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Preparation and Characterization of Biobriquettes from Coconut Shell, Nutmeg Shell, and Canary Shell Waste in North Maluku, Indonesia

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ABSTRACT: *North Maluku is an area with rich agricultural properties, including coconut, nutmeg, and canary. These waste materials have the potential to be used as alternative sources of energy. These shell wastes can be used to produce bio-briquettes, as a potential source of carbon for the production of activated carbon, and as biofuel. There is a lack of research on the characterization of biobriquettes made from shell waste. This study aims to characterize biobriquettes made from coconut shells, nutmeg shells, and canary shell waste in North Maluku, Indonesia. The study was conducted to evaluate the potential of these waste materials as alternative sources of energy. Biobriquettes were formulated using cassava flour as a binder. The shapes of the briquettes were produced in cube and cylinder sizes. The biobriquettes were characterized based on their physical and chemical properties, including calorific value, ash content, moisture content, volatile matter, and fixed carbon. The results showed that FTIR spectrophotometry analysis revealed higher hydroxyl groups in nutmeg shells, while coconut and canary shells had similar hydrocarbon levels. The carbonization and the powdering efficiency of coconut shells, nutmeg shells, and canary shell biobriquettes vary. Nutmeg shell biobriquettes yield the highest at 80%, while coconut shell biobriquettes yield 78%. Neem shell biobriquettes have a slightly lower yield of 90%. Cylindrical, cube-shaped, and cylindrical biobriquettes exhibit consistent weights and white ash production, indicating efficient combustion. In conclusion, the data from the proximate analysis and comparison with SNI standard No. 1/6235/2000 revealed that all biobriquettes fulfill or surpass the standard's requirements for moisture, ash, fixed carbon, and volatile matter.*

KEYWORDS: Biobriquette**,** Biomass, Canary, Coconut, Nutmeg, Maluku

INTRODUCTION

The level of consumption and energy patterns used by a country can indicate the social and economic conditions of the country. The International Energy Agency (IEA) estimates that there will be an increase in world energy demand by 34% from 2021 to 2035 [1]. Therefore, innovation and exploitation continue to be carried out to look for renewable energy sources that are cheap, environmentally friendly, and safe when related to their use as part of the food processing process for humans [2–4]. Exploitation and innovation to obtain renewable energy sources, including biofuels, have a history dating from the first generation to the fourth generation until now. The first generation started with biofuels, starting with the discovery of biodiesel and bioethanol, which were mainly made from oilseeds. The second generation is biofuel from biomass sourced from raw materials in the form of agroforestry residues with the main composition of lignin, hemicellulose, and cellulose. Next, the third generation is biofuel sourced from algae and microalgae, and the last is bioengineering by engineering the cellular metabolism of algae and cyanobacteria to increase fuel production [5].

One promising source of biofuels is derived from biomass residues, which are formed into briquettes through the briquette or densification process [6]. Biomass is a term used to refer to organic compounds originating from plants, animals, and microbes, as well as organic waste, which, in large quantities, can be used as a renewable energy source [7]. As a renewable energy source for many countries, including developed and developing countries [8, 9], much research has been carried out to test the quality of briquettes made using various kinds of raw materials from biomass. Other renewable energy sources include solar energy, wind energy, geothermal, and agricultural residues [10–12]. In contrast to non-renewable energy sources, for example, those originating from fossil fuels such as coal, oil, and natural gas, which will run out in the future, renewable energy sources have the advantage of being available at any time, renewable, and almost zero [1, 3, 13]. One of the current renewable energy sources that are promising as an energy source is which comes from local biomass, which has been packaged in the form of biobriquettes [13] and biopellets [14].

Many countries report the use of raw materials from local biomass around them, especially from agricultural countries and developing countries that have a lot of renewable energy resources. Agricultural countries will automatically produce agricultural waste, industrial residue from agriculture, and other industrial waste which can be useful as raw materials for biobriquettes. Research from Thailand uses madan wood to make charcoal briquettes [15]. Researchers from Uganda used rice husks [4]. Meanwhile, researchers from Ethiopia converted solid biomass waste into briquettes with the innovation of natural resin as a binder [16], using coffee husk [1, 10]. In Ghana, it combines food waste with agricultural residues [13], while in the Philippines they use carbonized rice husk, sawdust, and waste paper as binders (Romallosa, 2017. As an agricultural country that has a lot of biodiversity, of course, Indonesia also has many sources of biomass raw materials as a renewable energy producer.

Biodiversity in areas of Indonesia that have been researched has potential as raw materials for briquettes, including in the Aceh region, where solid waste from oil palm mills for briquette production was found [17]. South Kalimantan uses waste from the wood industry (sawmills from ironwood and galam [18], coconut shell and peanut shell [8], the canary shell from South Sulawesi [19, 20], cow dung waste [21], coffee shell and rice husk from West Java [22], and the use of nutmeg shell from Tidore [23].

Fig. 1: Northern Maluku Island location, illustrating the biomass producing area.

North Maluku Province (Figure 1), located in the eastern region of Indonesia, also has biodiversity, which has the potential to produce biomass for renewable energy. Almost the entire North Maluku region has coconut plants, which are usually processed into copra and leave coconut shell residue (*Cocos nucifera*). Likewise with the nutmeg plant (Myristica fragrans Houtt), whose processing results leave nutmeg shells, which are currently considered waste. Populations of canary trees (*Canarium indicum*) are found on Makian Island in the North Maluku region. Coconuts, nutmeg, and canary have been reported to contain oils or triglycerides, which are composed of fatty acids [24]. Types of biomass that contain lignocellulosic materials such as hemicellulose, cellulose, and lignin meet the requirements for making biobriquettes because they have a high energy value [23, 25, 26]. Research on the potential of coconut, nutmeg, and canary from North Maluku as materials for biobriquettes is still underreported. Hence, the development of techniques to convert biomass into secondary fuels possessing superior properties compared to the initial material is imperative [11]. At now, briquetting stands as one of the most viable and progressive technologies for the conversion of waste materials into solid biofuels intended for energy applications. Therefore, biofuel briquettes offer an environmentally friendly method for optimizing the exploitation of agricultural and other biomass byproducts [27].

Different types of biomasses have different properties and make-ups, which adds to the variety of feedstock used to make biobriquettes. The moisture content of the feedstock is the most critical parameter [28]. The appropriate moisture content is specified by the obligatory technical standard EN 18134-2, which is also regarded as having a significant impact on the quality of the final briquettes [29]. Additionally, the hardness and quality of briquettes can be assessed using a water test. A high-quality briquette, which has a specific density greater than that of water, should rapidly settle to the bottom [30]. Previous studies may have focused on a single biomass source [14, 23, 31], but the physicochemical properties of the biomass from North Maluku have not been reported yet. FTIR spectrophotometry is a versatile and powerful technique for analyzing the physicochemical properties of biomass, providing rapid and sensitive measurements with minimal sample preparation. Therefore, this research aimed to obtain data and prove that these three biomasses, which are still abundant, have the potential as raw materials for biobriquette production.

EXPERIMENTAL SECTION

Collection and pre-treatment of biomass

The production of coconut shells for copra in the Galela District, North Halmahera Regency, and North Maluku Province provided the material. In the Ternate City region, nutmeg seeds were processed to produce nutmeg skin. The residual canary processing on the Makian Island area of South Halmahera Regency, North Maluku Province, provided the canary shell. Figure 2 displays all the biomass that was gathered. Using a hammer mill machine, each sample was broken up into tiny pieces before beginning the carbonization phase.

