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Physicochemical and FTIR Characterization of Cocoa Pod Husk Charcoal Briquettes Bonded with Dragon Fruit Peel Powder Binder

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ABSTRACT

This study aims to investigate the physicochemical and Fourier Transform Infrared (FTIR) characteristics of cocoa pod husk charcoal briquettes bonded with dragon fruit peel powder as a natural binder. Briquettes were prepared using three binder concentrations (15%, 20%, and 25% w/w based on 100 g of charcoal), followed by characterization of density, compressive strength, calorific value, moisture content, ash content, volatile matter, fixed carbon, and functional groups using FTIR spectroscopy. Among the tested formulations, briquettes containing 15% dragon fruit peel powder binder exhibited the highest calorific value (5134.89 cal/g), a density of 0.7789 g/cm³, moisture content of 4.5851%, volatile matter of 12.30%, fixed carbon of 74.78%, compressive strength of 0.7137 kg/cm², and ash content of 8.33%. FTIR analysis confirmed the presence of hydroxyl, carbonyl, aromatic, and polysaccharide functional groups associated with lignocellulosic biomass and pectin-containing binder. The findings demonstrate the feasibility of utilizing cocoa pod husk and dragon fruit peel wastes to produce natural-binder charcoal briquettes and provide a basis for further optimization of briquette quality.

1. INTRODUCTION

Energy plays a very important role in everyday human life. Energy sources are categorized into renewable resources and nonrenewable resources. One type of nonrenewable resource that has increased is fossil energy (coal, oil, and gas), while renewable energy has not been widely used. This condition results in the availability of fossil energy, especially petroleum, becoming increasingly scarce, causing Indonesia to experience very serious energy problems [1].

Data from the Ministry of Energy and Mineral Resources shows that Indonesia's oil reserves are only available for 9.5 years and natural gas for 19.9 years, assuming there are no new discoveries of oil and gas reserves. Apart from that, looking at the consumption aspect, it shows that Indonesia's energy consumption has increased from 2020 to 2022, which is still dominated by the use of fossil energy [2].

Continuous use of petroleum not only makes the quantity increasingly depleted, but also causes various negative impacts in the form of environmental pollution. Environmental pollution can occur because the energy and raw materials used in petroleum processing can produce carbon monoxide, carbon dioxide, sulfur oxides, and water vapor gases which can have an impact on air pollution [3].

Some alternative energies that can be developed as a substitute for petroleum are natural gas and biomass. Biomass is a substitute for alternative energy sources that are based on raw materials that are easy to obtain, renewable, and whose products are easy to use by all humans, for example, solid organic waste. One of the biomass wastes that is abundant and underutilized is waste from plantation and agricultural activities, which can be utilized by turning it into a fuel called biobriquettes [4, 5].

Cocoa is one of the main plantation commodities whose role is quite important for the national economy. Central Sulawesi is the largest cocoa-producing region in Indonesia, with a total production of 125.9 thousand tons in 2023 and 125.2 thousand tons in 2024 [6]. High cocoa production also produces abundant cocoa pod waste, which has the potential to be used as a raw material for value-added products. Cocoa husk waste is a biomass with a composition that can be used as energy for briquette production because it contains approximately 23–54% cellulose [7, 8].

The parts of the cocoa plant that are most often used are the seeds and fruit, while cocoa pod shells are the largest waste from the cocoa production process, weighing 706.500 tons in 2021, down around 0.97% compared to the previous year [9]. This cocoa shell waste is only used as fertilizer and animal feed but still has weaknesses due to its high lignin content [10]. One way to deal with this waste is to process it into charcoal briquettes, which can be used as an alternative fuel.

Briquettes are solid fuels that can be used as an alternative energy source in a certain form. The main ingredient that must be contained in the raw material for charcoal briquettes is lignocellulose. Lignocellulose consists of cellulose, hemicellulose, and lignin. The lignin content of cocoa fruit is

60.67%, cellulose (holocellulose) 36.47%, and hemicellulose 18.90%. This content indicates that cocoa pod skin can be processed into charcoal, which contains a lot of carbon [11].

Of course, making charcoal briquettes cannot be separated from the addition of adhesive. Adhesive is a substance that has the ability to bond two objects through surface bonds. There are two types of raw materials that are commonly used as binders for making briquettes, namely inorganic binders and organic binders. Good adhesives generally use materials containing amylopectin, which is useful for binding charcoal particles; with adhesive, the pressure will be much smaller compared to briquettes without adhesive [12, 13].

Materials commonly used as adhesives include tapioca flour and sago flour. Sago flour contains around 27% amylose and around 73% amylopectin. Amylose is hard, while amylopectin is sticky, so it is suitable for use as an adhesive for charcoal briquettes. Sago bark waste contains important components, namely 57% cellulose and 38% lignin, so sago bark has great potential to be used as charcoal briquettes [14]. Meanwhile, tapioca has starch consisting of amylose and amylopectin, which makes it capable of binding the carbon in charcoal briquettes. Amylose provides hard properties, while amylopectin causes sticky properties [15].

