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Research Article

Utilization of Cassava Peel (*Manihot utilissima*) Waste as an Adhesive in the Manufacture of Coconut Shell (*Cocos nucifera*) Charcoal Briquettes

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Abstract. Coconut shells and waste cassava peels could be used as the main raw material for biomass briquettes for alternative energy sources in Indonesia. This study aims to analyze the quality of briquettes based on a coconut shell and cassava peel adhesive through proximate analysis with three treatment ratio variations. The ratio of coconut shell to cassava peel used varied from V1 (75%:25%), V2 (70%:30%), and V3 (65%:35%). Based on the result, the charcoal briquettes produced have a density of 0.61 gram/cm³-0.66 gram/cm³, water content of 5.51%-7.85%, ash content of 1.50%-2.86%, combustion rate of 0.021 gram/s-0.026 gram/s, and the calorific value of 6,161 cal/gram-6,266 cal/gram. However, all the treatment variations appropriate the SNI 01-6235-2000, the national standard of Indonesia for the quality of charcoal briquette, which includes the calorific value (>5,000 cal/gram), moisture content (<8%), and ash content (<8%). Briquettes with the best quality were generated by V1 with a density of 0.66 gram/cm³, water content of 5.51%, ash content of 1.50%, combustion rate of 0.026 gram/s, and calorific value of 6,266 cal/gram. Furthermore, briquette material from the coconut shell waste with natural cassava peel adhesive can be feasible as an alternative fuel.

Keywords: Biomass, Briquettes, Cassava Peel Waste, Coconut Shell, Proximate Analysis

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1. Introduction

The amount of energy needed has increased due to Indonesia's population growth. In 2021, energy consumption from coal could reach 17% of the total national energy consumption mix (BPPT, 2021). This certainly encourages the importance of using alternative and renewable energy sources. In this case, biomass is a renewable energy source that can be used as an alternative fuel to replace fossil fuels with abundant availability (Budi Surono, 2019; Sunardi, Djuanda, & Mandra, 2019; Tzelepi *et al.*, 2020). Biomass includes agricultural, plantation, forest waste, and organic components from industry and households (Yana, Nizar, Irhamni, & Mulyati, 2022). Furthermore, the development of biomass as an alternative energy source has many challenges, and one of them is the production process (Cuong *et al.*, 2021; Dani & Wibawa, 2018; Yana *et al.*, 2022). However, the briquette is a biomass product that can be produced through a simple process with economic value, high heat content, and abundant availability of raw materials to compete with other fuels (Sunardi *et al.*, 2019).

Various types of waste can be used as raw materials to produce briquettes while solving the waste management problem (Ardelean *et al.*, 2022; Bazhin, Kuskov, & Kuskova, 2019; Ganesan & Vedagiri, 2022; Vaish, Sharma, & Kaur, 2022). Coconut shell (*Cocos nucifera*) is a waste product that can be utilized to produce charcoal briquettes. In this case, Indonesia has quite extensive coconut plantations that can be used. This follows statistical data from the Directorate General of Plantation (2021) that the total area of coconut plantations is 3,401,893 Ha, with a total production of 2,839,852 tons. Besides, the coconut shell also contains a high calorific value reaching 7,283.5 cal/gram (Nurhilal, Suryaningsih, & Indrana, 2018), and the coconut shell water content is only 10.03% (Ghafar, Halidi, & So'aib, 2020). However, in charcoal briquette production, natural adhesives are usually needed to support the quality of the briquettes. The addition of adhesive is meant to reduce the briquette's pores and give them a solid structure, permitting them to be shipped and stored without being easily destroyed (Jiang *et al.*, 2022; Kamunur, Ketegenov, Kalugin, Karagulanova, & Zhaksibaev, 2022). In addition, the coconut shell charcoal's fine grains are combined with the adhesive substance to be molded as required.

