquid smoke that make it effective as a preservative include: phenols, acids, carbonyls, and alcohols (Lingbeck *et al.* 2014; Saputra *et al*. 2021).

Liquid smoke can be used for various purposes, one of which is to preserve or extend the shelf life of a product (Assidiq *et al*. 2018). Traditionally produced copra is blackish brown because it absorbs a lot of tar, the smoke flavor is very strong, and it can cause air pollution. To overcome this problem, the use of re-distilled liquid smoke was pioneered to reduce the tar content (Umami *et al.* 2023). Organic acid compounds contained in liquid smoke can inhibit the formation of spores and suppress the growth of microbes in food products, namely bacteria and fungi. Phenolic compounds in liquid smoke show effective antimicrobial activity against various organisms such as bacteria, yeast and fungi (Suryani *et al.* 2020). Liquid smoke treatment is expected to replace sulfur fumigation treatment of copra, which is a production input that requires financing and is not environmentally friendly (Amperawati *et al.* 2012).

Puspanantasari (2024) stated that charcoal briquettes have several advantages compared to other fuels, such as firewood or coal. Here are some of the advantages: environmentally friendly, stable combustion, economical, high energy, low ash, waste utilization, easy to store and transport, and almost smokeless.

The novelty of this study was the knowledge of the potential data of coconut shell and coconut fiber waste as by-products of copra production. Both by-products were produced through pyrolysis to form liquid smoke and charcoal briquettes which will later become input for white copra production in the circular economy model, namely as botanical preservatives and copra heating oven fuel, respectively. Therefore, this study also determined the effectiveness of liquid smoke as a preservative to replace sulfur fumigation and coconut shell charcoal briquettes as fuel. The specific objective of the study was to determine the equivalence of the quantity of coconuts from white copra as the main product and liquid smoke and charcoal briquettes as by-products to realize production efficiency, a circular economy and zero waste.

2. MATERIALS AND METHODS

2.1. Materials

The materials used in this experiment were coconuts of the tall variety obtained from coconut plantations in Mangkubumi District, Tasikmalaya City, Dunia Kimia Lestari natural sulfur powder for copra fumigation, NaOH pellets Merck CAS Number 215-185-5 to made 0.1 N NaOH solution, $FeCl_3$ powder Merck CAS Number 10025-77-1 to made 1% $FeCl_3$ solution, and distilled water for solvents and rinsing tools.

The tools used in this experiment were biomass pyrolysis reactor equipment with a volume of 200 dm^3 which was a product of previous research, distillation equipment, Pyrex Erlenmeyer flasks (100, 250, 500 mL), Pyrex chemical bottles (100, 250, 1,000 mL), funnels, Duran distillation kits and analog heating mantle AHM 3000-S (3,000 mL), digital precision balance ACIS type AD-300 (300x0.01 g), digital humidity tester type R&D MT-10, hygrometer temperature humidity test HTC-2, Thermometer Pudax, magnetic stirrer Spinbar Polygon type f37120-0060, measuring cups (10 and 500 mL), label paper, filter paper, stationery and other supporting tools

2.2. Methods

2.2.1. Determination of coconut fruit components

Determination of the weight of each fruit component was carried out by observing the results of peeling 100 ripe coconuts of the tall variety as samples, so that data was obtained per coconut for the proportion of coconut fiber, shell, water and flesh.

2.2.2. Determination of pyrolisis product

Pyrolysis is a thermal decomposition process ranging from 300 to 350 °C to a lignocellulosic biomass in conditions without oxygen, then liquid smoke, charcoal, and tar are produced. Pyrolysis of the entire shell from the peeling stage, then the quantity of liquid smoke, charcoal and tar is recorded until the end of pyrolysis.

2.2.3. Characterization of liquid smoke

Liquid smoke directly resulting from pyrolysis is crude or grade 3 liquid smoke, so it needs to be purified through two distillations, which produces grade 1 liquid smoke.

Here is how to determine the four quality parameters of liquid smoke:

(1) pH value. Testing the pH value using a pH-meter by dipping the tool into a coconut shell liquid

smoke solution. The scale value was read after the pointer was constant.

(2) Specific gravity. Specific gravity was tested using a pycnometer that can measure the volume of the solution objectively. The results measurement were then calculated using the following formula:

$$\text{Specific gravity} = \frac{\text{Mass of liquid smoke (g)}}{\text{Z x Volum of pycnometer (mL)}}$$

(3) Acid content. The acid content was tested using the liquid smoke titrimetric method by a 0.1N NaOH standard solution in a burette. The calculation of this acid content used the formula (Diatmika 2019):

$$\text{Acid content} = \frac{\text{V x N x Mr}}{\text{S x 1,000}} \text{ x } 100\%$$

where V is the volume of NaOH (mL); N is the concentration of NaOH (mgeq/L); Mr is the relative molecular weight of CH_3COOH; and S is the sample weight (g)

(4) Phenol content. The content of phenol compounds tested in liquid smoke was proven by the reactant of 1% $FeCl_3$ solution. The occurrence of a change in the color of liquid smoke to a brownish purple color means that liquid smoke contains phenol compounds.

2.2.4. Characterization of charcoal briquettes

The resulting charcoal as much as 850 g was mixed evenly with 50 g of tapioca flour as a binder, and 100 mL of clean water so that with a weight ratio of 85:5:10, to form a homogeneous dough. Then the mixture was pressed hydraulically with a pressure of 80 kg/cm^2, so that briquettes are formed.

The pyrolysis process produces coconut shell charcoal, which is subsequently ground and filtered. 5% starch binder is combined with the powdered charcoal until a homogenous mixture is achieved. The mixture is run through a manual hydraulic press machine to make briquettes. After that, the sun is used to dry the briquettes for two days (Arafah & Harsono 2021).