One of the biomass wastes that can be used as adhesive is red dragon fruit skin. Red dragon fruit skin has quite a large percentage of the total weight of red dragon fruit and has a fairly high pectin content, namely ± 10.80%, while the pectin content in dried red dragon fruit is 14.6–20.14% [16]. The pectin contained in dragon fruit skin can be used as an adhesive in making charcoal briquettes. The use of adhesive from red dragon fruit peel, which contains pectin, also aims to reduce the use of inorganic adhesives, which can pollute the environment and can harm health, as well as reduce environmental pollution caused by red dragon fruit peel.

Previous studies have demonstrated the feasibility of utilizing cocoa pod husk biomass for the production of charcoal briquettes using starch-based binders. Among others, cocoa pod husk briquettes prepared using cassava starch as a binder exhibited a moisture content of 10.5%, ash content of 6.5%, volatile matter of 34.7%, fixed carbon of 58.8%, and a higher heating value of 17.94 MJ/kg, demonstrating the potential of cocoa pod husk as a renewable biomass fuel [17]. Another study reported that composite briquettes produced from dried cocoa pod husk and coconut fiber with a ratio of 20:80 achieved a calorific value of 25.83 MJ/kg, along with satisfactory moisture content, ash content, density, and durability, using cassava starch as an adhesive [18]. Although starch-based adhesives, such as starch and cassava starch, have been proven to be able to produce biobriquettes with good characteristics, both materials are food commodities with relatively high economic value. Widespread use as a food ingredient can limit their long-term sustainability as a binder for industrial briquettes. Therefore, alternative adhesives are needed that not only produce high-quality biobriquettes but also come from underutilized biomass waste. One potential waste product is dried dragon fruit peel, which contains pectin and lignocellulose components that are expected to improve interparticle bonds and increase the added value of agricultural waste.

Dragon fruit peel was selected because it contains relatively high amounts of pectin together with cellulose and hemicellulose, which are expected to promote interparticle bonding through hydrogen interactions during briquette molding and drying. Moreover, the direct utilization of dried dragon fruit peel powder without prior pectin extraction offers a simpler and more economical processing route compared with purified pectin or conventional starch-based binders. Nevertheless, information regarding the physicochemical characteristics and Fourier Transform Infrared (FTIR) profiles of cocoa pod husk charcoal briquettes prepared using dried dragon fruit peel powder as a natural binder remains very limited.

Therefore, this study investigated the feasibility of using dried dragon fruit peel powder as a natural binder at concentrations of 15%, 20%, and 25% (w/w based on the mass of charcoal) for the production of cocoa pod husk charcoal briquettes. These binder concentrations were selected to evaluate the effect of binder content on the physicochemical properties and FTIR characteristics of the briquettes while maintaining a practical formulation for briquette production. The produced briquettes were characterized in terms of density, compressive strength, calorific value, moisture content, ash content, volatile matter, fixed carbon, and functional groups using FTIR spectroscopy. This study provides new insight into the simultaneous valorization of cocoa pod husk and dragon fruit peel wastes through the production of charcoal briquettes using a natural pectin-rich binder, thereby contributing to the development of more sustainable biomass-based solid fuels.

2. METHOD

2.1 Charcoal making

Fresh cocoa pod husks were washed with tap water to remove adhering dirt and impurities before being sun-dried for approximately three days until a constant weight was obtained. The dried husks were then carbonized in a closed metal drum under limited oxygen conditions for approximately 3 h to produce charcoal while preventing complete combustion. After cooling naturally to room temperature, the charcoal was crushed using a mortar and pestle and sieved through a 120-mesh sieve to obtain a uniform particle size prior to briquette preparation.

2.2 Making charcoal briquettes

For each formulation, 100 g of cocoa pod husk charcoal powder was mixed with dried dragon fruit peel powder as a natural binder at concentrations of 15 g, 20 g, and 25 g, corresponding to 15%, 20%, and 25% (w/w based on the mass of charcoal), respectively. Distilled water (75 mL) was added to each formulation to produce a homogeneous mixture. The mixture was thoroughly stirred and then molded into cylindrical briquettes using a steel mold with a diameter of 2.0 cm and a height of 2.7 cm. The briquettes were compressed using a hydraulic press at a pressure of 10 MPa and maintained under pressure for approximately 1 min before being removed from the mold. The molded briquettes were subsequently sun-dried for three days until a constant weight was achieved and then stored in airtight containers prior to physicochemical characterization.

The binder concentration was calculated based on the mass of dried dragon fruit peel powder relative to the mass of charcoal using the following equation:

$$Binder\ concentration\ (\%) = \frac{(Mass\ of\ binder)}{(Mass\ of\ charcoal)} \times 100\% \quad (1)$$

where the charcoal mass was maintained at 100 g for all formulations.

2.3 Charcoal briquette testing

The parameters for testing the quality of briquettes in this research are: calorific value, density, compressive strength, water content, ash content, volatile matter content, and bound carbon content.