A B C

Fig. 2: Biodiversity of biomass utilized as a source for bio-briquettes, including coconut shell (A), nutmeg shell (B), and canary shell (C).

Functional group characterization of biomass

In the analysis of the physicochemical properties of coconut shell, nutmeg shell, and canary shell, a method was employed wherein dried fine powder of each shell was subjected to infrared spectrum measurement using a Cary 630 FTIR spectrometer within the wavelength range of 500–4000 cm^{-1}. The acquired spectra were then analyzed using MicroLab Expert 1.0.0.7 software to identify and interpret various vibrational bands and peaks, allowing for the characterization of the molecular composition of each shell. Through careful spectral interpretation, specific features such as O-H vibrations, C-H stretches, and C=O stretches were scrutinized to assess the unique physicochemical properties of the individual shells. This comprehensive method facilitated a detailed comparison of the molecular compositions of coconut shells, nutmeg shells, and canary shells, providing valuable insights into their distinct characteristics.

Procedure of carbonization

A carbonization technique was used to transform dry shells from biomass into charcoal. Carbonization was done the old-fashioned way, in the form of a drum, with minimal equipment. A heat-resistant kiln or pit was used to enclose biomass materials during carbonization. The biomass was loaded into the kiln and covered with insulating materials to create a sealed environment. The biomass was ignited, releasing gases and liquids like smoke and tar. After carbonization, the kiln or pit cools, and the resulting charcoal is removed. The biochar was then crushed or ground into smaller particles for various applications. As indicated in Figure 3, a particular number of dry biomass samples were burned in a drum at a temperature ranging from 400-440 °C until they produced charcoal. The obtained charcoal was weighed to measure the yield of carbonization results.

A **B** **C**

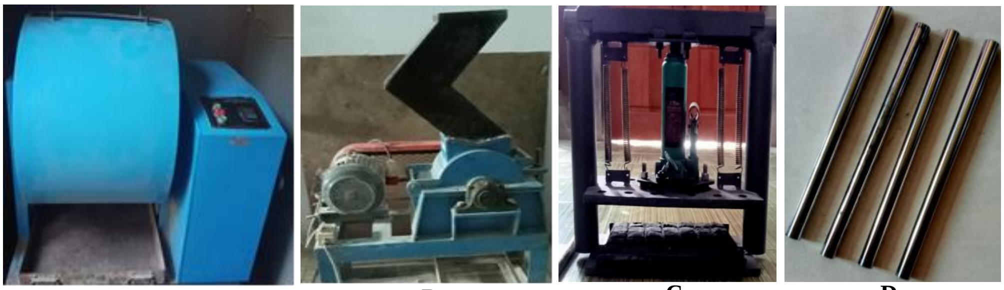
Fig. 3: The results of carbonization operations using coconut shells (A), nutmeg shells (B), and canary shells (C).

The yield of carbonization efficiency was estimated using a formula:

$$\text{Carbonization efficiency} = \frac{\text{Charcoal weight}}{\text{Dry biomass weight}} \times 100\% \qquad (1)$$

Preparation of powder charcoal

Following the carbonization process, the charcoal powder was transformed via some process stages (Figure 4) till sifting to create a homogeneous powder with a mesh size of 60. Each biomass yielded charcoal powder (Figure 5).



A B C D

Fig. 4: Equipment for processing charcoal into charcoal powder and briquetting: (A) hammer mill; (B) crushing machine; (C) hand briquette press; and (D) manual briquette mold.

The efficiency of the charcoal powder-making process was calculated using the formula:

$$\text{Powdering efficiency} = \frac{\text{Powder weight}}{\text{Charcoal weight}} \times 100\% \qquad (2)$$

Procedure of briquetting

A molding procedure called briquette or densification converts biomass powder into a solid lump of fuel [32]. Each biomass powder (1,000 g) was combined with a binder in an amount of 100 g, as illustrated in Figure 5. Cassava starch was utilized as the binding agent, and it has previously been made using a biomass powder to cassava starch ratio (10:1). Combine it with a specific amount of hot water to create a binder. For every 1,000 g of powder, 50 g of binder was utilized. Stirring was done until the powder was evenly and uniformly wet.

A B C

Fig. 5: Raw material biomass powder from coconut shells (A), nutmeg shells (B), and canary shells (C).

Two different types of molding equipment, namely cube molds and cylindrical molds, were used to shape the mixture of each raw ingredient. The molded briquettes were dried for 30 minutes in an oven set to 150-160 °C.

Characterization of charcoal briquettes

Determining the physical qualities and burning characteristics of the created briquettes is part of evaluating their quality. Included in the physical characteristics were the amount of moisture, ash, volatile matter, and fixed carbon [33]. The measurement findings were compared with SNI 2000 values. In addition, the physical characteristics of the briquettes, such as their shape, and their burning characteristics, were reported.

Physical properties

Moisture content

Moisture content (MC) was determined by crushing 1 g of briquette samples in a mortar and then depositing them in crucibles that were previously weighed empty. The samples were cooked for one hour at 150 °C in an oven. The sample-containing crucibles were promptly cooled at room temperature in a desiccator and weighed again. The calculation of relative humidity was:

$$\text{Moisture content} = \frac{\text{Initial sample weigh (g)} - \text{Sample weight after heating in the oven (g)}}{\text{Initial sample weight (g)}} \times 100\% \qquad (3)$$

Volatile matter

The volatile matter (VM) content was determined by weighing 1 g of the residual sample from the moisture content test and heating it in a furnace for 7 minutes at a range of 950-1000 °C. The samples were promptly chilled in a desiccator and weighed again at room temperature. Using the following formula, calculate volatile matter:

$$\text{Volatile matter} = \frac{\text{Sample weight of moisture content (g)} - \text{Sample weight after heating in the furnace (g)}}{\text{Sample weight of moisture content (g)}} \times 100\% \qquad (4)$$

Ash content

During the volatile matter evaluation, ash content (AC) is determined by obtaining samples from the treatment. 1 g was weighed and fired in a range of 750-800 °C furnace for 2 hours. The sample was weighed again after cooling in a desiccator at ambient temperature. A formula is used to calculate ash content.:

$$\text{Ash content} = \frac{\text{Sample weigh of volatile matter (g)} - \text{Sample weigh after heating in furnace (g)}}{\text{Sample weigh of volatile matter (g)}} \times 100\% \qquad (5)$$

Fixed carbon

Fixed carbon (FC) was determined by subtracting the values of moisture content (MC), volatile matter (VM), and ash content (AC) successively from the initial sample weight, using the formula:

$$\textbf{Fixed carbon} = \mathbf{100}\% - (\%\,\mathbf{MC} + \%\,\mathbf{VM} + \%\,\mathbf{AC}) \qquad \textbf{(6)}$$

Burning characteristic

The ignition time, the combustion rate, and the time it takes for water to boil are the criteria that were used to evaluate the burning characteristics.