Following the procedure of ASTM D5142-02 (2017) and Ajimotokan *et al*. (2019) determination of the characteristics of coconut shell charcoal briquettes as follows:

(1) Moisture content. The water content (M_c) of 0.5 g of sample (W_0) was determined by heating each sample at 105°C for 1 hour in an oven. The samples were removed from the oven and allowed to cool in a desiccator. The samples were reweighed to obtain the final (dry) weight (W_d). The water content was then calculated using the equation :

$$M_c = \frac{W0 - Wd}{W0} \text{ x } 100\%$$

(2) Volatile matter content. The cup with known mass and its lid was filled with the test sample and placed in the furnace. It was heated in the furnace at a temperature of 900 ºC for 7 minutes, then cooled in a desiccator and weighed. The volatile matter (V_m) was then evaluated as the percentage loss in mass of the sample using the equation:

$$V_m = \frac{B - C}{B} \text{ x } 100\%$$

where *B* is the weight of the oven-dried sample and *C* is the weight of the furnace-dried sample.

(3) Ash content. One gram of each pulverized briquette sample was measured and then placed in a container of known mass and dried in an oven to constant mass. These samples were then heated in a furnace at 800°C for five hours and weighed after cooling. The ash content was then estimated from the percentage loss of mass of the sample using the following equation:

$$A_c = \frac{D}{B} \text{ x } 100\%$$

where A_c is the percentage ash content, *D* is the weight of ash (furnace dried), and *B* is the weight of the oven-dried sample.

(4) Fixed-carbon content. Fixed carbon is the fraction of carbon in briquettes, in addition to the fraction of water, volatile matter and ash. The fixed carbon content is calculated using the equation:

$$F_c = 100 - (V_m + M_c + A_c)$$

where F_c is the fixed carbon (%) ; V_m is the volatile content (%) ; M_c is the moisture content (%); and A_c is the ash content (%).

(5) Briquett density. Briquette density. Generally speaking, density is expressed as a weight to volume ratio, which is determined by weighing and measuring the volume in dry air. The following formula could be used to determine the density of briquettes:

$$D = \frac{M}{V}$$

where D is the briquettes density (g/cm^3); M is the briquett weight (g); an V is the briquettes volume (cm^3)

(6) Compressive strength. The briquette is compressed until it breaks in order to perform the compressive strength test. It is possible to compute compressive strength using the following formula:

$$S = \frac{P}{A}$$

where S is the compressive strength (kg/cm^2); P is the compressive load (kg); and A is the surface area (cm^2)

(7) Calorific value. A silica cup containing one gram of the material was placed inside the bomb calorimeter tube. A manual perioxide bomb calorimeter was the instrument used to calculate this calorific value. The following formula could be used to calculate the calorific value:

$$C_v = T_2 - T_1 - 0.05 \text{ x m x } 0.24$$

where T_1 is the water's initial temperature (°C); T_2 is the water's temperature after burning (°C); and C_v is the calorific value of charcoal briquettes. Temperature owing to wire heat increase (0.05); m is the calorimeter specific temperature (m = 73529.6 (kJ/kg); and 0.24 constant (1 J = 0.24 cal).

2.2.5. Effectiveness of liquid smoke as a preservative for white copra

Grade 1 liquid smoke was dissolved with distilled water at the concentrations tested, namely concentration levels of 5%, 7.5%, 10%, 12.5%, and 15%, which were compared with the existing preservation method with sulfur fumigation. The seven treatments were applied in a laboratory experiment arranged in a randomized block design (RBD) with four replications.

The response data in the form of percent intensity of fungal infection, copra color level score, and oil yield from copra were subjected to ANOVA. Because there was a significant response to the treatment, it was continued with Duncan's multiple test.

(1) Intensity of fungal infection. The growth of fungal mycelium on the surface of copra is observed visually during drying. Calculation of the intensity of fungal attacks (Rahmat & Albaki 2019):

$$I = \frac{\Sigma(\text{n x V})}{\text{Z x N}} \text{ x } 100\%$$

where I is the damage intensity (%); nis the number of each category of attacks; Vis the scale value of each category; Z is the scale value of the highest category; and Nis the number of samples observed.

(2) Copra color. Determining the color of copra visually was direct observation of copra based on the scale namely a rating range of 0 to 4 (Apriyanto & Rujiah 2019), with scale details 1 = white; 2= somewhat white; 3= slightly yellow; and 4= yellow.

(3) Oil yield. Calculation of the yield of coconut oil produced from each unit weight of copra (Hernawati & Jirana 2018), with the following formula :

$$\text{Oil yield} = \frac{\text{Mass of coconut oil produced (g)}}{\text{Mass of copra}} \text{ x } 100\%$$

3. RESULTS AND DISCUSSIONS

3.1. Zero waste and circular economy efforts in coconut processing

This study attempts to implement the principle of zero waste by designing a circular economic model in processing coconuts into white copra. Meanwhile, other components of the fruit, such as shells, fibers, and coconut water are also processed into products that are valuable financially and in terms of production and environmental sustainability. The white copra industry in Indonesia has high potential to increase farmers' income, if the utilization of by-products and waste is pioneered to be processed into valuable materials.

The processed products are liquid smoke, charcoal briquettes, and tar as illustrated in Figure 1. However, products from coconut water were not studied in this study.