2.4 Fourier Transform Infrared analysis

FTIR spectroscopy was performed to identify the functional groups present in cocoa pod husk charcoal briquettes prepared with different concentrations of dried dragon fruit peel powder binder (15%, 20%, and 25% w/w based on the mass of charcoal). Prior to analysis, the briquette samples were ground into fine powder using a mortar and pestle to obtain a homogeneous sample. The FTIR spectra were recorded over the wavenumber range of 4000–500 cm^{-1} at room temperature. The obtained spectra were analyzed to identify the characteristic absorption bands corresponding to hydroxyl (O–H), aliphatic (C–H), carbonyl (C=O), aromatic (C=C), and polysaccharide (C–O) functional groups. Variations in the absorption bands were used to evaluate the interaction between cocoa pod husk charcoal and the dried dragon fruit peel powder binder within the briquette matrix.

2.5 Calorific value

The calorific value of the briquettes was determined using a bomb calorimeter. The sample was combusted to completion, and the heat released per unit mass was calculated (cal/g).

The calorific value was measured using a bomb calorimeter following these steps. The sample (≤ 1.0 g) was weighed. The length of the Ni–Cr ignition wire was measured before the test (5 cm and 8 cm), and the nichrome wire was attached to the electrodes. Then 2 kg of water was put into the reservoir. The bomb was assembled and tightened, avoiding excessive pressure. Then a cover, anode/cathode cable, and thermometer were installed, and then waited for 10 minutes until the temperature on the LED was constant; then the last bombing of the sample was performed, and the temperature at the time of bombing the sample was recorded.

Calculation of calorific value is done using the Gross Energy formula, namely:

$$GE\left(\frac{Cal}{g}\right) = \frac{(T_2 - T_1) \times 1.325.605}{sample\ weight} \quad (2)$$

where, T_1 is the initial temperature (°C), T_2 is the final temperature (°C), and 1.325.605 is the hydrothermal equivalent value (HE)/ temperature constant (cal/°C).

2.6 Density

The density of the briquettes was determined from the ratio of mass to volume. Briquette mass was measured using an analytical balance, while the diameter and height of each cylindrical briquette were measured using a digital caliper. The briquette volume was calculated using the cylinder volume equation, and density was expressed in g/cm³ [5].

$$p\left(\frac{g}{cm^3}\right) = \frac{m}{v} \quad (3)$$

where, p is the density, m is the mass of the briquette, v is the volume of the briquette.

To determine the volume of the briquette (cylinder volume), the dimensions of the briquette need to be measured using a caliper.

2.7 Moisture content

The method of testing water content is done by putting the cup to be used into the oven at 105 °C until the weight of the cup is constant for ± 30 minutes, then cooling it in a desiccator and then weighing it as the weight of the empty cup. A 2 g charcoal briquette sample was placed in a cup and oven-dried at 105 °C for 30 min. After that, it was cooled in a desiccator and then weighed, repeating this step until a constant sample weight was obtained [19]. Moisture content is calculated using the formula:

$$Moisture\ content(\%) = \frac{(b - c)}{(b - a)} \times 100\% \quad (4)$$

where, a is the weight of the empty cup (g), b is the weight of the empty cup + sample (g), and c is the weight of the empty cup + sample after heating in the oven (g) [20].

2.8 Ash content

Ash content was determined by first placing a clean, dry porcelain crucible in an oven at 105 °C for 30 min until a constant weight was obtained. The crucible was then cooled in a desiccator and weighed. Approximately 1 g of the charcoal briquette sample was placed into the porcelain crucible. The crucible containing the sample was transferred to a muffle furnace and heated at 600 °C for 3 h. After heating, the crucible was cooled in a desiccator and weighed. The sample used for the ash content determination was the residue obtained from the moisture content test [19].

Ash content was calculated using the formula:

$$Ash\ content(\%) = \frac{(c - a)}{(b)} \times 100\% \quad (5)$$

where, a is the weight of the empty cup (g), b is the weight of the sample (g), and c is the weight of the empty cup + the weight of the sample after heating in the furnace (g) [20].

2.9 Volatile matter

Volatile matter was determined by first drying a clean porcelain crucible in an oven at 105 °C for 30 min, cooling it in a desiccator, and weighing it. The drying–cooling–weighing cycle was repeated until a constant mass was obtained. Then cooled in a desiccator and weighed. Then, 1 g of charcoal briquette sample was put into the cup and heated in a furnace at 950 °C for 3 hours. After that, it was cooled in a desiccator and weighed. The volatile substance content test uses samples from the results of the water content test.

Calculation of volatile substances is done using the formula:

$$Volatile\ Matter\ (\%) = \frac{(W_1 - W_2)}{W_1} \times 100\% \quad (6)$$

where, W_1 is the dry sample weight of the water content (g), W_2 is the dry sample weight of the water content after heating (g) [19].

2.10 Experimental replication

All briquette formulations were prepared independently, and each physicochemical property was measured in triplicate. The values presented in this study represent the average of three independent measurements conducted under identical experimental conditions.

2.11 Fixed carbon content

Fixed carbon content is obtained from the value of water content, ash content, and volatile or fly substance content.

Method of calculation:

$$Fixed\ carbon\ content\ (\%) = 100\% - (MC + VM + Ash\ content) \quad (7)$$

where MC is the moisture content (%), and VM is the volatile matter content (%).