Ignition time

This parameter was used to determine the time when the briquettes start to light to increase the temperature of the briquettes [1, 20, 34], which was calculated using the formula:

$$\textbf{Ignition time} = \textbf{The briquette ignited time} - \textbf{The burner lighted time} \quad (7)$$

Combustion rate

During the course of this assessment, changes in the briquette mass were tracked and noted as they occurred [22, 34]. The formula for calculating the rate of combustion is as follows:

$$\textbf{Combustion rate} = \frac{\textbf{Burning briquette mass (g)}}{\textbf{Burning time (minutes)}} \quad (8)$$

Water boiling time

This measurement was carried out by keeping track of the amount of time it took to bring one liter of water to a boil using the fuel that was being evaluated, with each briquette being given the same amount of weight, which was 500 grams.

Data analysis

The descriptive analysis method is used in data analysis. The same set of measurements was taken three times for each repetition.

Table 1: Nomenclature section of the paper

Parameter Notation	**Parameter Definition**
% MC	Moisture content
% VM	Volatile matter
% AC	Ash content
%T	Percent transmittance
O-H	Hydroxy or hydroxyl group
C-H, $C-H_2$	Alkane group
CO or C=O	Carbonyl group
CCB	Coconut shell cylindrical biobriquettes
NCB	Nutmeg shell cylindrical biobriquettes
KCB	Canary shell cylindrical biobriquettes
CV	Calorific value

RESULTS AND DISCUSSION

Physicochemical properties of biomass

The physicochemical properties of coconut shell, nutmeg shell, and canary shell were compared through Fourier Transform Infrared (FTIR) spectrophotometry, focusing on the vibrational bands in the wavelength range of 500–4000 cm^{-1} (Figure 6). In terms of hydroxyl groups, the coconut shell exhibited an O-H vibration with a %T value of 86.21, while the nutmeg shell had a slightly higher %T value of 89.62, indicating a relatively higher concentration of hydroxyl groups. Canary shells, on the other hand, displayed an O-H vibration with a %T value of 86.21, comparable to coconut shells.

In the alkyl region, representing C-H stretch vibrations, both the nutmeg shell and the canary shell showed similar %T values of 91.52, suggesting a comparable abundance of aliphatic hydrocarbons. Coconut shell displayed a slightly lower %T value in this region. Regarding carbonyl groups, the coconut shell, and nutmeg shell exhibited C=O stretches with %T values of 86.84 and 93.11, respectively, indicating a higher concentration of carbonyl groups in the nutmeg shell. Canary shell also displayed a significant %T value of 91.09 in the C=O region.

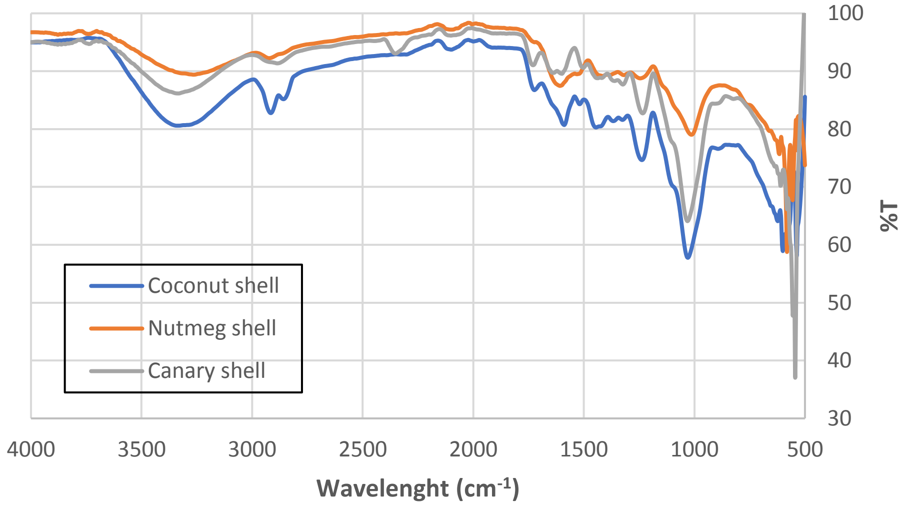


Fig. 6: FTIR spectra of coconut shell, nutmeg shell, and canary shell at the wavelength range of 500–4000 cm^{-1}.

In the methylene and methyl bending regions, both the coconut shell and nutmeg shell demonstrated similar characteristics, while the canary shell displayed distinctive vibrational bands. The C-H deformation associated with halogen-substituted compounds was prominent in both nutmeg shells and canary shells. The C-S=O sulfoxy stretch region showed variations, with the nutmeg shell displaying the highest %T value of 79.02, followed by the canary shell and coconut shell. Additionally, the C-Hal stretch associated with carbon-halogen bonds was observed in the canary shell with a %T value of 37.02.

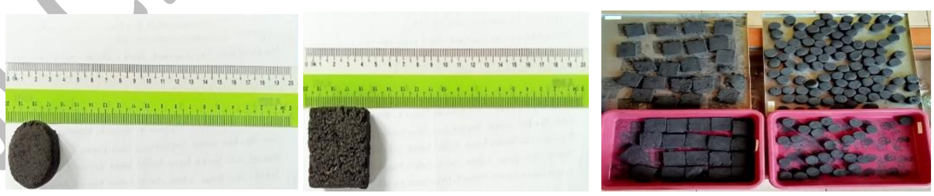
Pure linear hydrocarbons are generated from biomass, with hexane and pentane being identified as the principal constituents of cellulose [35]. There is evidence to suggest that augmenting the number of carbon atoms within a fuel molecule significantly impacts many physical characteristics. This is attributed to the heightened intermolecular forces that arise from the increased surface area of the molecule. It has been reported that carbon functional groups significantly alter the melting, flash, and boiling temperatures of substances while maintaining the carbon number constant [36]. As the carbon number increases, intermolecular interactions intensify, resulting in corresponding changes in density, boiling temperature, melting point, and flash point.

In summary, the comparison of physicochemical properties using FTIR spectra highlighted both similarities and differences among coconut shells, nutmeg shells, and canary shells. These distinctions in vibrational bands suggest variations in the molecular composition of these biomass materials, providing valuable insights for potential applications in fields such as bioenergy and materials science.

Physical characteristics of biobriquettes

Biodiversity in Indonesia also includes the availability of biomass to be used as raw material for renewable energy sources, for example, briquettes. Several sources state that the material requirement to be used as briquette fuel is the presence of lignocellulose content [16, 23, 37]. Lignocellulose biomass, a renewable energy source, contains neutral carbon, which can be converted into biofuels and chemicals [26]. The biomass used in this research was the waste shell from coconut (*Cocos nucifera*), nutmeg (*Myristica fragrans*), and canarys (*Canarium indicum*). Cellulose, hemicellulose, and lignin are the main components of plant cell walls, with cellulose being the primary structural component, hemicellulose contributing to the matrix, and lignin providing rigidity. Coconut shell contains cellulose, lignin, and hemicellulose [38]. Nutmeg shell contains lignocellulose, which consists of hemicellulose, cellulose, and lignin [23], while canary shells contain lignin, hemicellulose, cellulose, and halocellulose [20, 26]. The cellulose content in many lignocellulosic materials, such as coconut shells, can range from 40% to 50%, while hemicellulose content varies between 20% and 35%, and lignin content often falls within the range of 15% to 30% [39].

The biobriquettes used in this research project were printed in the shape of cubes and cylinders with corresponding dimensions of 4 by 4 by 3 centimeters and 3 by 3 by 2 centimeters (Figure 7). Both kinds of briquettes were manufactured in response to the fuel requirements of the respective towns. The cylinder shape is intended for the requirements of organizing local community traditional events, such as for tahlilan activities or for the requirement to care for newborn babies following the bakera custom. The cube shape is typically used at the household or small business level for cooking or grilling food products such as smoked fish and grilled fish.