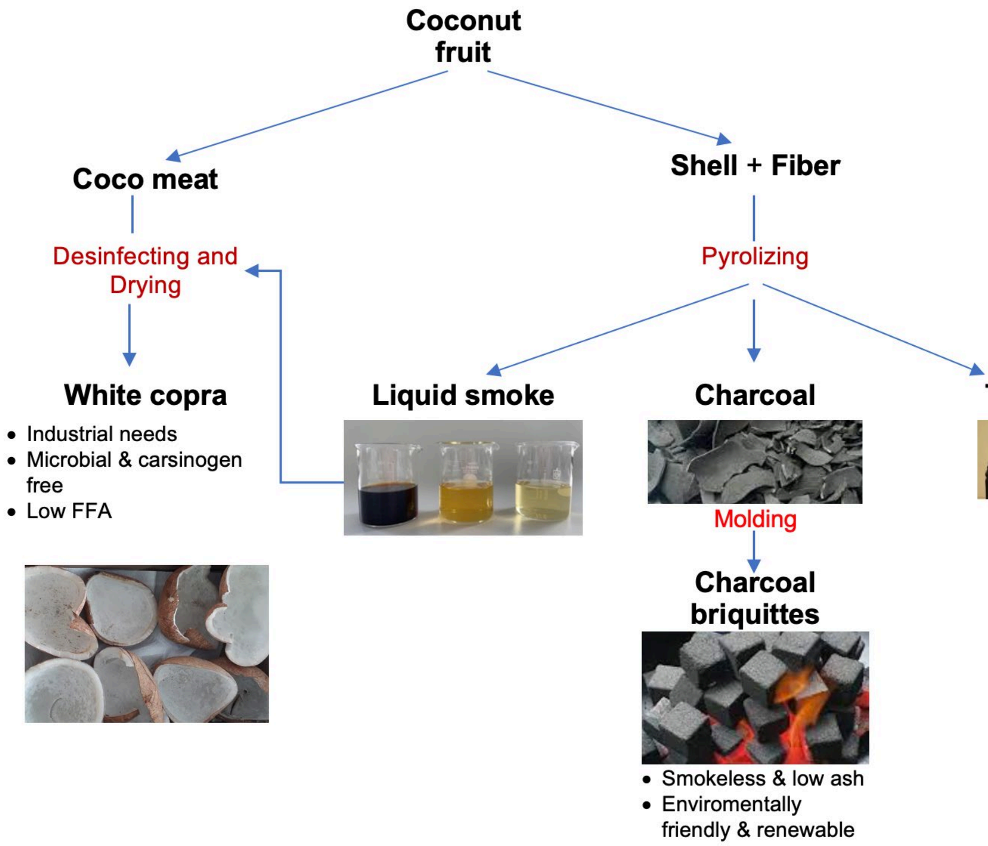

Fig. 1: Implementation of the zero waste and circular economy model in processing coconut into white copra, liquid smoke, charcoal briquettes, and tar.

The following are several ways of utilization that can increase the added value and income of coconut farmers..

a. Coconut shells can be carbonized to produce charcoal, which has a high calorific value and can be used as fuel, briquettes, or even activated charcoal for the food and pharmaceutical industries (Labombang & Nirmalawati 2017; Pomalingo *et al*., 2022).

b. Coconut shell processing also produces liquid smoke that can be used in the food industry. This liquid smoke not only adds value to the product but also reduces environmental pollution due to burning (Pojoh 2017; Pomalingo *et al*., 2022).

c. Coconut fiber, which is usually considered waste, can also be utilized in the following ways: Coconut fiber can be processed into coco fiber, which is used in various applications, including textile products and raw materials for handicrafts (Stelte *et al.* 2023).

d. Water from coconut processing can be used to make Nata de Coco, a popular food product with high economic value (Basuki & Fahadha, 2020).

3.2. Quantity of coconut fruit components

Table 1. Quantity of 100 coconut fruit components

Coconut fruit components	Weight total of 100 coconut fruits (kg)	Average Weight per fruit (g)	Proportion (%)

Fruit meat	48.9	489	27.93
Shell	23.2	232	13.25
Fiber	70.6	706	40.32
Cocowater	32.4	324	18.50
Total	175.1	1,751	100.00

Table 1 shows the average data of the peeling test results on 20 coconuts of the tall variety. The main components of coconuts were the meat and its by-products which were often waste from the copra industry, namely shells and fibers. The proportion of fibers and shells in tall coconut varieties was 13.25% and 40.32% respectively. Based on these proportions, if 100 fruits from tall coconut varieties are peeled, the shells and fibers will be obtained as much as 232 g and 706 g, respectively. If these two coconut components are not processed into useful products, they will become biomass waste with a proportion of 62% (Obeng *et al*., 2020). This quantity of biomass has the potential to be turned into valuable and useful products, such as tar, charcoal briquettes, and liquid smoke through the pyrolysis process. Moreover, if these two products are included again as one of the inputs for white copra production, they will play a role in improving the quality and increasing the efficiency of white copra production.

3.3. Quantity of coconut shell pyrolysis products

Table 2. Quantity of pyrolysis products from each 23,2 kg coconut shells

Pyrolisis replication	**Quantity of product**		
	Liquid smoke (g)	**Charcoal (g)**	**Tar (g)**
1	8,965.00	7,540.14	563.08
2	9,276.26	6,751.06	563.09
3	9,138.70	7,175.35	597.76
Average	9,126.65	7,155.52	574.64
Proportion (%) *	39.34	30.84	2.48

* Total pesentase proporsi produk pirolisis tidak mencapai 100%, karena ada komponen gas-gas yang tidak bisa dikondensasi pada bagian akhir reaktor pirolisis dengan proporsi 27.43 % .

This quantity of biomass has the potential to be turned into valuable and useful products, such as tar, charcoal briquettes, and liquid smoke through the pyrolysis process. Table 2 shows that the pyrolysis occurred on 250 to 300 ºC of 20 kg of coconut shells produced liquid smoke, charcoal, tar, and non-condensable gases of 7,867.81 g (39.35%), 6,168 g (30.99%), 295.405 g (2.16%), (27.51%), respectively. This percentage is comparable to the findings of other studies, which showed that the yields of char, liquid, and gas were, respectively, 22 to 31%, 38 to 44%, and 30 to 33%. The findings show that heating rate and residence time have less of an impact on the pyrolysis yield than do temperature and particle size (Sudaram and Natarajan, 2009). The pyrolysis process consists of multiple stages, with significant degradation of hemicellulose and cellulose occurring between 230°C and 400°C. Above 400°C, lignin starts to decompose, affecting the overall product yields (Wang & Sarkar 2018).

In addition, this pyrolysis product is also influenced by smaller particle sizes lead to higher surface area-to-volume ratios, enhancing heat transfer and potentially increasing bio-oil yields (Anggraini *et al*. 2024). However, excessively small particles may lead to operational challenges such as clogging. Moisture must be removed before effective pyrolysis can occur; high moisture content can lower the overall yield of bio-oil and other products due to energy being used for evaporation rather than pyrolysis (Wang & Sarkar, 2018).