3. RESULTS AND DISCUSSION

3.1 Charcoal briquette characteristics

Charcoal briquettes in this study were made with various concentrations of dragon fruit peel adhesive, namely 15%, 20%, and 25% (w/w based on 100 g charcoal). The briquettes are then characterized, including density, compressive strength, calorific value, water content, ash content, volatile matter content, and bound carbon content. The results of the characterization of charcoal briquettes from cocoa shells with dried dragon fruit peel powder binder are presented in Table 1.

3.2 Making charcoal briquettes

Cocoa pod shells are a promising lignocellulosic biomass for charcoal briquette production because they contain high amounts of lignin, cellulose, holocellulose, and hemicellulose, which contribute to char formation during carbonization. The relatively high lignin content enhances the fixed carbon yield and improves the structural integrity of the resulting charcoal, whereas cellulose and hemicellulose thermally decompose to form volatile compounds and carbonaceous residues [21].

Drum carbonization was selected because it provides a limited-oxygen environment that minimizes complete combustion and promotes the formation of charcoal with a higher carbon content and lower ash production. The carbonization process was carried out for 3 h, which allowed sufficient thermal decomposition of the biomass while minimizing carbon loss due to overburning [5].

The resulting charcoal was ground and sieved to 120 mesh to obtain a uniform particle size. Fine particles provide a larger specific surface area and more contact points between the charcoal and the binder, thereby improving particle packing during compaction. This uniformity contributes to higher briquette density, enhanced mechanical strength, and more stable combustion behavior.

The briquettes were compacted at 10 MPa, a pressure sufficient to increase particle contact without causing structural damage. Higher compaction pressure reduces void spaces between particles, resulting in denser briquettes with improved mechanical integrity and combustion performance. These factors collectively contribute to the improved physical quality of the briquettes.

The effectiveness of red dragon fruit peel powder as a natural binder is attributed to its pectin-rich polysaccharide matrix, together with cellulose and hemicellulose, which contain abundant hydroxyl (–OH) and carboxyl (–COOH) functional groups [16]. These functional groups promote hydrogen bonding with oxygen-containing functional groups on the charcoal surface, as supported by the FTIR spectra presented in this study [22]. During compaction, the hydrated binder fills the voids between charcoal particles and forms a continuous matrix that bridges adjacent particles. After drying, moisture removal strengthens this network, thereby increasing interparticle adhesion, reducing porosity, and improving the structural stability of the briquettes [13]. Consequently, this binding mechanism explains the enhanced density, mechanical strength, and fuel properties observed in the briquettes containing red dragon fruit peel powder.

Table 1. Physicochemical characteristics of cocoa shell charcoal briquettes and comparison with international standards

Briquette Properties	Experimental Results			Briquette Standards			
	15%	20%	25%	SNI	Japan	UK	USA
Adhesive mass per 100 g charcoal (g)	15	20	25	-	-	-	-
Density (g/cm³)	0.7789	0.8739	0.8851	> 0.5-0.6	1-2	0.46	1
Compressive strength (kg/cm²)	0.7137	1.4274	1.7843	50	60-65	12.7	62
Calorific value (cal/g)	5134.89	4319.04	3835.65	5000	6000-7000	7300	6500
Moisture content (%)	4.5851	5.3664	5.3849	< 8	6-8	3.6	6.2
Ash content (%)	8.33	8.67	8.76	< 8	3-6	5.9	8.3
Volatile matter (%)	12.30	10.65	9.36	< 15	15-30	16.4	19-24
Fixed carbon (%)	74.78	75.31	76.50	> 77	60-80	75.3	60

Drying is carried out in the sun for 3 days to reduce the water content of the briquettes, which comes from the powder binder solvent, namely distilled water, making it easier to burn the briquettes. The dried briquettes are then put into an airtight container so that the briquettes remain dry because charcoal briquettes are hygroscopic; if left in the open air, the briquettes will absorb water molecules from the surrounding air, which will cause the quality of the briquettes to decrease. The resulting briquettes are then characterized.

3.3 Fourier Transform Infrared analysis of cocoa shell charcoal briquettes

FTIR spectroscopy was employed to investigate the chemical structure of cocoa shell charcoal briquettes produced using different concentrations of dragon fruit peel powder binder. The FTIR spectra of the briquettes are presented in Figure 1.

The FTIR spectra of cocoa shell charcoal briquettes prepared with different concentrations of dragon fruit peel powder binder are presented in Figure 1, while the corresponding functional group assignments are summarized in Table 2. The spectra exhibited several characteristic absorption bands corresponding to the major functional groups present in the briquette components. A broad absorption band observed in the region of 3200–3600 cm^{-1} was attributed to O–H stretching vibrations associated with hydroxyl groups originating from cellulose, hemicellulose, and pectin compounds. The presence of this absorption band confirms the contribution of lignocellulosic materials from cocoa pod husk and pectin-rich dragon fruit peel powder binder [22, 23].