A B C

Fig. 7: Printed results of oval-shaped briquettes (A), cube-shaped (B), and a collection of bio-briquette products (C).

Briquetting, also known as densification, is a process that involves compressing loose wastes from biomass production into a solid block that has a high density and can be utilized as a fuel source. This procedure's goal is to effect a change in the biomass so that the starting material acquires a low density and a low heating value while simultaneously experiencing a reduction in humidity [9, 10, 40].

Efficiency of carbonization, powdering, and briquetting

Collecting the biomass material, drying it, grinding it, charring it, milling it, and finally smoothing it out before printing are the first steps in the process of creating biomass briquettes. In the process of creating briquettes, the stage known as carbonization or carbonization is a key step. The yield data for the three different types of biobriquettes offer some really useful insights into the effectiveness of the carbonization process and the appropriateness of these briquettes for the manufacturing of charcoal (Table 2). After going through the carbonization process, the yield of the coconut shell biobriquettes was found to be 78%. This indicates that charcoal constitutes 78 percent of the total weight that was initially present. Even though this yield is rather high, it suggests that there is some material waste caused by the carbonization process. The possible loss was caused by things like the amount of moisture, contaminants, or even the characteristics of the coconut shell biomass itself. After carbonization, the yield of the nutmeg shell biobriquettes is shown to be 80 percent, which is a slightly greater percentage than the yield of the coconut shell biobriquettes. This hints that the biomass derived from nutmeg shells is ideally suited for carbonization techniques, which results in very little material being wasted. It's possible that the make-up of the nutmeg shell biomass, along with its features, contributed to the increased output. After carbonization, the canary shell biobriquettes have a lower yield than other types, coming in at 58 percent. This suggests that there was a considerable amount of material lost during the operation. It is important to keep in mind that canary shells may have special characteristics or present particular difficulties during the carbonization process, which results in a lower yield in comparison to the other two biomass sources.

Table 2: Yield of a variety of biobriquettes during the carbonization process.

	Variety of biomass	Initial weight (kg)	Final weight of carbonization (kg)			Average of final weight of carbonization (kg)	Yield (%)			Average of yield (%)
1	Coconut shell	50	40	35	42	39±3.6	80	70	84	78±7.2
2	Nutmeg shell	50	38	48	35	40±6.8	76	96	70	81±13.6
3	Canary shell	50	25	24	39	29±8.4	50	48	78	59±16.8

Carbonization is a charcoal process that will convert organic materials into charcoal at a certain temperature and with a limited amount of oxygen. The carbonization process will release combustible substances, such as CO, CH_2, H_2, and formaldehyde. Carbonization also aims to remove volatile materials [17] and increase the fixed carbon value so that fuel energy can increase [5]. Because of this, the volatile material content and the amount of bonded carbon rose throughout the carbonization process, which resulted in a rise in the briquettes' calorific value. In addition to the carbonization method, there are some other ways to change biomass into biocoal. These include processes that include temperature transformation as well as chemical means [37].

Table 3: Yield of a variety of biobriquettes during the powdering process.

	Variety of biomass	Initial weight (kg)	Final powder weight (kg)			Average of final powder weight (kg)	Yield (%)			Average of yield (%)
1	Coconut shell	10	9.8	9.4	9.5	9.5±0.2	98	94	95	96±2.1
2	Nutmeg shell	10	9.5	8.5	9.0	9.0±0.5	95	85	90	90±5.0
3	Canary shell	10	9.5	9.0	10	9.5±0,5	95	90	100	95±5.0

The data on yield for the three different types of biobriquettes offer important insights into the effectiveness of the powdering process and the make-up of these briquettes (Table 3). The high output of 96 percent was demonstrated by the biobriquettes made from coconut shells. This indicates that following the powdering process, 95% of the material's initial weight will remain in the form of a fine powder. Because of this high yield, it appears that coconut shell biobriquettes can be easily converted into powder form with little material being wasted in the process. The yield of the biobriquettes made from neem shells was 90 percent, which is only a little bit lower than the yield of the biobriquettes made from coconut shells. Although the yield was still very high, this finding suggests that there is some material wasted during the powdering process. This could be because of the composition of neem shells, which, in comparison to coconut shells, might be more difficult to pulverize or less amenable to doing so effectively. The yield of the biobriquettes made from canary shells was 95 percent, which was comparable to the yield of the biobriquettes made from coconut shells. It would appear from this that canary hulls can be ground into a powder with only a minor amount of the original substance being lost. Because of their high output, canary shell biobriquettes are a promising choice for use in processes that include the conversion of biomass.

Table 4: Physical characteristics of cylindrical-shaped biobriquettes.

No	Variety of biomass	Weight of bio-briquettes (g)	Average of weight (g) (*n*=3)	Average temperature of briquette coals (°C) (*n*=3)	**Ash colour (*n*=3)**
1	CCyB 1	11			
2	CCyB 2	11	11.0±0.0	822±30.1	White
3	CCyB 3	11			
1	NCyB 1	10			
2	NCyB 2	10	10.3±0.6	760±55.7	White
3	NCyB 3	11			
1	KCyB 1	12			
2	KCyB 2	12	11.7±0.6	820±36.1	White
3	KCyB 3	11			

Cylindrical biobriquettes made from coconut cylindrical-shaped biobriquettes (CCyB), nutmeg cylindrical-shaped biobriquettes (NCyB), and canary cylindrical-shaped biobriquettes (KCyB) each have their own unique set of physical features, but they differ from one another in some ways (Table 4). There were significant variations in the typical temperature of the coal, even though the average weight of the briquettes is generally comparable, indicating that they were simple to handle and transport. The greatest coal temperature was produced by KCyB biobriquettes, which may qualify them for use in applications that require a significant amount of heat output. In addition, the creation of white ash by all three sources indicates efficient combustion, which was a quality that should be regarded favorably. The physical properties of coconut cube-shaped biobriquettes (CCuB), nutmeg cube-shaped biobriquettes (NCuB), and canary cube-shaped biobriquettes (KCuB) biobriquettes that were cube-shaped exhibit similarities and variations between the three types (Table 5).

Table 5: Physical characteristics of cube-shaped biobriquettes.

No	Variety of biomass	Weight of bio-briquettes (g)	Average of weight (g) (*n*=3)	Temperature of briquette coals (°C) (*n*=3)	Average temperature of briquette coals (°C)	Ash colour (*n*=3)
1	CCuB 1	17	16.6±0.6	800	820±43.6	White
2	CCuB 2	16		790		
3	CCuB 3	17		870		
1	NCuB 1	16	16.3±0.6	720	760±45.8	White
2	NCuB 2	17		810		
3	NCuB 3	16		750		
1	KCuB 1	17	16.6±0.6	850	847±5.8	White
2	KCuB 2	17		840		
3	KCuB 3	16		850		

The fact that their average weights are comparable suggests that they were both manageable and transportable with relative ease. However, the average temperature of the flame produced by biobriquettes can vary, with KCuB biobriquettes having the greatest flame temperature. This could make them appropriate for applications that call for a high level of heat production. In addition, the fact that all three of these sources produce white ash is evidence that their combustion processes were highly efficient. The temperature profiles and energy exchanges of cylindrical biobriquettes have been studied, revealing significant variations in the typical temperature despite the briquettes' comparable average weight [41]. The shape and composition of the biobriquettes, as well as the carbonization process, have been identified as key factors influencing the temperature and combustion characteristics of the briquettes. Additionally, the calorific value, bulk density, and mechanical performance of the biobriquettes have been investigated, providing insights into their physical properties and potential for use as alternative fuels [42].