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In this case, various adhesive materials in the manufacture of briquettes have been developed (Helwani *et al.*, 2020; Maulina, Sarah, Misran, & Anita, 2021; Suryaningsih, Resitasari, & Nurhilal, 2019). Cassava peel (*Manihot Utilissima*) is one of the materials that can be utilized as an alternative due to its availability to assist the production of coconut shell briquettes as a biomass raw material. It can be seen that the production of cassava plants in Indonesia can reach 19,053,748 tons (Ministry of Agriculture, 2021). Cassava peel has the potential to be used as an adhesive in the production of briquettes due to its moisture content of 9.93-11.46%, volatile materials of 77.93-81.93%, ash content of 1.93-4.36%, fixed carbon content of 13.44-15.51%, lignin content of 6.5-16.0%, cellulose content of 5.5-14.5%, hemicellulose content of 41.0-56.0%, and calorific value of 3,843.84 cal/gram (Hirniah, 2020; Kayiwa, Kasedde, Lubwama, & Kirabira, 2021a, 2021b). Furthermore, cassava peel has a carbohydrate content of about 30.15% that can be used as an adhesive (Anggraeni, Girsang, Nandiyanto, & Bilad, 2021; Kariuki, Muthengia, Erastus, Leonard, & Marangu, 2020).

Proximate testing is needed to determine the quality of briquettes based on SNI. However, due to its ready-to-use product characteristic, proximate testing is required to determine the ability of briquettes as fuel. In charcoal briquette production, it is necessary to consider the value of water content, volatile matters, ash, solid carbon (fixed carbon), and calorific value as the main parameters of the quality of briquettes. The water content indicates the ease of burning, and briquettes are easier to mold when the water content is high. Volatile matter, ash, and solid carbon as total fixed carbon refer to the amount of smoke when the briquettes are burned (Srisang *et al.*, 2022). Besides, the calorific value represents the energy produced from briquettes and the ease of burning (Adeleke, Odusote, Ikubanni, Olabisi, & Nzerem, 2022; Guo *et al.*, 2020; Velusamy, Subbaiyan, Kandasamy, Shanmugamoorthi, & Thirumoorthy, 2022).

The novelty of this research is the composition of raw materials and adhesives for the production of the briquettes. Although coconut shell has been commercialized as a raw briquette material, tapioca flour is still used as an adhesive. However, cassava peel is an excellent adhesive material because it has a starch content above 30%. Therefore, this research aims to determine the concentration level between coconut shell biomass and cassava peel natural adhesive according to the five aspects based on the SNI 01-6235-2000 in Indonesia. This is expected to produce a suitable correlation to obtain the development of charcoal briquettes better. As a result, the production of charcoal briquettes as an alternative fuel with high economic value, wide availability, and simplicity of access, can serve in the development of new and ecologically friendly energy sources.

2. Method

2.1 Development of Coconut Shell (Cocos nucifera) Charcoal Briquettes Material

In this research, coconut shell waste is used as raw material for briquettes production, and cassava peel waste is used as an adhesive. The chemical and physical properties of the coconut shell and cassava peel is shown in Table 1 and 2. Coconut shell as the raw material that has been dried is then pyrolyzed using a furnace at a temperature of 300°C for 7 hours (Rizal *et al.*, 2020; Sarkar & Wang, 2020; Tu *et al.*, 2021). During the pyrolysis process, the raw material of coconut shells is charred evenly. The result of the coconut shell that has been charcoaled is then pounded.

Table 1
Chemical and physical properties of coconut shell (Kabir Ahmad *et al.*, 2022)

Parameters	Properties	Description
Proximate Analysis	Moisture Content	5.56%
	Volatile Matter	70.82%
	Fixed Carbon	21.80%
	Ash	1.80%
Ultimate Analysis	C	40.08%
	H	5.22%
	N	0.22%
	S	0.17%
	O	54.31%
Potential as Energy Source	Porosity	24.39%
	Compressibility Index	40.24%
	Calorific Value	19.4 MJ/kg
	Fuel Value Index	4441

Table 2
Chemical and physical properties of cassava peel (Kayiwa *et al.*, 2021a)

No.	Properties	Description
1	Moisture Content	9.77-11.50%
2	Volatile Matter	78.22-82.31%
3	Fixed Carbon	13.44-15.51%
4	Ash Content	1.85-4.40%
5	Lignin	6.5-16.0%
6	Cellulose	5.5-14.5%
7	Hemicellulose	41.0-56.0%

Then, the coconut shell is sieved using a 40-mesh which aims to produce a fine, uniform particle size, and suitable as a briquette material (Abyaz, Afra, & Saraeyan, 2020; Meytij, Santoso, Rampe, Tiwow, & Apita, 2021; Setter, Sanchez Costa, Pires de Oliveira, & Farinassi Mendes, 2020).