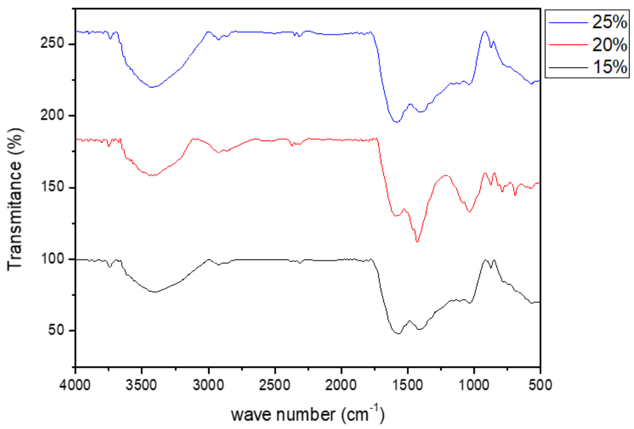

Figure 1. Fourier Transform Infrared (FTIR) spectra of cocoa shell charcoal briquettes prepared with 15%, 20%, and 25% dragon fruit peel powder binder concentrations

As shown in Table 2, the absorption band around 2850–2950 cm^{-1} corresponded to aliphatic C–H stretching vibrations, indicating the presence of hydrocarbon structures commonly found in biomass-derived materials. Absorption peaks observed in the region of 1600–1700 cm^{-1} were assigned to carbonyl (C=O) stretching and aromatic C=C vibrations associated with lignin and pectin components [24, 25]. These functional groups contribute to the binding mechanism between charcoal particles and the natural powder binder.

Table 2. Assignment of Fourier Transform Infrared (FTIR) absorption bands of cocoa shell charcoal briquettes

Wavenumber (cm^{-1})	Functional Group	Assignment
3200-3600	O–H	Hydroxyl stretching vibration
2850-2950	C–H	Aliphatic stretching vibration
1600-1700	C=O / C=C	Carbonyl and aromatic vibration
1400-1500	C–H bending	Lignocellulosic structure
1000-1200	C–O	Polysaccharide stretching vibration
700-900	Aromatic C–H	Out-of-plane aromatic vibration

Furthermore, strong absorption bands in the range of 1000–1200 cm^{-1} were attributed to C–O stretching vibrations of polysaccharides, mainly cellulose and pectin. The persistence of these bands indicates that bioactive components from dragon fruit peel remained present in the briquette matrix after the molding and drying processes. Similar absorption bands have been reported for lignocellulosic biomass and pectin-containing materials [16, 23].

Differences in the intensity of O–H and C=O absorption bands among the briquettes suggest that increasing powder binder concentration affects the abundance of oxygen-containing functional groups within the briquette structure. This observation confirms the incorporation of dragon fruit peel powder binder into the briquette matrix and supports its role as an effective natural binder. The presence of hydroxyl and carbonyl functional groups is expected to enhance intermolecular interactions and improve particle cohesion during briquette formation [13].

3.4 Characteristics of charcoal briquettes

Calorific value

Determining the calorific value is the most important quality standard for charcoal briquettes as fuel, so the calorific value will determine the quality of the charcoal briquettes. The higher the calorific value of the fuel, the better the quality produced. The high or low calorific value is influenced by the water content and ash content of the charcoal briquettes. The higher the water content and ash content of the briquettes, the lower the calorific value of the briquettes produced [24, 25].

The calorific value produced at each powder binder concentration can be seen in Table 1. Based on this, it can be seen that the highest calorific value is obtained from a powder binder concentration of 15%, amounting to 5134.89 cal/g, and the lowest calorific value is obtained from a powder binder concentration of 25%, amounting to 3835.65 cal/g. The higher the powder binder concentration, the lower the calorific value produced. This is because the calorific value of briquettes is influenced by the water content of the briquettes; briquettes with a high powder binder concentration contain a lot of water content, so that it will reduce the heat in the briquettes themselves; the heat is first used to evaporate the water in the briquettes [19, 25]. The best calorific value and compliance with SNI 01-6235-2000 in this study were found at a powder binder concentration of 15%, namely 5134.89 cal/g.

Density

Density shows the ratio between the mass and volume of charcoal briquettes. The size of the density is influenced by the size of the powder and the strength of the pressure during the printing process. The size of the density is influenced by the size of the powder and the strength of the pressure during the printing process. The density value influences the burning rate and heating value of the briquettes. Density is influenced by the homogeneity of the powder binder mixture with charcoal; with more even mixing, the stronger the charcoal briquettes produced will be. This causes the charcoal particles to be fairly even [5, 19]. Therefore, to obtain a good density value, the researchers in this study first sifted the cocoa shell charcoal using a mesh 120 sieve so that the size of the charcoal powder would be finer. The briquette density values in this study can be seen in Table 1. Based on this data, it can be seen that density is directly proportional to powder binder concentration. The results of the research obtained the density value of briquette charcoal ranging from 0.7789–0.8851 g/cm^3, which meets SNI 01-6235-2000, namely > 0.5-0.6.

The highest density value (Table 1) was obtained from charcoal briquettes with 25% powder binder, namely 0.8851 g/cm^3, and the lowest with 15% powder binder, namely 0.7789 g/cm^3. This shows that the higher the powder binder content, the higher the density value of the briquettes. Increasing powder binder content will increase the bonding power between particles so that it can reduce the voids in charcoal briquettes [26]. Briquetted charcoal that has a high density has advantages, including being denser and stronger, and having high stability [5, 19].