Table 6: Burner characteristics for cube-shaped biobriquettes.

No	Variety of biomass	Ignition time (min)			Average of ignition time (min)	Combustion rate (g/min)			Average Combustion rate (g/min)	Water boiling time (min)			Average of water boiling time (min)	Weight of remaining briquettes from the water boiling time evaluation (g)			The average weight of remaining briquettes from the water boiling time evaluation (g)
1	CCuB	5	2.5	2.5	3.3±1,4	1	1.5	0.5	1±0.5	12	10	8	10±2.0	490	290	200	326±148.4
2	NCuB	3.5	5	6	4.8 ±1.3	4	5	2	4±1.5	15	12	15	14±1.7	190	360	280	277±85.0
3	KCuB	5.5	3	4.5	4.3±1.3	2	0.5	1	1±0.8	8	15	8	10±4.0	340	450	280	357±86.2

The results of measurements taken to evaluate the combustion characteristics of biobriquettes in the form of cubes are presented in Table 6. Because these biobriquettes are intended to be used for cooking, it was essential to determine how well they could be burned before purchasing them. The three different sources each have their own set of advantages and disadvantages when it comes to the burner properties of the cube-shaped biobriquettes. Because it has the quickest ignition time and a moderate combustion rate, CCuB is ideal for applications that call for quick ignition but have moderate combustion rates. Because it has the fastest combustion rate, NCuB is an excellent choice for applications that call for the rapid release of heat. Because KCuB is so effective at reducing the amount of time it takes for water to boil and achieving complete combustion, it is an excellent option for continuously heating or preparing food. Ignition time is susceptible to being affected by factors such as briquettes' low particle size, low porosity, and high bonding force, all of which were not measured in this study [1, 34].

The aim of measuring the combustion rate is to determine the effectiveness of the briquettes [22]. We were able to calculate the rate of combustion by dividing the difference in briquette mass by the amount of time that the briquette was allowed to burn. According to the findings of the earlier study, the calorific value (CR) value can be affected by a wide variety of elements, some of which include humidity, particle size, density, and the shatter index of each briquette, which is also related to the raw materials that are utilized. The findings of this research indicate that nutmeg briquettes have the highest CR, which translates to the fact that 4 grams of nutmeg briquettes are required for a flame to last for one minute when burned. The purpose of analyzing the amount of time required to bring one liter of water to a boil using the weight of each test briquette, which is 500 grams, is to collect data on the people who will be utilizing the briquettes as a cooking element in their homes. The boiling time for water with any of the three briquettes tested was between 10 and 14 minutes. For the water boiling test, an average of 222 g of briquettes, 173 g of briquettes, and 142 g of briquettes were utilized for NCuB, CCuB, and KCuB, respectively. Figure 8 is an activity log that records the activity of testing the burning properties of briquettes.

A B C D

Fig. 8: Evaluation of burning characteristics: combustion rate and ignition time (A), boiling water time (B), briquettes for tahlinan activities in local customs of the North Maluku community (C), and smoking fish using bio-briquettes (D).

In this investigation, all briquettes were manufactured with the same amount and kind of binder, namely a 1 percent cassava starch solution. Cassava has been widely reported as a binder in briquettes [5, 13]. The binder is a crucial component in the briquette process [38]. The binder in the biobriquette formulation is intended to improve bond strength and combustion quality [16]. Aside from cassava starch, additional binders used in the production of briquettes include gum Arabic [43], CMC [23], natural resin [16], and paper pulp [1]. The advantage of using cassava starch is that it is widely available, including in Indonesia, therefore creating biobriquettes can be directly applied to the general people, specifically at the household and small company levels. Cassava starch or tapioca flour also has the benefit of forming strong bonds at high temperatures due to the creation of a transparent amylopectin paste [22].

Quality parameters of biobriquettes

The parameters used to check the quality of a briquette have been thoroughly reviewed [5, 37]. Moisture content, ash content, fixed carbon, and volatile matter are among these criteria (Table 7). Based on the results of the proximate analysis and a comparison with the SNI standard No. 1/6235/2000, it is clear that all three biobriquette sources satisfy or surpass the standard's requirements for moisture content, ash content, fixed carbon, and volatile matter. This indicates that these biobriquettes are of good quality and have the potential to be employed as a clean and efficient alternative fuel source.

Table 7: Proximate evaluation of biobriquettes (in percentage) according to SNI standard No.1/6235/2000.

No	Parameter	SNI standard	Coconut biobriquettes			Average of coconut biobriquettes	Nutmeg biobriquettes			Average of nutmeg biobriquettes	Canary biobriquettes			Average of canary biobriquettes
1	Moisture content	≤ 8	6.8	7.9	5.1	6.6±1.4	6.5	7.3	6.3	6.7±0.5	6.8	4.9	4.2	5.3±1.3
2	Ash content	≤ 8	5.9	3.8	4.8	4.8±1.1	4.3	6.0	4.0	4.8±1.1	4.7	5.9	5.6	5.4±0.6
3	Fixed carbon	≥ 77	79	90	86	85.0 ±5.6	90	86	80	85,3 ±5.0	85	79	89	84.3 ±5.0
4	Volatile matter	≤ 15	3.3	3.0	4.0	3.4±0.5	2.8	3.0	2.1	2.6±0.5	5.1	6.0	4.3	5.1±0.9

In evaluating biobriquettes, the amount of moisture they contain is a crucial component to take into account. The amount of moisture that is contained in biobriquettes can affect the qualities of the product, including its density and its long-term performance [44]. The equilibrium moisture content (EMC) of a substance is a measurement that determines how much water is present in the material when it is exposed to a given relative humidity. There has been a comparison made between the EMC of biomass briquettes and that of other materials, such as cotton stalks [45]. The appropriate amount of moisture for the manufacturing of briquettes can change based on the type of biomass that is being used. For the production of briquettes employing fast-growing species, the moisture content can be employed up to 15 percent of the time, for instance [46]. Moisture content has a substantial influence on briquette density, perhaps more so than fiber length [47]. Estimating moisture content is critical for determining the calorific value of briquettes made from rice husk coupled with cassava starch [48].

Because a high ash content might result in a fall in heating value, which in turn results in a decline in the quality of the briquettes, this is a criterion that needs to be taken into consideration. Potassium, calcium, magnesium, and silicon dioxide make up the bulk of the ash's composition. The residue of combustion that does not contain any carbon components is referred to as ash content [49].

Volatile matter is another important factor in the evaluation of biobriquettes. Volatile matter consists of elements such as carbon, hydrogen, and oxygen that are present in the biomass, but do not contain water [50]. The percentage of volatile matter in biobriquettes can impact their ignition and combustion characteristics. A range of 10% to 25% is considered good for quality briquettes [48]. The percentage of volatile matter can vary depending on the type of biomass used. For example, the volatile matter of biobriquette from coconut husks has the lowest value of 22.11%, while rice husks have the highest value of 58.20% [41]. High volatile matter results in briquettes that might not be easy to ignite, but once ignited, they will burn smoothly [51]. The percentage of volatile matter can be analyzed along with other factors such as moisture content, ash content, fixed carbon, and calorific value to evaluate the physical and combustion properties of briquettes [7].