The production of cassava peel adhesive begins with cleaning the attached peel dirt. Then, the cassava peel is dried and mashed using grinding. When the cassava peel has been processed into flour, it is filtered, combined with hot water in a 1:2 ratio, and stirred thoroughly to remove lumps. The purpose of the hot water addition is to make the mixing process easier.

Variations in the mixture of briquette raw materials were carried out using coconut shell charcoal which had been mashed using adhesive homogeneously with a predetermined composition, namely variation 1 (V1), variation 2 (V2), and variation 3 (V3), as shown in Table 3. Furthermore, the finished raw material mixture is placed into the briquette mold in the shape of a cylinder with a material weight of 30 grams. The briquette mixture was flattened to a height of 5.7 cm, then pressed 60% to produce briquettes with a height of 2.3 cm. The briquettes harden during the one-minute pressure hold. The drying process was then continued by heating for 4 hours at 105°C in an oven. The briquettes were consequently stored at room temperature for 24 hours.

Table 3
Composition variations of coconut shell charcoal briquettes

Variation Name	Briquettes Material Composition	
	Coconut Shell Charcoal	Cassava Peel Adhesive
V1	75% (22.5 grams)	25% (7.5 grams)
V2	70% (21 grams)	30% (9 grams)
V3	65% (19.5 grams)	35% (10.5 grams)

Table 4
Specifications of instruments used in the study

Instrument	Specification
Wire mesh	GB/T6003.1-2012 40 mesh
Heater UNB 400 (oven)	230 VAC; 6.1 A; 50/60 Hz
Furnace Carbolite ELF 11/6B	230 VAC; 9.6 A: 2000 Watt; Max temp 1100℃
M20 Universal Mill (Grinder)	230/115 ±10% VAC; 50/60 Hz; 550 Watt; 20,000 rpm; 250 ml
IKA © 2000 Bomb Calorimeter	230/115 VAC; 50/60 Hz; 1.8 kW; measurement range 40,000 J

2.2 Experimental and Testing Instruments

In the manufacturing and analysis performed, this research uses several types of equipment, such as a 40-mesh sieve, mortar, briquette press, heater (oven), grinding, baking sheet, mixing tank, pan, cup, analytical balance, pyrolysis equipment, IKA © 2000 Bomb Calorimeter, stopwatch, and caliper. Further details for the instrument used in this study are shown in Table 4.

2.3 Quality Test of Briquettes

The quality testing of coconut shell charcoal briquettes included density, moisture content, ash, combustion rate, and calorific value. Density can be examined by measuring the mass of briquettes and the volume of briquette samples using Equation (1):

$$\rho = \frac{m}{v} \tag{1}$$

Whereas ρ (g/cm^3) is density, m (g) is the mass of briquettes, and v (cm^3) is the volume of the briquettes.

Moisture content can be tested by weighing the sample to determine the initial weight and then heated in an oven at 105℃ for 6 hours. The sample was weighed again to decide its final weight after being dried in the oven for an hour. The water content can be calculated using Equation (2):

$$MC = \frac{X1 - X2}{X1}\, 100\% \tag{2}$$

Where MC is moisture content, $X1$ (g) is the initial weight of the sample, and $X2$ (g) is the final weight of the sample.

Ash content is the residue from burning briquettes that are not completely burned. The ash content test was carried out by weighing the empty weight of the cup, then 1 gram of the sample in the cup was heated in the furnace gradually at a temperature of 450-950℃ for 1-2 hours and then allowed to stand at room temperature until the temperature was normal. Equation (3) can calculate ash content as follow:

$$AC = \frac{B-A}{C-A}\, x\, 100\% \tag{3}$$

Where AC is ash content, A is the weight of an empty cup, B is the weight of the cup and ash, and C is the weight of the cup and the sample.