3.4. Properties of redistilated liquid smoke

The distillation process aimed to remove toxic substances contained in liquid smoke. In liquid smoke there are differences in content indicated in the color of each grade of liquid smoke, as seen in Figure 2.

Grade 3 Grade 2 Grade 1

Fig. 2: Comparison of visual appearance on increasing purity of liquid smoke in succession grade 3 (crude), grade 2 (result of one distillation), and grade 1 (result of two distillations)

Crude liquid smoke, also known as grade 3, is the liquid smoke that results from the direct pyrolysis process. In this grade 3 liquid smoke, it still contains tar which is toxic and benzo(a)pyrene which is carcinogenic, so two redistillation processes must be carried out, which respectively produce grade 2 and grade 1 (food grade) liquid smoke.

The results of the physical and chemical properties test show that the liquid smoke from coconut shells is of good quality and meets the standards. This can be seen in Table 3, namely the liquid smoke has a specific gravity, color, acid content, pH, and no dispersed substances according to international standards (Wu *et al*. 2015).

Table 3. Properties of grade 1 liquid smoke

Quality parameters	**Value**	**Japenese standard**
Yield (mL/kg)	248,25	-
Color	pale yellow	yellowish brown
pH	2	1.3 – 3.7
Transparency	transparent	transparent
Density (g/mL)	1.02	> 1.001
Total acid content (%)	7.56	1 - 18
Phenol content (%)	2.78	-
Benzo(a)pyrene (%)	naught	-

Grade 1 liquid smoke, which can be used as a direct food preservative to make food safe for consumption, was used in the investigation. The entire batch of grade 1 coconut shell liquid smoke was produced with a quality parameter value that complies with international criteria for liquid smoke quality. The characterization of the liquid smoke aimed to determine the composition of liquid smoke as an antimicrobial for copra.

The quality parameters of liquid smoke are crucial for its application in food preservation and flavoring. These parameters include pH, titratable acidity, phenolic content, and specific chemical characteristics. Liquid smoke typically exhibits a pH range of 1.5 to 5.5, depending on the wood source and processing methods used. For example, a study noted that a full-strength liquid smoke had a pH of 2.3, while refined products had higher pH values ranging from 4.2 to 5.7 (Montazeri *et al*. 2013). Phenolic compounds are critical for the flavor and preservative qualities of liquid smoke. For instance, the phenolic content in liquid smoke produced from Lamtoro wood was measured at 481.2 ppm, while corn cob liquid smoke had 335 ppm (Swastawati, 2007). These compounds contribute to the antimicrobial properties and overall flavor intensity of the product.

The color of liquid smoke can vary significantly, with good quality liquid smoke typically exhibiting a pale yellow to reddish-brown hue. The chemical composition is influenced by the type of wood used; hardwoods generally yield different profiles compared to agricultural residues like corn cob (Budaraga *et al*. 2016). Quality assessments also include checking for undesirable compounds such as Benz(a)pyrene, a known carcinogen found in some smoked products. Studies have shown that certain types of liquid smoke do not contain this compound, enhancing their safety for consumption (Murcovic, 2004).

3.5. Properties of charcoal briquettes

Table 4. Characteristics of coconut shell charcoal briquettes

Test Parameters	Units	Sample Briquette Values	Standards	
			Indonesian	Japanese
Water content	%	7.79	8	6 - 8
Volatile content	%	13.75	15	15 - 30
Ash content	%	2.76	8	3 - 6
Fixed carbon content	%	68.66	77	60 - 80
Density	g/cm^3	0.92	-	1.0 - 1.2
Compress strength	kg/cm^2	64.22	-	60 - 65
Calorific value	cal/g	6,521	5,000	6,000-7,000

The water content of the sample charcoal briquettes in this test was lower than the average water content in Indonesia, which is 8% (BSN 2019). The water content of the briquettes increases with increasing concentration of binder and decreasing compaction pressure in the molding process. The hygroscopic nature of the carbonized material and the water's availability in the binder are assumed to be the causes of the high water content (Aransiola *et al*. 2019).

The test sample charcoal briquettes had a 13.75% volatile content. Compared to Japanese and Indonesian standards, this value is superior. This demonstrates that the created coconut shell charcoal briquettes satiated the specifications. Materials with higher stability levels produce less smoke when briquettes burn. Volatile matter is a component that evaporates when briquettes are burned, including hydrocarbon compounds such as methane and carbon monoxide. This content is directly related to the amount of smoke produced during combustion (Rusman *et al*., 2023).

The test sample's charcoal briquettes had an ash percentage of 2.83%, which is still within the range allowed by the Japanese standard but below the Indonesian norm. It is imperative to maintain a low ash content in the briquettes to prevent the heating level from dropping. The biomass material's density and mineral content have an impact on the charcoal briquettes' ash content. Low-density biomass will contain a lot of minerals. The varying inorganic components of the raw materials are assumed to be the cause of the variation in ash content (Alpian *et al*. 2020).

The fixed carbon content of the coconut shell charcoal briquettes sample tested at 68.66%, which is within the Japanese Standard's required range but less than the Indonesian Standard. Fixed carbon is the carbon fraction remaining after the combustion process, and is the main indicator of the quality of charcoal briquettes. The higher the fixed carbon content, the better the quality of the briquettes (Abimanyu *et al*. 2024). Briquettes with high fixed carbon content have better calorific value, making them more efficient when used as fuel. In research, the ideal fixed carbon content to meet quality standards is above 77% (Dewi *et al*. 2020).

Coconut shell charcoal briquettes have a density of 0.92 g/cm^3, although in reality it is below the Japanese standard. According to earlier studies, the density of charcoal briquettes manufactured from coconut trash is 0.86 g/cm^3, whereas the density of charcoal briquettes made from madan wood is 0.68 g/cm3. This analysis suggests that the material's specific gravity accounts for the majority of the density (Kongprasert *et al*. 2019).