Ignition time refers to the time duration of briquette ignition, which can be measured in various ways, such as the time duration of burning briquette to boil one liter of water [50]. The optimal ignition time can vary depending on the type of biomass used and the mixture of binders. The ignition time may decrease with an increase in the mixture of binders [52]. The ignition time of biobriquettes can be affected by factors such as the shape, density, and binder used. For example, the average ignition time of fecal matter-sawdust briquettes ranged from 2.7 to 3.7 minutes, irrespective of shape and binders [53]. The ignition time can be analyzed along with other factors such as burning time, maximum temperature, and adhesion test to evaluate the quality of biobriquettes [54]. The analysis of ignition time and the duration of biobriquette combustion can be performed using variations of carbonization duration [55].

Water boiling time can be used to evaluate the combustion efficiency of biobriquettes. The time taken to boil one liter of water can be measured to determine the combustion efficiency of the briquettes [56]. The optimal water boiling time can vary depending on the type of biomass used and the mixture of binders. For example, briquettes made from sesame hull with 100% binder had a water boiling time of 4.02 minutes [57]. The water boiling time of biobriquettes can be affected by factors such as the shape, density, and binder used. For example, briquettes made from mixed biomass of rice husk and corn cob had a water boiling time of 15 minutes [58]. The analysis of water boiling time can be performed along with other factors such as ignition time, burning time, maximum temperature, and adhesion test to evaluate the quality of biobriquettes [59].

Fixed carbon is the carbon content that remains after the volatile matter has been driven off during combustion [60]. The percentage of fixed carbon in biobriquettes can impact their combustion efficiency and heating value. Higher fixed carbon content can lead to higher heating values and better combustion efficiency. The optimal percentage of fixed carbon can vary depending on the type of biomass used and the mixture of binders. For example, briquettes produced from sesame hull with 100% binder had a higher fixed carbon content of 13.78% [57]. The analysis of fixed carbon content can be performed along with other factors such as moisture content, ash content, volatile matter, and calorific value to evaluate the quality of biobriquettes [61]. The fixed carbon content of biobriquettes can be compared to that of other materials, such as coal, to evaluate their quality and potential as a fuel source [60].

The advantage of biomass innovated into biobriquettes compared to charcoal in its use is that when burned it does not produce smoke, gas, and other particles that can harm human health [4]. The use of briquettes is very widespread both in developing and developed countries [5]. This research was deliberately conducted using fairly simple equipment so that later it could also be applied by local communities considering that the raw materials used were also found to local agricultural waste from local communities in North Maluku.

The briquettes offer several advantages over coal. High burning efficiency: Briquettes produce high BTUs (British Thermal Units) per pound, making them more efficient than coal. Briquettes produce almost no smoke when burned, making them a cleaner fuel source than coal [62]. Briquettes are denser and more compact than loose biomass, offering a more concentrated form of energy than firewood or charcoal [63]. Easily stored and transported: Briquettes are easy to store and transport due to their compactness and uniform shape [64]. Briquettes can be more economical than coal, and they are a renewable source of energy [65].

While briquettes offer several disadvantages over coal. Lower-quality briquettes may contain chemical fillers that can affect the inside of kamados [66]. Briquettes can take longer to light compared to coal [67]. Briquettes can produce a chemical smell when burned [68]. Briquettes can generate more ash compared to lump charcoal [69]]. Briquettes contain additives, which can impact their burning efficiency and heating value [70].

Good qualities of briquettes include smooth texture, not easily broken, being safe for public relations and the environment as well as having the properties of a good ignition such as being flammable, burning time is not enough, do not cause soot, a little smoke, and quickly disappear and the caloric value is high enough [71]. Utilizing nutmeg and canarys to convert them into briquettes also helps protect the environment because up to now nutmeg shells and canary shells are waste, especially since canarys which have thick shells will be slowly degraded by nature [72].

It is necessary to calculate the efficiency of briquettes from an economic perspective so that the economic comparison of briquettes with other fuels is known. Research on binder variations and formulations of combinations of raw materials is still needed to obtain briquette formulas that have good performance as fuel, especially for household cooking.

CONCLUSION

An investigation has been undertaken to analyze biobriquettes produced from waste canary shells, coconut shells, and nutmeg shells in the Indonesian province of North Maluku. The distinctive molecular compositions uncovered by FTIR research indicate that they may serve as a renewable energy source. Among the evaluated biomass varieties, coconut shells exhibited a notable yield of 78% in the carbonization process, complemented by a high yield of 96% in the powdering process. The cylindrical-shaped biobriquettes derived from coconut shells reached a temperature of 822°C, while cube-shaped biobriquettes achieved a temperature of 820°C. These findings suggest that coconut shell is a promising biomass source, offering a balanced combination of high yields and favorable combustion temperatures. Nutmeg shells, despite a slightly lower yield in the carbonization process (81%), demonstrated an efficient powdering process with a yield of 90%. The temperature of both cylindrical and cube-shaped biobriquettes was consistent at 760°C. This suggests that nutmeg shells could be a viable alternative for biobriquette production, offering stable yields and combustion temperatures. Canary shell, while exhibiting a lower yield in the carbonization process (59%), showcased excellent results in the powdering process with a yield of 95%. The temperature of cylindrical-shaped biobriquettes was 820°C, and cube-shaped biobriquettes reached a slightly higher temperature of 847°C. Canary shell's characteristics make it a potential candidate for biofuel production, especially considering its high powdering yield and elevated combustion temperatures. In summary, the choice of the best biobriquette from the variety of biomass depends on specific priorities, whether emphasizing high yields, efficient powdering, or optimal combustion temperatures. Additional research is required to evaluate the calorific value, durability, and combustion efficiency.

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REFERENCES

[1] Kebede T., Berhe D.T., Zergaw Y. 'Combustion characteristics of briquette fuel produced from biomass residues and binding materials', *J. Energy*, **2022** (2022).

[2] Ibrahim M., Bello S., Ibrahim A. 'Biomass briquettes as an alternative source of cooking fuel towards green recovery post-COVID-19', *Saudi J Engin Technol*, **5**: 285–290 (2020).

[3] Aswadi K., Jamal A., Syahnur S., Nasir M. 'Renewable and Non-renewable Energy Consumption in Indonesia: Does it Matter for Economic Growth?', *Int. J. Energy Econ. Policy*, **13**: 107 (2023).

[4] Yiga V.A., Nuwamanya A., Birungi A., Lubwama M., et al. 'Development of carbonized rice husks briquettes: Synergy between emissions, combustion, kinetics and thermodynamic characteristics', *Energy Rep.*, **9**: 5977–5991 (2023).

[5] Marreiro H.M., Peruchi R.S., Lopes R.M., Andersen S.L., et al. 'Empirical studies on biomass briquette production: A literature review', *Energies*, **14**: 8320 (2021).

[6] Vaish S., Sharma N.K., Kaur G. 'A review on various types of densification/briquetting technologies of biomass residues', *in: IOP Publishing*, 012019 (2022).