The rate of burning of briquettes is determined by the weight of the briquettes burned over a certain period using Equation (4):

$$V = \frac{m_t}{t} \tag{4}$$

Where V (g/s) is the rate of burning of briquettes, m_t (g) is the mass of the burned briquettes, and t (second) is the required burning time.

Fig. 1 Briquette preparation schematic diagram

The heat produced by briquettes and oxygen at a fixed volume can be evaluated using a bomb calorimeter to determine the calorific value. Figure 1 shows the method used in this study to produce coconut shell charcoal briquettes using waste cassava peel as an adhesive.

2.4 Data Analysis

In this study, we performed a quantitative analysis of density, moisture content, ash content, combustion rate, and calorific value of the coconut shell charcoal briquettes production using adhesive from waste cassava peel in each variation in the ratio of material composition. The analysis was carried out to determine whether the values of the various parameters complied with the Indonesian National Standard (SNI) 01-6235-2000. Moreover, a one-way Analysis of Variance (ANOVA) test was conducted to investigate whether variations in the material composition used to create adhesive from waste cassava peel during the production of coconut shell charcoal briquettes affected each of the parameters analyzed in this study. Furthermore, posthoc analysis using the Tukey method was carried out to determine the significant differences between each variation (Aransiola, Oyewusi, Osunbitan, & Ogunjimi, 2019; Karimibavani, Sengul, & Asmatulu, 2020; Niño, Arzola, & Araque, 2020).

3. Results and Discussion

3.1 Density

The briquette density test was carried out using the ratio of mass and volume. The homogeneity and size of the charcoal are affected by the density the briquettes produce. The results of the density measurement of charcoal briquettes V1, V2, and V3 are presented in Figure 2.

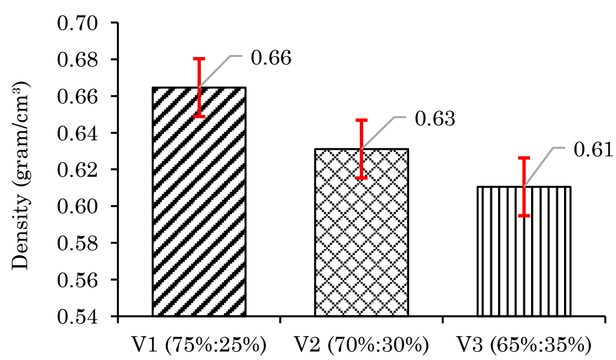

Fig. 2 Density of coconut shell briquettes with cassava peel adhesive

Table 5
Density analysis using the Tukey method with 95% confidence

Variation	N	Mean	Grouping		
V1	3	0.66456	A		
V2	3	0.63108		B	
V3	3	0.61050			C

Based on Figure 2, it can be seen that the highest density value is in V1 of 0.66 g/cm^3 with a ratio of coconut shell to cassava peel adhesive of 75%:25%, while the lowest value is in V3 with a ratio of coconut shell to cassava peel adhesive of 65%:35%. However, the values of the three densities are not much different, but the treatment value in V1 shows the results of better briquette density compared to other variations. This is due to the amount of adhesive that meets the void ratio formed by the particle size of 40 mesh.

High pressure can also increase the density value. It follows the research conducted by Sunardi *et al.* (2019) about the characteristics of corncob briquettes with a pressure of 44.80 kg/cm^3 and a particle size of 60 mesh, which produces a higher density level than corncob briquettes using a pressure of 22.42 kg/cm^3 with a particle size of 40 mesh. Consequently, the adhesive will tend to fill the surface of the charcoal as the bonds between the molecules of the charcoal become stronger, reducing the cavity filled with water or air (Satya, Raju, Praveena, & Jyothi, 2014). Therefore, the higher the density value of the briquettes, the smaller the cavity and the rate of combustion is slower (Haryanti, Wardhana, & Suryajaya, 2020). Furthermore, in statistical analysis using the one-way ANOVA method to determine the effect of variations in the composition of coconut shell charcoal and cassava peel waste, it is known that the P-value is <0.05, representing that the composition affects the density value of the briquettes. In the post hoc Tukey analysis, it is also known that each variable V1, V2, and V3 is significantly different from each other, as shown in Table 5.