The test sample's coconut shell charcoal briquettes had a compressive strength of 64.22 kg/cm^2, falling between the 60 and 65 kg/cm^2 quality range specified by the Japanese Standard. Compressive strength is the ability of the briquettes to withstand axial loads without failure. It is a crucial mechanical property that indicates how much compressive force a briquette can endure before collapsing. This property is significant for ensuring the durability and stability of briquettes during handling, storage, and transportation (Putri & Andasuryani 2017). This degree of compressive strength is critical to the briquettes integrity during packing and transit. Small particle size, low water content, and high molding pressure all have an impact on compressive strength. Additionally, at 150 MPa applied pressure, the briquette unit density increases from 2.8 to 3.0 kg/dm^3 when the binder content is increased from 10% to 30% (Khlifi *et al*. 2020).

According to the test results, the charcoal briquette sample had a calorific value of 6.521 cal/g. This value is more than the Indonesian Standard and falls between the range of the Japanese Standard value (ASTM 2017). The calorific value, often expressed in megajoules per kilogram (MJ/kg) or kilocalories per kilogram (kcal/kg), indicates the energy content of the briquettes (Utami *et al*. 2024). Briquettes with higher calorific values provide more energy per unit mass, which translates to better fuel efficiency. This means less material is required to achieve the same heating effect, making them more economical and environmentally friendly (Suluh *et al*. 2022). The calorific value significantly affects market pricing and competitiveness. Fuels with higher energy content are generally more desirable and can command higher prices due to their efficiency and lower consumption rates (Pari *et al*. 2023).

3.6. Effectiveness of liquid smoke as a preservative for white copra

Based on the analysis of variance and Duncan's test (Gomez & Gomez 1983), it was proven that the treatment of liquid smoke concentration had a significant effect on the intensity of fungal infection, color, and yield of copra oil. Furthermore, the difference test between the treatments tested was as shown in Table 5.

Table 5. Effect of liquid smoke treatments on the fungal infection, copra color, and oil yield

Treatment	Fungal Infection (%)	Copra color *	Oil yield (%)
A = sulfur fumigation dosage 30 g/m^3	10.16 a	1.22 a	47.33 b
B = liquid smoke concentration 5%	24.22 b	1.94 c	39.84 a
C = liquid smoke concentration 7.5%	21.09 b	1.97 c	41.34 a
D = liquid smoke concentration 10%	11.72 a	1.91 bc	49.34 b
E = liquid smoke concentration 12.5%	7.81 a	1.13 a	51.51 b
F = liquid smoke concentration 15%	7.81 a	1.22 a	48.22 b

Note: in each column, thee Duncan's multiple range test indicates that there is no significant difference between numbers that are followed by the same letters at the 5% level. *: Color score range from white to brown: 1 to 4

The acidic compounds in liquid smoke inhibit the growth of microorganisms by penetrating cell walls and causing cell lysis. This property is particularly beneficial in preventing spoilage caused by bacteria and fungi, thus enhancing food safety (Desniorita & Maryam 2015). While studies on the antifungal effects of liquid smoke are less extensive, some evidence suggests it can inhibit fungal growth as well. For instance, liquid smoke has been shown to prevent mold growth on fibrous food casings and inhibit specific molds like *Aspergillus oryzae* and *Penicillium spp*. on cheese (Gracia & Ismail 2020). The minimum inhibitory concentrations for molds such as *Aspergillus niger* have been reported to range from 1.5% to 5% (Deliephan *et al*. 2023).

Liquid smoke has been shown to prolong the shelf life of various food products, including sauces and meats. For instance, adding liquid smoke powder to sauces can increase their shelf life significantly; sauces treated with liquid smoke showed an increase in shelf life from 3 days (without treatment) to 13 days (with 6% liquid smoke) due to reduced microbial growth and flavor retention (Keryanti *et al*. 2020).

The organic acids found in liquid smoke made from coconut shells include acetic and carboxylic acids, phenols, furans, aldehydes, and ketones (Rizal *et al*. 2020). Thus, coconut shell liquid smoke can be one of the materials to prevent and inhibit the growth of microorganisms in coconut meat.

The color of copra was impacted by sulfur fumigation and the treatment of coconut shell liquid smoke. The treatment of sulfur fumigation, 12.5% liquid smoke, and 15% produced the same copra color, which was close to pure white. While the treatment of 5, 7.5, and 10% liquid smoke produced a yellowish white copra color (Figure 3). Yellowish color was caused by the intensity of fungal growth attacks on the surface of the copra meat (Subramanian *et al*. 2018).

On the second day of copra drying, fungi are seen starting to grow on the surface of the copra. Fungi that grow in the early stages appear white which is their mycelium. On the next day until the seventh day, the fungi develop and begin to experience changes in the color of the infection zone spots, namely yellow, green, brown, reddish brown, gray, to black until the 7th day.

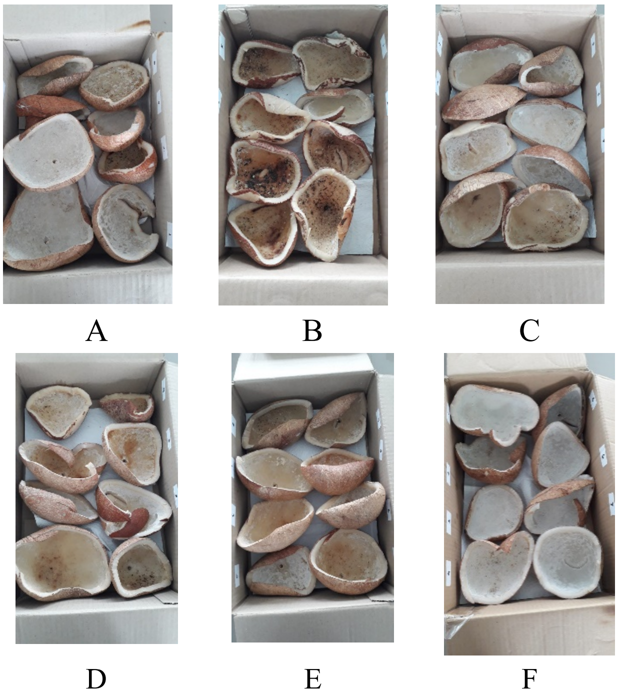

Fig. 3: Copra color in treatment : (A) sulfur fumigation; (B) liquid smoke treatment of 5%; (C) liquid smoke treatment of 7.5%; (D) liquid smoke treatment of 10%; (E) liquid smoke treatment of 12.5%; and (F) liquid smoke treatment of 15%