Compressive strength

Compressive strength testing in making charcoal briquettes is very necessary because it can determine how resistant the charcoal briquettes are when hit by a hard object, so it is useful during the packaging, distribution, and storage process [26]. Compressive strength is a characteristic of briquetted charcoal that is related to the durability or sturdiness of the briquetted charcoal against external pressure, causing the briquetted charcoal to break or crumble. The higher the compressive strength value, the better the resistance of the charcoal briquette to breaking [27].

Based on the data in Table 1, the highest compressive strength was observed for briquettes with 25% binder (1.7843 kg/cm²), whereas the lowest value was observed for those with 15% binder (0.7137 kg/cm²). The dragon fruit peel powder binder used in the process of making charcoal briquettes makes the density of the charcoal briquettes greater. The greater the powder binder concentration used in the charcoal briquette composition, the compressive strength value of the resulting charcoal briquettes will increase [19, 27].

Moisture content

The water content of solid fuels affects combustion characteristics. Therefore, the water content in biobriquettes must be as low as possible so that it does not require a lot of energy to dry it. High water content will cause the resulting briquettes to be difficult to ignite [5, 26].

Based on research data in Table 1, the water content obtained was 4.5851% to 5.3849%, which meets the quality of SNI 01-6235-2000, namely < 8%. This is because the water content in the cocoa pod husks evaporates during the carbonization process; the longer the carbonization process, the lower the water content [26]. The water content value influences the combustion characteristics, where briquette charcoal that has a low water content will cause a fast combustion process. Meanwhile, charcoal briquettes with high moisture content will burn slowly [19, 27].

Ash content

Ash content is a mineral that cannot be burned and is what remains after the combustion process; the changes or reactions that accompany it are complete. High ash content will affect the quality of charcoal briquettes, especially the calorific value produced. High ash content can reduce the calorific value of briquettes, thereby reducing the calorific value of briquettes [19, 25].

The results of the analysis of ash content in charcoal briquettes from cocoa shell waste with red dragon fruit peel powder binder are shown in Table 1. In the sample with 15% powder binder, the ash content was 8.33%, the sample with 20% powder binder was 8.67%, and the sample with 25% powder binder was 8.76%. This shows that the higher the powder binder concentration, the higher the ash content produced. High ash content causes low quality of charcoal briquettes. The cause of the high ash content in briquettes is that the amount of biomass is increasing, so the silica contained in the biomass is also increasing [8, 28]. The ash content results obtained met the American standard, namely 8.3% (Table 1).

Volatile matter levels

Volatile content is a substance (volatile matter) that can evaporate as a result of the decomposition of compounds that are still contained in charcoal other than water. The high content of volatile substances in charcoal briquettes will cause more smoke when the briquettes are lit. The high smoke content is caused by a reaction between carbon monoxide (CO) and alcohol derivatives [5, 27].

The results of testing volatile substance levels can be seen in Table 1. The highest levels of volatile substances were obtained from charcoal briquettes with a powder binder concentration of 15% at 12.30%, followed by charcoal briquettes with a powder binder concentration of 20% at 10.65%, and the lowest from charcoal briquettes with a powder binder concentration of 25% was 9.36%. The low level of volatile substances is caused by the lack of non-carbon compounds in the sample, for example, oxygen atoms, which are strongly bound to the carbon atoms in the briquettes in the form of carbon dioxide and carbon monoxide. The level of volatile substances is influenced by the perfection of the carbonization process as well as the temperature and time of combustion. The higher the temperature and cooking time, the higher the amount of volatile matter that is wasted, so that during the test it will produce low volatile matter [8, 27]. The high levels of volatile substances in briquettes will produce quite a lot of smoke when the briquettes are burned [24]. Overall, in testing the levels of volatile substances from the three powder binder concentrations met SNI 01-6235-2000, namely below 15%.

Fixed carbon content

The fixed carbon content represents the carbon fraction remaining in the briquettes after subtracting the moisture, ash, and volatile matter contents. It is an important quality parameter because a higher fixed carbon content generally contributes to a higher calorific value, longer burning time, and cleaner combustion with reduced smoke generation [14, 19]. As shown in Table 1, the fixed carbon content increased slightly with increasing dried dragon fruit peel powder binder concentration, from 74.78% at 15% binder to 75.31% at 20% binder and 76.50% at 25% binder. This trend indicates a slight increase in fixed carbon content with increasing binder concentration. The observed increase may be associated with the lignocellulosic constituents of the dried dragon fruit peel powder, although the overall fixed carbon values remained slightly below the minimum requirement specified by SNI 01-6235-2000. Therefore, additional studies are required to clarify the contribution of the binder to fixed carbon formation.

Overall, the physicochemical characterization revealed that moisture content and volatile matter met the requirements of SNI 01-6235-2000 for all briquette formulations. However, the ash content slightly exceeded the maximum allowable limit, whereas the fixed carbon content (74.78–76.50%) remained marginally below the minimum requirement of 77%. Only the briquettes containing 15% dried dragon fruit peel powder binder achieved the minimum calorific value specified by the standard (5000 cal/g). These findings indicate that optimizing the binder concentration and the briquette manufacturing process is necessary to improve fuel quality and achieve full compliance with SNI 01-6235-2000. Despite these limitations, dried dragon fruit peel powder exhibited promising potential as a sustainable natural binder for biomass briquettes due to its favorable influence on the overall physicochemical characteristics of the briquettes.