3.2 Moisture Content

Briquettes have hygroscopic properties or easily absorb water, which shows that the value of water content needs to be considered because it can affect the quality of the briquettes produced. In this case, the moisture content of coconut shell briquettes with cassava peel adhesive ranged from 5.51-7.85%, as presented in Figure 3.

Figure 3 shows that the highest water content was obtained in treatment V3 at 7.85%, while the lowest water content was found in V1 at 5.51%. Treatment V1 with a ratio of coconut shell to cassava peel adhesive of 75%:25% had better briquette quality than other variations.

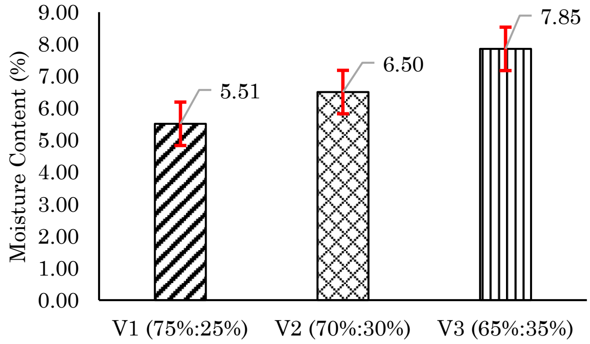

Fig. 3 Moisture content of coconut shell briquettes with cassava peel adhesive

Table 6
Moisture content analysis using the Tukey method with 95% confidence

Variation	N	Mean	Grouping		
V3	3	7.8525	A		
V2	3	6.503		B	
V1	3	5.511			C

This is due to the low water content, and the cassava peel adhesive that blends with coconut shell charcoal will be tighter because its pores become smaller. The high and low water content produced can be influenced by the type and percentage of adhesive used to manufacture briquettes (Kong, Loh, Bachmann, Rahim, & Salimon, 2014). The addition of more adhesive causes the water contained in the adhesive to enter the pores of the charcoal (Permatasari & Utami, 2015)

Based on Figure 3, it can be seen that the smaller the percentage of adhesive used, the smaller the water content, which means the quality of the briquettes produced will be better. This is in line with the research by Maryono *et al.* (2013) about the quality of coconut shell charcoal briquettes with the addition of higher levels of starch adhesive will produce higher water content as well. The maximum moisture content of charcoal briquettes is 8%, according to SNI 01-6235-2000. In this case, the water content in each treatment has met the SNI standard because it is below 8%, indicating that the coconut shell briquettes with cassava peel adhesive are suitable for alternative fuels. However, the P-value of the one-way ANOVA test is <0.05, which indicates that the variation in the composition of coconut shell charcoal with cassava peel waste affects the value of the resulting water content. Moreover, the post hoc Tukey's analysis results show that each variation V1, V2, and V3 is significantly different, as shown in Table 6.

3.3 Ash Content

Ash content is one of the references to determine the quality of briquettes. Ash content can affect the calorific value and carbon. The ash content produced in this study ranged from 1.50-2.86%. The results of the ash content test are presented in Figure 4.