This result is in line with previous research, that copra with sulfur fumigation produced white copra. Liquid smoke treatment that was comparable to sulfur fumigation was 12.5% and 15% treatment which correlated with the results of the effect of liquid smoke in inhibiting fungal infections. Copra that was given a soaking treatment in a sulfite solution for 6 to 24 hours was grayish white. The grayish color was caused by the oil content in the copra meat. But copra that was given treatment without washing was slightly white to slightly yellow. This was thought to be because there was still sugar on the surface of the coconut so that when heated it browns (Kaseke 2016).

Liquid smoke treatment with concentrations of 10, 12.5, and 15% gave the same value as the comparison treatment of sulfur fumigation. This proved that the three liquid smoke treatments were able to provide protection against copra damage caused by microbes that infected copra, which was correlated with oil yield from copra. However, liquid smoke treatment with concentrations of 5 and 7.5% was not effective enough to protect copra from damage by microbes. The above facts prove that the application of liquid smoke can prevent a decrease in oil yield due to microbial infections that damage the coconut meat tissue. The liquid smoke can maintain the yield of copra oil which can decrease due to the growth of fungi such as *Rhizopus sp*., *Aspergillus flavus*, *Aspergilus niger*, *Penicillium glaucum*; and the oil produced from the copra has the lowest levels of protein, cholesterol and free fatty acids (FFA) (Amperawati *et al*. 2012).

Based on the description above, several advantages are obtained from using coconut shell liquid smoke as a preservative for white copra, including: (a) Liquid smoke is more economical than traditional smoking methods, saving time, energy, and reducing the need for extensive equipment and labor. It streamlines the smoking process, making it suitable for large-scale production (Pojoh 2017); (b) It effectively reduces the risk of food contamination by inhibiting the growth of various food-borne pathogens. This property helps in maintaining food safety during storage (Deliephan *et al*. 2023); (c) Unlike traditional smoking, which can result in variable flavors and colors, liquid smoke provides a consistent product quality. This is crucial for commercial applications where uniformity is important (Nithin *et al*. 2018); and (d) The production of liquid smoke is generally less harmful to the environment compared to traditional methods, as it produces fewer emissions and reduces waste associated with wood burning (Wibowo *et al*. 2023).

4. CONCLUSIONS

The results of this study indicate that the weight of 100 coconuts of the tall variety sample was 175.1 kg or an average weight of 1,751 g per coconut. After peeling all the coconuts, the components of meat, shell, fiber, and fruit water were obtained, each weighing 48.9 kg, 23.2 kg, 70.6 kg, and 32.4 kg. Furthermore, 23.2 kg of shells were pyrolyzed and produced liquid smoke, charcoal and tar of 9,126.70 g, 7,155.52 g and 574.64 g, respectively, which was the average of three pyrolysis repetitions.

Coconut shell charcoal briquettes were formed and quality tested of water content, volatile matter, ash, fixed carbon, specific gravity, compressive strength and calorific value were 7.79%, 13.75%, 2.76%, 68.66%, 0.92 g/cm^3, and 64.22 kg/cm^2, 6,521 cal/g, respectively. All the results of the charcoal briquette test parameters met Indonesian and Japanese Standards.

In the processing of coconut meat, 25.67 kg of white copra was obtained which was treated with 12.5% liquid smoke with a quality equivalent to the results of sulfur fumigation, namely free from fungal infection and the highest oil yield and copra brightness.

This study provided new findings on the circular economy model and the principle of zero waste in white copra production with the facts that, each tall coconut variety produced 489 g of coconut meat and 232 g of shell. From the shell, 91.13 g of liquid smoke and 82.15 g of charcoal briquettes were produced, and 26.67 g of white copra was produced as the main product.

ACKNOWLEDGEMENTS

We would like to thank you for the research grant support from the Head of the Institute for Research and Community Service; permission from the Rector, Director of the Postgraduate Program, and Dean of the Faculty of Agriculture, Siliwangi University. We would also like to thank the lecturers and students involved in the research activities and publication of this article.

REFERENCES

Abimanyu, R, Zuhdi, FM, Billah, M, Karaman, N & Pujiastuti C 2024, Charcoal briquettes from candlenut shell waste and sengon sawdust with arpus adhesive using carbonization process. G-Tech: Applied Technology Journal, 8: 2050-2059.

Achi, C., Snyman, J, Ndambuki, JM & Kupolati, WK 2024, Advanced waste-to-energy technologies: A review on pathway to sustainable energy recovery in a circular economy. *Nature Environment & Pollution Technology*, 23 : 1239-1259.

Ahmad, RK, Sulaiman, SA, Yusup, S, Dol, SS, Inayat, M & Umar, MH 2022, Exploring the potential of coconut shell biomass for charcoal production. *Ain Shams Engineering Journal*, 13:1-13

Ajimotokan, HA, Ehindero, AO, Ajao, KS, Adeleke, AA, Ikubanni, P & Shuaib-Babata, L 2019, Combustion characteristics of fuel briquettes made from charcoal particles and sawdust agglomerates. *Scientific African*, 6: 1-9.

Alpian, A, Panjaitan, R, Jaya, A, Yanciluk, Y, Suprianti, W & Antang, EU 2020, Chemical properties of charcoal briquette with composition types of gerunggang (*Cratoxylon arborescens*) and tumih (*Combretocarpus rotundatus*) wood from Tropical Peatlands. *Journal of Tropical Peatlands*, 10: 17-22.

Amperawati, S, Darmadji, P & Santoso, U 2012, The effect of coconut shell liquid smoke on the growth of fungi during copra drying. *Agritech*, 32:191-198.