4. CONCLUSIONS

This study demonstrated that dried dragon fruit peel powder can be utilized as a natural binder for the production of cocoa pod husk charcoal briquettes with acceptable physicochemical characteristics. Among the tested formulations, each binder concentration exhibited distinct performance characteristics. Briquettes prepared with 15% binder showed the highest calorific value (5134.89 cal/g) and the lowest ash content (8.33%), whereas increasing the binder concentration improved the density, compressive strength, and fixed carbon content of the briquettes. All formulations satisfied the Indonesian National Standard (SNI 01-6235-2000) requirements for moisture content, volatile matter, and fixed carbon, although the ash content slightly exceeded the specified SNI limit. FTIR analysis confirmed the presence of hydroxyl (O–H), carbonyl (C=O), aromatic (C=C), and polysaccharide (C–O) functional groups, indicating the successful incorporation of dried dragon fruit peel powder into the briquette matrix. These findings demonstrate the potential of simultaneously valorizing cocoa pod husk and dragon fruit peel wastes for the production of biomass-based charcoal briquettes using a natural pectin-rich binder. Further studies are recommended to evaluate combustion performance, gaseous emissions, and long-term storage stability before practical large-scale application.

REFERENCES

[1] Basri, M.H., Rizky, R., Febrianto, A., et al. (2021). Utilization of irrigation channels as hydroelectric power plants (VORTEX) for areas not affected by PLN electricity supply. GUYUB: Journal of Community Engagement, 2(1): 12-25. https://doi.org/10.33650/guyub.v2i1.1907

[2] Pambudi, N.A., Firdaus, R.A., Rizkiana, R., et al. (2023). Renewable energy in Indonesia: Current status, potential, and future development. Sustainability, 15(3): 2342. https://doi.org/10.3390/su15032342

[3] Adebiyi, F.M. (2022). Air quality and management in petroleum refining industry: A review. Environmental Chemistry and Ecotoxicology, 4: 89-96. https://doi.org/10.1016/j.enceco.2022.02.001

[4] Vaish, S., Kaur, G., Sharma, N.K., Gakkhar, N. (2022). Estimation for potential of agricultural biomass sources as projections of bio-briquettes in Indian context. Sustainability, 14(9): 5077. https://doi.org/10.3390/su14095077

[5] Rahmawati, S., Pathuddin, Sakung, J., Suherman, Fudholi, A., Sushmita, L. (2020). The utilization of corncob for the manufacture of charcoal briquette as an alternative fuel. Journal of Physics: Conference Series, Jember, 1563: 012022. https://doi.org/10.1088/1742-6596/1563/1/012022

[6] Badan Pusat Statistik. (2025). Indonesia's Annual Plantation Crop Statistics 2024 (Palm Oil, Coffee, Cocoa, Rubber, Tea, and Leading Plantation Commodities). BPS. https://www.bps.go.id/id/publication/2025/08/29/8d2a6ab3510f9828daf73191/statistik-tanaman-perkebunan-tahunan-indonesia-2024--kelapa-sawit--kopi--kakao--karet--teh--dan-komoditas-perkebunan-unggulan-.html.

[7] Sari, S.W., Masthura, M., Husnah, M. (2025). The effect of variations in cocoa shell carbon on the characteristics of environmentally friendly stamp ink. Jurnal Phi Jurnal Pendidikan Fisika Dan Fisika Terapan, 11(1): 45-51. https://doi.org/10.22373/p-jpft.v11i1.20137

[8] Aunillah, M.A.N.T., Cezarridfalah, B.B., Putri, J.K., Nurmawati, A., Febrianto, N.A., Saputro, E.A. (2024). Utilization of cocoa pod husk and wood charcoal into briquettes as an environmentally friendly alternative fuel. Pelita Perkebunan (a Coffee and Cocoa Research Journal), 40(2): 161-170. https://doi.org/10.22302/iccri.jur.pelitaperkebunan.v40i2.616

[9] Izzah, S.N., Brugman, E., Baladraf, T.T., Rachmadita, F. (2023). An overview of cocoa nibs shell waste potential to achieve sustainable agriculture. IOP Conference Series: Earth and Environmental Science, Makassar, 1230: 012028. https://doi.org/10.1088/1755-1315/1230/1/012028

[10] Lu, F., Rodriguez-Garcia, J., Van Damme, I., et al. (2018). Valorisation strategies for cocoa pod husk and its fractions. Current Opinion in Green and Sustainable Chemistry, 14: 80-88. https://doi.org/10.1016/j.cogsc.2018.07.007

[11] Putri, R.E., Kasim, A., Emriadi, Asben, A. (2019). Pyrolysis and characterization of liquid smoke from cacao pod husks. IOP Conference Series: Earth and Environmental Science, 327: 012011. https://doi.org/10.1088/1755-1315/327/1/012011

[12] Ali, O.A.M., Buchori, L., Djaeni, M. (2021). Quality improvement of charcoal briquette from modified coconut shell as a solid fuel source with the starch adhesive. IOSR Journal of Engineering (IOSRJEN), 11(10): 1-14. https://www.iosrjen.org/Papers/vol11_issue10/A1110010114.pdf.