[7] Pranowo D., Savira T.D., Perdani C.G., Setyawan H.Y. 'Characteristics of Briquette as an Alternative Fuel Made of Mixed-Biomass Waste (Dairy Sludge and Coconut Shell)', *in: Atlantis Press*, 148–154 (2021).

[8] Dalimunthe Y.K., Kasmungin S., Sugiarto E., Sugiarti L., et al. 'Making briquettes from waste of coconut shell and peanut shell Indonesia', **J. Urban Environ. Technol.,** 196–209 (2021).

[9] Obi O.F., Pecenka R., Clifford M.J. 'A review of biomass briquette binders and quality parameters', *Energies*, **15**: 2426 (2022).

[10] Asresu A.T. 'Biomass briquetting: opportunities for the transformation of traditional biomass energy in Ethiopia', *J Energy Technol Policy*, **7**, 46–54 (2017).

[11] Kaur A., Roy M., Kundu K. 'Densification of biomass by briquetting: A review', *Int. J. Recent Sci. Res.*, **8**: 20561–20568 (2017).

[12] Handayani K., Krozer Y., Filatova T. 'From fossil fuels to renewables: An analysis of long-term scenarios

considering technological learning', *Energy Policy*, **127**: 134–146 (2019).

[13] Nikiema J., Asamoah B., Egblewogbe M.N., Akomea-Agyin J., et al. 'Impact of material composition and food waste decomposition on characteristics of fuel briquettes', *Resour. Conserv. Recycl. Adv.*, **15**: 200095 (2022).

[14] Yerizam M. Zaman M. Jauhari T. Yuli N. et al. 'Production of Bio-Pellet Briquettes From Coconut Shell Waste as Alternative Energy for Household Scale', *in: Atlantis Press*, 57–61 (2021).

[15] Kongprasert N., Wangphanich P., Jutilarptavorn A. 'Charcoal briquettes from Madan wood waste as an alternative energy in Thailand', *Procedia Manuf.*, **30**: 128–135 (2019).

[16] Bekele Bayu A., Mustefa Beyan S., Abeto Amibo T., Tadesse Mekonnen D. 'Production of fuel briquette from solid waste biomass using natural resin as a binder', *Environ. Health Eng. Manag. J.*, **9**: 321–328 (2022).

[17] Nabila R., Hidayat W., Haryanto A., Hasanudin U., et al. 'Oil palm biomass in Indonesia: Thermochemical upgrading and its utilization', *Renew. Sustain. Energy Rev.*, **176**: 113193 (2023).

[18] Pratama B.H., Syarief A., Saputra M.R.P., Azis A.P. 'Effect of Compaction Pressure and Sawdust Size on Briquette Made from Ulin Wood (Eusideroxylon Zwageri) and Gelam Wood (Melaleuca Cajuputi) to Combustion Characteristics', *Int. J. Mech. Eng. Technol. Appl.*, **3**: 100–106 (2022).

[19] Widodo S., Astriani A., Asmiani N. 'Utilising of canary shell as the material of bio-briquette', *Int. J. Eng. Sci. Appl.*, **6**: 31–38 (2019).

[20] Yuliansyah A.T., Hidayat M., Annas A., Putra P., et al. 'Preparation and characterization of bio-coal briquettes from pyrolyzed biomass-coal blends', *J Eng Sci Technol.*, **14**: 3569–3581 (2019).

[21] Anatasya A., Umiati N.A.K., Subagio A. 'The effect of binding types on the biomass briquette calorific value from cow manure as a solid energy source', *in: EDP Sciences*, 13004 (2019).

[22] Aliah H., Winarti I., Iman R.N., Setiawan A., et al. 'Influence of sieve size on calorific value and proximate properties of bio-briquette composites', *Influ. Sieve Size Calorific Value Prox. Prop. Bio-Briquette Compos.*, **24**: 25–34 (2023).

[23] Idris R., Yuliansyah A.T., Purwono S. 'Development of biobriquette from nutmeg seed shells', *in: EDP Sciences*, 01016 (2018).

[24] Rahman H., Sitompul J.P., Tjokrodiningrat S. 'The composition of fatty acids in several vegetable oils from Indonesia', *Biodiversitas J. Biol. Divers.*, **23**: (2022).

[25] Nurhayati A.Y., Naufal A.Z.N., Hariadi Y.C. 'Energy Yield of the Carbonized Plant Leaf, Petiole and Branch Biomass Briquettes for Sustainable Production of Future Fuels', *Comput. Exp. Res. Mater. Renew. Energy*, **5**: 68–77 (2022).

[26] Garba K., Mohammed I.Y., Isa Y.M., Abubakar L.G., et al. 'Pyrolysis of Canarium schweinfurthii hard-shell: Thermochemical characterisation and pyrolytic kinetics studies', *Heliyon*, **9**: (2023).

[27] Li Y., Liu H. 'High-pressure densification of wood residues to form an upgraded fuel', *Biomass Bioenergy*, **19**: 177–186 (2000).

[28] Mitchual S.J., Frimpong-Mensah K., Darkwa N.A. 'Effect of species, particle size and compacting pressure on relaxed density and compressive strength of fuel briquettes', *Int. J. Energy Environ. Eng.*, **4**: 1–6 (2013).

[29] Saptoadi H. 'The best biobriquette dimension and its particle size', *Asian J Energy Env.* **9**: 161–175 (2008).

[30] Križan, P., 'Research of factors influencing the quality of wood briquettes', *Acta Montan. Slovaca Roč.*,

12: 223–230 (2007).

[31] Font R., Villar E., Garrido M.A., Moreno A.I., et al. 'Study of the Briquetting Process of Walnut Shells for Pyrolysis and Combustion', *Appl. Sci.*, **13**: 6285 (2023).

[32] Papuangan N., Jabid A. 'Pre-design of bio-briquette production using kenari shell', *in: IOP Publishing*, 012051 (2019).

[33] Lisowski A., Klonowski J., Sypuła M. 'Comminution properties of biomass in forage harvester and beater mill and its particle size characterization', *Agron. Res.*, **8**: 459–464 (2010).

[34] Onukak I.E., Mohammed-Dabo I.A., Ameh A.O., Okoduwa S.I., et al. 'Production and characterization of biomass briquettes from tannery solid waste', *Recycling*, **2**: 17 (2017).

[35] de Beeck B.O., Dusselier M., Geboers J., Holsbeek J., et al. 'Direct catalytic conversion of cellulose to liquid straight-chain alkanes', *Energy Environ. Sci.*, **8**: 230–240 (2015).

[36] Syamsiro M., Syamsiro M. 'Effect of catalytic reforming on pyrolytic oil production from waste plastics', *Doctoral Thesis* (2015).

[37] Waheed M., Akogun O., Enweremadu C. 'An overview of torrefied bioresource briquettes: quality-influencing parameters, enhancement through torrefaction and applications', *Bioresour. Bioprocess.*, **9**: 1–18 (2022).

[38] Mazumder S., Zhang N. 'Cellulose–Hemicellulose–Lignin Interaction in the Secondary Cell Wall of Coconut Endocarp', *Biomimetics*, **8**:188 (2023).

[39] Himmel M.E., Ding S.-Y., Johnson D.K., Adney W.S., et al. 'Biomass recalcitrance: engineering plants and enzymes for biofuels production', *Science*, **315**: 804–807 (2007).