Anggraini, SPA, Suprapto, S, Juliastuti, S R, & Mahfud, M 2024, Optimization of pyrolytic oil production from coconut shells by microwave-assisted pyrolysis using activated carbon as a microwave absorber. *Int. J. of Renewable Energy Development,* 13*:*145-157

Apriyanto, M & Rujiah, R 2019, The effect of sulfite solution soaking and sulfur fumigation on the quality of white copra in Indragiri Hilir Regency. *Journal of Agricultural Technology*, 8: 91–96.

Arafah, AD & Harsono SS 2021, Analysis of the effect of mixed dosage of coconut shell charcoal and adhesive materials on the characteristics of herbal medicine dregs briquettes. *Science and Technology Periodicals*, 9:179-185.

Aransiola, EF, Oyewusi, TF, Osunbitan, JA & Ogunjim, LA 2019, Effect of binder type, binder concentration and compacting pressure on some physical properties of carbonized corncob briquette. *Energy Reports*, 5: 909–918.

Assidiq, F, Rosahdi, TD & El Viera, BV 2018, Utilization of coconut shell liquid smoke in preserving beef. *Al-Kimiya*, 5: 34–41.

ASTM D5142-02. 2017. Standard test methods for proximate analysis of coal and coke analysis samples with instrumental procedures.

Basuki, M & Fahadha, RU 2020, Identification of the causes nata de coco production defects for quality control. *Industrial Spectrum*,18:175-181.

Bradley, WL & Conroy, S 2019, Using agricultural waste to create more environmentally friendly and affordable products and help poor coconut farmers. The 1st International Conference on Automotive, Manufacturing, and Mechanical Engineering. E3S Web of Conferences 13001034, 1:10. BSN 2009, Wood charcoal briquettes. Indonesian National Standard, SNI 01-6235-2000.

Budaraga, IK , Arnim, A , Marlida, Y & Bulanin, U 2016, Liquid smoke production quality from raw materials variation and different pyrolysis temperature. *Int Advance Sci. Engineering Information Tech.*, 6:306-315

Chen, L, Yang, M, Chen, Z, Xie, Z, Huang, L, Osman, AI, Farghali, M, Sandanayake, M, Liu, E, Ahn, YH, Al-Muhtaseb AH, Rooney, DW & Yap PS 2024, Conversion of waste into sustainable construction materials: A review of recent developments and prospects. *Materials Today Sustainability*, 27, 100930.

Deliephan, A, Dhakal, J, Subramanyam, B, & Aldrich, CG 2023, Effects of liquid smoke preparations on shelf life and growth of wild type mold and *Aspergillus flavus* in a model semi moist pet food. *Front. Microbiol., Sec. Food Microbiology*, 14: 1-11.

Desniorita & Maryam 2015, The effect of adding liquid smoke powder to shelf life of sauce. *Int. Advance Sci. Engineering Information Tech.*, 5: 457-459.

Dewi, RP, Saputra, TJ & Purnomo, SJ 2020, Fixed carbon and volatile matter content test of charcoal briquettes with variation of charcoal powder particle size. National Proceedings of the on Industrial Technology, Environment and Infrastructure. Malang, Indonesia

Diatmika, IGA, Kencana, PKD & Arda, G 2019, Characteristics of liquid smoke from tabah bamboo stems (*Gigantochloa nigrociliata* Buse-Kurz) pyrolyzed at different temperatures. *Journal of Biosystems and Agricultural Engineering*, 7: 278-285.

Hernawati, D & Jirana, J 2018, Analysis of free fatty acids and cholesterol in fermented coconut oil. *Scientific Journal*, 4: 194-199.

Gomez, KA & Gomez, AA 1984, Statistical procedures for agricultural research. John Wiley &Sons Inc. 2nd Ed.

Gracia, KA & Ismail, Y 2022, The study of pyrolysis temperature toward total phenol content, total acid content and pH in spent coffee ground liquid smoke. *Serambi Engineering*, 7: 2954 - 2964

Kambey, E, Tooy, D & Rumambi, D 2023, Coconut quality test briquettes as alternative biomass energy source. *Cocos Journal*, 15: 1-8.

Kaseke, H 2016, Analysis of free fatty acids and cholesterol in fermented coconut oil. *Scientific Journal*, 8: 151-158.

Khlifi, S, Lajili, M, Belghith, S, Mezlini, S, Tabet, F & Jeguirim, M 2020, Briquettes production from olive mill waste under optimal temperature and pressure conditions: Physico-chemical and mechanical characterizations. *Energies*, 13: 1-14.

Kongprasert, N, Wangphanich, P & Jutilarptavorn, A 2019, Charcoal briquettes from madan wood waste as an alternative energy in Thailand. *Procedia Manufacturing*, 30: 128–135.

Labombang, M & Nirmalawati 2017, Utilization of coconut shells as acoustic panels. National Seminar on Information Systems 2017, September 14, 2017 Faculty of Information Technology, Malang Indonesia.

Lingbeck, JC, Cordero, P, O'Bryan, P, Johnson, MG, Ricke, M & Crandall, PG 2014, Functionality of liquid smoke as an all-natural antimicrobial in food preservation. *Meat Science*. 97: 197–206.

Montazeri, N, Oliveira, ACM , Himelbloom, BH , Leigh, MB & Crapo, CA 2013, Chemical characterization of commercial liquid smoke products. *Food Science & Nutrition*, 1: 102– 115

Mulyawanti, I, Kailaku, SI, Syah, ANA & Risfaheri, R 2019, Chemical identification of coconut shell liquid smoke. IOP Conf. *Series: Earth and Environmental Science*, 309, 012020.

Murkovic, M 2004, Food Contamination by Polycyclic Aromatic Hydrocarbons (PAHs) in Smoked Food*s*. In Handbook of Food Chemistry.

Nithin, CT, Joshy, CG, Chatterjee, NS, Panda, SK, Yathavamoorthi, R, Ananthanarayanan, TR, Mathew, S, Bindu, J & Gopal, TKS 2018, Liquid smoking as a method for addressing polycyclic aromatic hydrocarbons (PAH) in traditional *masmin. Indian J. Fish.,* 65(3): 84-94.