[13] Imam, S.H., Bilbao-Sáinz, C., Chiou, B.S., Glenn, G.M., Orts, W.J. (2013). Biobased adhesives, gums, emulsions, and binders: Current trends and future prospects. Journal of Adhesion Science and Technology, 27(18-19): 1972-1997. https://doi.org/10.1080/01694243.2012.696892

[14] Tambunan, H., Nuryawan, A., Iswanto, A.H., Risnasari, I., Basyuni, M., Fatriasari, W. (2023). Briquettes made of branches wood of three mangrove species bonded by starch adhesive. Materials, 16(15): 5266. https://doi.org/10.3390/ma16155266

[15] Raghunathan, R. (2016). Hierarchical structure of field pea starches and their impact on physicochemical properties. Doctoral dissertation, Memorial University of Newfoundland. https://hdl.handle.net/20.500.14783/7461.

[16] Ismail, N.S.M., Ramli, N., Hani, N.M., Meon, Z. (2012). Extraction and characterization of pectin from dragon fruit (*Hylocereus polyrhizus*) using various extraction

conditions. Sains Malaysiana, 41(1): 41-45. http://www.ukm.edu.my/jsm/pdf_files/SM-PDF-41-1-2012/05%20Norazelina.pdf.

[17] Akam, N.G., Diboma, B.S., Mfomo, J.Z., Ndiwe, B., Bôt, B.V., Biwolé, A.B. (2024). Physicochemical characterization of briquette fuel produced from cocoa pod husk case of Cameroon. Energy Reports, 11: 1580-1589. https://doi.org/10.1016/j.egyr.2024.01.029

[18] Yirijor, J., Arhin, E., Agyepong, L., Badu, G., Bagonluri, F.M. (2022). Investigation of the mechanical and combustion characteristics of cocoa pod and coconut husk composite briquette. Journal of Materials Science Research and Reviews, 5(2): 154-163. https://journaljmsrr.com/index.php/JMSRR/article/view/189.

[19] Supriadi, Rahmawati, S., Abram, P.H., Afadil, Parwati, N.G.A.M., Anggraini. (2022). Characteristics of charcoal briquettes from kepok banana peel waste (Musa paradisiaca f.) as alternative fuel. Rayasan Journal of Chemistry, 15(1): 108-115. https://doi.org/10.31788/RJC.2022.1516607

[20] Zulhijrah, Z., Marwita Sari, P., Yulia, O. (2020). Physical chemical characteristics of the typical "Mando Table" of the gray catfish (Thunnus Tonggol). Doctoral dissertation, Universitas Maritim Raja Ali Haji. https://repositori.umrah.ac.id/1049/.

[21] Daud, Z., Kassim, A.S.M., Aripin, A.M., Awang, H., Hatta, M.Z.M. (2013). Chemical composition and morphological of cocoa pod husk and cassava peels for pulp and paper production. Australian Journal of Basic and Applied Sciences, 7(9): 406-411.

[22] Coates, J. (2006). Interpretation of infrared spectra, a practical approach. In Encyclopedia of Analytical Chemistry, pp. 10815-10837. https://doi.org/10.1002/9780470027318.a5606

[23] Poletto, M., Pistor, V., Zattera, A.J. (2013). Structural characteristics and thermal properties of native cellulose. In Cellulose-Fundamental Aspects. https://doi.org/10.5772/50452

[24] Osueke, C.O., Olayanju, T.M.A., Ezugwu, C.A., et al. (2018). Comparative calorific evaluation of biomass fuel and fossil fuel. International Journal Civil Engineering and Technology, 9(13): 1576-1590. https://eprints.lmu.edu.ng/id/eprint/1818.

[25] Rezania, S., Din, M.F.M., Kamaruddin, S.F., et al. (2016). Evaluation of water hyacinth (Eichhornia crassipes) as a potential raw material source for briquette production. Energy, 111: 768-773. https://doi.org/10.1016/j.energy.2016.06.026

[26] Kpalo, S.Y., Zainuddin, M.F., Manaf, L.A., Roslan, A.M. (2020). Production and characterization of hybrid briquettes from corncobs and oil palm trunk bark under a lowpressure densification technique. Sustainability, 12(6): 2468. https://doi.org/10.3390/su12062468

[27] Rahmawati, S., Rabasia, Afadil, et al. (2023). The utilization of durian peels (Durio zibethinus) for the manufacturing of charcoal briquettes as alternative fuel. Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan (Journal of Natural Resources and Environmental Management), 13(1): 76-87. https://doi.org/10.29244/jpsl.13.1.76-87

[28] Nazari, M.M., San, C.P., Atan, N.A. (2019). Combustion performance of biomass composite briquette from rice husk and banana residue. International Journal on Advanced Science Engineering and Information Technology, 9(2): 455-460. https://doi.org/10.18517/ijaseit.9.2.2408