[40] Romallosa A.R.D. 'Quality analyses of biomass briquettes produced using a jack-driven briquetting machine', *Int. J. Appl. Sci. Technol.*, **7**: 8–16 (2017).

[41] Suryaningsih S., Nurhilal O., Yuliah Y., Mulyana C. 'Combustion quality analysis of briquettes from variety of agricultural waste as source of alternative fuels', *in: IOP Publishing*, 012012 (2017).

[42] Deng W., Hu M., Xu S., Hu M., et al. 'Pyrolysis of sludge briquettes for the preparation of cylindrical-shaped biochar and comparison between CO2 and steam activation', *Fuel*, **338**: 127317 (2023).

[43] Sabo M.N., Aji M.M., Yaumi A., Mustafa B.G. 'Preparation and Characterization of Biomass Briquettes Produced from Coconut Shell and Corncobs', *Arid Zone J. Basic Appl. Res.*, **1**: 47–54 (2022).

[44] Saeed A.A.H., Yub Harun N., Bilad M.R., Afzal M.T., et al. 'Moisture content impact on properties of briquette produced from rice husk waste', *Sustainability*, **13**: 3069 (2021).

[45] Singh R. 'Equilibrium moisture content of biomass briquettes', *Biomass Bioenergy*, **26**: 251–253 (2004).

[46] Hansted A.L.S., Nakashima G.T., Martins M.P., Yamamoto H., et al. 'Comparative analyses of fast-growing species in different moisture content for high quality solid fuel production', *Fuel*, **184**: 180–184 (2016).

[47] Cabrales H., Arzola N., Araque O. 'The effects of moisture content, fiber length and compaction time on African oil palm empty fruit bunches briquette quality parameters', *Heliyon*, **6**: (2020).

[48] Inegbedion F., Ikpoza E. 'Estimation of the moisture content, volatile matter, ash content, fixed carbon and calorific values of rice husk briquettes', *in Proceedings of the International Conference on Industrial Engineering and Operations Management Nsukka*, 5–7 (2022).

[49] Khoo C.G., Lam M.K., Mohamed A.R., Lee K.T. 'Hydrochar production from high-ash low-lipid

microalgal biomass via hydrothermal carbonization: Effects of operational parameters and products characterization', *Environ. Res.*, **188**: 109828 (2020).

[50] Ajimotokan H., Ehindero A., Ajao K., Adeleke A., et al. 'Combustion characteristics of fuel briquettes made from charcoal particles and sawdust agglomerates', *Sci. Afr.*, **6**: e00202 (2019).

[51] Falemara B.C., Joshua V.I., Aina O.O., Nuhu R.D. 'Performance evaluation of the physical and combustion properties of briquettes produced from agro-wastes and wood residues', *Recycling*, **3**: 37 (2018).

[52] Lestari L., Variani V.I., Sudiana I.N., Sari D.P., et al. 'Characterization of briquette from the corncob charcoal and sago stem alloys', *in: IOP Publishing*, 012012 (2017).

[53] Kabok P.A., Nyaanga D., Mbugua J., Eppinga R. 'Effect of shapes, binders and densities of faecal matter-sawdust briquettes on ignition and burning times', *J. Pet. Environ. Biotechnol.*, **9**: 370–375 (2018).

[54] Handra N., Abuzar A., Perdana M., Junaidi J., et al. 'The effect of percentage binder on fiber bio-briquettes EFB on ignition quality', *in: AIP Publishing*, (2023).

[55] Handayani H., Ningsih Y., Meriansyah M. 'Effects of carbonization duration on the characteristics of bio-coal briquettes (coal and cane waste)', *in: IOP Publishing*, 012027 (2019).

[56] Senchi D., Kofa I. 'Comparative studies of water boiling test and ignition time of carbonized rice husk using starch and gum arabic as adhesives', *IRE J.*, **4**: 27–32 (2020).

[57] Idowu A., Ayodeji I., Musa A. 'Combustion quality evaluation of briquettes produced from sesame hull as source of sustainable energy', *Asian J. Energy Transform. Conserv.*, **4**: 30–39 (2020).

[58] Suryaningsih S., Nurhilal O., Widyarini R., Suhendi N. 'The analysis of ignition and combustion properties of the burning briquettes made from mixed biomass of rice husk and corn cob', *in: IOP Publishing*, 012006 (2019).

[59] Onuegbu T., Ekpunobi U., Ogbu I., Ekeoma M., et al. 'Comparative studies of ignition time and water boiling test of coal and biomass briquettes blend', *IJRRAS*, **7(2)**: 2011.

[60] Tamilvanan A. 'Preparation of biomass briquettes using various agro-residues and waste papers', *IndianJournal.com*, **4(2)**: 47-55 (2013).

[61] Dragusanu V., Lunguleasa A., Spirchez C. 'Evaluation of the Physical, Mechanical, and Calorific Properties of Briquettes with or without a Hollow Made of Wheat (Triticum aestivum L.) Straw Waste', *Appl. Sci.*, **12**: 11936 (2022).

[62] Tesfaye A., Workie F., Kumar V.S. 'Production and characterization of coffee husk fuel briquettes as an alternative energy source', *Adv. Mater. Sci. Eng.*, **2022**: 1–13 (2022).

[63] Oladeji J. 'Theoretical aspects of biomass briquetting: a review study', *J. Energy Technol. Policy*, **5**: 72–81 (2015).

[64] Okot D.K., Bilsborrow P.E., Phan A.N. 'Effects of operating parameters on maize COB briquette quality', *Biomass Bioenergy*, **112**: 61–72 (2018).

[65] Sharma M.K., Priyank G., Sharma N. 'Biomass briquette production: a propagation of non-convention technology and future of pollution free thermal energy sources', *Am. J. Eng. Res. AJER*, **4**: 44–50 (2015).

[66] Růžičková J., Raclavská H., Juchelková D., Šafář M., et al. 'The use of polymer compounds in the deposits from the combustion of briquettes in domestic heating as an identifier of fuel quality', *Environ. Sci. Pollut. Res.*, **30**: 8582–8600 (2023).

[67] Sun J., Zhi G., Hitzenberger R., Che Y., et al. 'Emission factors and light absorption properties of brown

carbon from household coal combustion in China', *Atmospheric Chem. Phys.*, **17**: 4769–4780 (2017).
[68] Rahmawati S., Sakung J., Fudholi A., Sushmita L. 'The utilization of corncob for the manufacture of charcoal briquette as an alternative fuel', *in: IOP Publishing*, 012022 (2020).
[69] Jelonek Z., Drobniak A., Mastalerz M., Jelonek I. 'Environmental implications of the quality of charcoal briquettes and lump charcoal used for grilling', *Sci. Total Environ.*, **747**: 141267 (2020).
[70] Song B., Cooke-Willis M., Theobald B., Hall, P. 'Producing a high heating value and weather resistant solid fuel via briquetting of blended wood residues and thermoplastics', *Fuel*, **283**: 119263 (2021).
[71] Antwi-Boasiako C., Acheampong B. 'Strength properties and calorific values of sawdust-briquettes as wood-residue energy generation source from tropical hardwoods of different densities', *Biomass Bioenergy*, **85**: 144–152 (2016).
[72] Leszczyńska M., Malewska E., Ryszkowska J., Kurańska M., et al. 'Vegetable fillers and rapeseed oil-based polyol as natural raw materials for the production of rigid polyurethane foams', *Materials*, **14**: 1772 (2021).