Nordahl, SL, Preble, CV, Kirchstetter, TW & Scown, CD 2023, Greenhouse gas and air pollutant emissions from composting. *Environ Sci. Technol.*, 57:2235-2247.

Obeng, GY, Amoah, DY, Opoku, R, Sekyere, C, Adjei, EA & Mensah, E 2020, Coconut wastes as bioresource for sustainable energy: quantifying wastes, calorific values and emissions in Ghana. *Energies, 13*: 1-13.

Pari, G, Efiyanti, L, Darmawan, S, Saputra, NA, Hendra, D, Adam, J, Inkriwang, A & Efendi, R 2023, Initial ignition time and calorific value enhancement of briquette with added pine resin. *J. Korean Wood Sci. Technol.*,51(3): 207-221

Pojoh, B 2017, Potency of liquid smoke accumulation of coconut and its by-product processing. Jurnal Penelitian Teknologi Industri, 9: 49-60

Pomalingo, N, Rantelinggi, D & Sirajuddin, Z 2022, The economic potential of coconut through the utilization of coconut derivative products in Gorontalo Regency. *Buletin Poltanesa,* 23:792-797

Puspanantasari, E.P. (2024). Renewable energy: Charcoal briquettes from coconut shells. Book chapter : *Physics and mechanics of new materials and their applications*, 541-548.

Putri, RE & Andasuryani, A 2017, Briquette quality study with biomass waste raw materials. *Journal of Andalas Agricultural Technology*, 21: 143-151.

Radam, RM, Lusyiani, L, Ulfah, D, Sari, NM & Violet, V 2018, The Qualty of charcoal briquettes that made from nypah (*Nypa fruticans)* outshell to product energy. *Tropical Forest Journal*, 6: 52-62.

Rahmat, B & Albaki, AZH 2021, Fungicidal action of coconut waste liquid smoke on citrus fruit-rot pathogens (*Penicillium digitatum* and *Penicillium italicum*). *Internat. J. of Microbiology and Biotechnology*, 6: 53-58.

Rizal, WA, Nisa, K, Maryana, R, Prasetyo, DJ, Pratiwi, D, Jatmiko, TH, Ariani, D & Suwanto, A 2020, Chemical composition of liquid smoke from coconut shell waste produced by SME in Rongkop Gunungkidul. *OP Conference Series: Earth and Environmental Science*, 462, 012057.

Rizal, WA Suryani, R, Maryana, R, Prasetyo, DJ, Pratiwi, D, Ratnawati, YA, Ariani, D & Suwanto, A 2022, Coconut shell waste treatment technology for a sustainable waste utilization: A case study of the SMEs in Bohol Village, Indonesia. *ASEAN Journal of Community Engagement*, 6: 278-293.

Rusman, LO, Lestari, L, Raharjo, S, Usman, I & Desi Chrismiwahdani, D 2023, Effect of activation temperature on the quality of rice husk activated charcoal briquettes. *Journal Online of Physics,* 8: 39-46.

Saputra, NA, Komarayati, S & Gusmailina, G 2021, Chemical organic compound of five liquid smokes. Forest Products Research Journal, 39: 39-54.

Stelte, W, Reddy, N, Barsberg, S & Sanadi, AR 2023, Coir from coconut processing waste as a raw material for applications beyond traditional uses. *BioResources Journal,* 18: 2187-2212. Subramanian, P, Thamban, C,

Hegde, V, Hebbar, KB Bhat, R, Krisnakumar, V, Niral, V & Josephrajkumar, A 2018, *Coconut Technical Bulletin* No. 133.

Sudaram, EG & Natarajan, E 2009, Pyrolysis of coconut shell: an experimental investigation. *Journal Engineering and Research*, 6: 33-39.

Suluh, S , Salo, LA , Mangera, E , Ramba, D & Barru, Y 2022, Perfomance analysis of coconut shell charcoal briquettes in terms of variations in immersion time as an alternative energy source. *ARPN Journal of Engineering and Applied Sciences*, 17:1611-1617

Suryani, R, Rizal, WA, Pratiwi, D & Prasetyo, DJ 2020, Characteristics and antibacterial activity of liquid smoke from white wood (*Melaleuca leucadendra*) and teak wood (*Tectona grandis*) biomass. *Journal of Agricultural Technology*, 21:106-117.

Toopa, TA, Ward, S, Oldfield, T, Hulla, M, Kirbya, ME & Theodoroua, MK 2017, Agrocycle-developing cyrcular economy in agriculture. *Energy Procedia,* 123: 76–80.

Umami, T, Masitah, M & Nursalam, N 2023, Analysis of the feasibility of white copra business in Toari District, Kolaka Regency. *Wiratani: Scientific Journal of Agribusiness*, 6:1-10.

Utami, IS, Rusdiana, D , Nahadi, N , Suwarma, IR , Guntara, Y , Amida, N, Rahman, NFA & Oktarisa, Y 2024, How to make biomass briquettes with their characteristics analysis. *Indonesian Journal of Science & Technology*, 9: 585-610.

Vieira, F, Santana, HEP, Jesus, M, Santos, J, Pires, P, Vaz-Velho, M, Silva, DP & Ruzene, DS 2024, Coconut waste: Discovering sustainable approaches to advance a circular economy. *Sustainability*, 16, 3066.

Wang, Q & & Sarkar, J 2028, Pyrolisis behaviors of waste coconut shell and husk biomasses. *Int. J. of Energy Prod. & Mgmt.,* 3: 34–43.

Wibowo, S, Syafii, W, Pari, G & Herliyana, EN 202, Utilizaton of lignocellulosic waste as a source of liquid smoke : a Literature Review. *Journal of Environmental Health,* 15: 196-216.

Wu, Q, Zhang, S, Hou, B, Zheng, H, Deng, W, Liu, D. & Tang, W 2015, Study on the preparation of wood vinegar from biomass residues by carbonization process. *Bioresource Technology*, 179: 98-103.