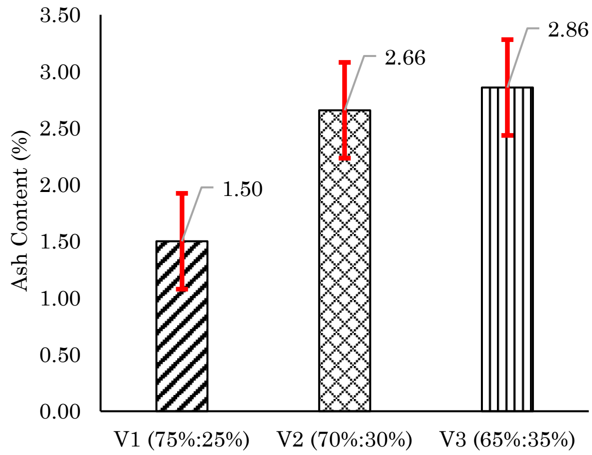

Fig. 4 Ash content of coconut shell briquettes with cassava peel adhesive

Table 7
Ash content analysis using the Tukey method with 95% confidence

Variation	N	Mean	Grouping	
V3	3	2.8579	A	
V2	3	2.6569	A	
V1	3	1.501		B

V3 produced the highest ash content with a ratio of coconut shell to cassava peel adhesive of 65%:35%. In contrast, the lowest ash content was obtained in V1 at 1.50%, with a ratio of coconut shell to cassava peel adhesive of 75%:25%. The amount of adhesive applied can influence the high and low levels of ash produced (Hasan *et al.*, 2017; Modolo *et al.*, 2015). Ash content affects the heating value and carbon content. The lower the ash content, the higher the calorific value and the fixed carbon content in the briquettes (Lu *et al.*, 2019; Román Gómez, Cabanzo Hernández, Guerrero, & Mejía-Ospino, 2018; Todaro, Rita, Cetera, & D'Auria, 2015). In addition, the content of inorganic materials in adhesives, such as silica (SiO_2), MgO, Fe_2O_3, $A1F_3$, MgD_3, and Fe, can also increase the ash content of briquettes (Haryanti *et al.*, 2020). Based on these findings, it can be shown that the ash content increases as the adhesive content increases. This is similar to Maryono *et al.* (2013), where the ash content of coconut shell briquettes increased with cassava peel adhesive applied.

The higher ash content in briquettes can reduce the calorific value and combustion rate, preventing air voids from penetrating the furnace (Sunardi *et al.*, 2019). The maximum permissible ash content in SNI 01.6235.2000 is 8%, while the ash content produced in this study ranges from 1.50-2.86%. It shows that the briquettes produced had good quality. The composition of the comparison of coconut shell with cassava peel adhesive is best produced by V1. It has the lowest ash content compared to other variations. The one-way ANOVA analysis obtained a P-value <0.05, it can be seen that the composition of coconut shell charcoal and cassava peel waste affects the ash content results. Furthermore, in the post hoc Tukey analysis, it is known that the variations V2 and V3 are not significantly different from each other, while the variations of V1 are significantly different from each other with V2 and V3, as shown in Table 7.

3.4 Combustion Rate

Five briquettes were used to heat 700 ml of water using three iterations of each variation in the combustion rate test to measure the rate of briquette combustion starting at the speed of the briquette flame. The calculation of the briquette burning rate result in this study ranged from 0.021-0.026 gram/s, as shown in Figure 5.

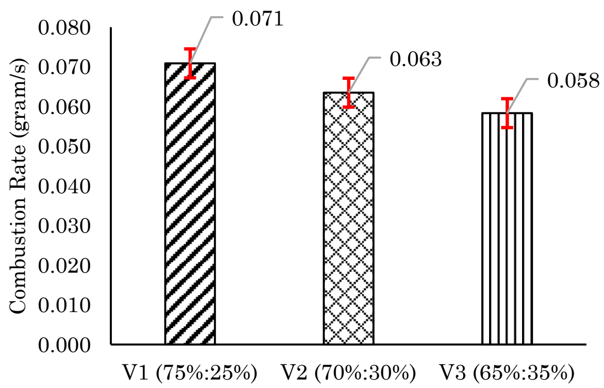

Fig. 5 Combustion rate of coconut shell briquettes with cassava peel adhesive

Table 8
Combustion rate analysis using the Tukey method with 95% confidence

Variation	N	Mean	Grouping		
V1	3	0.071000	A		
V2	3	0.063000		B	
V3	3	0.058000			C

The fastest burning rate is produced by V1 at 0.026 gram/s, while V3 has the slowest burning rate at 0.021 gram/s. Figure 5 shows that the percentage ratio of the adhesive composition can affect the rate of combustion produced. This is in line with Syarief *et al.* (2021), that the higher the percentage of adhesive added, the slower the burning rate, and vice versa.

The high percentage of adhesive addition will make the granules on the briquettes stick firmly. It makes the briquette pores smaller and difficult for air to enter to speed up the combustion process. Comparison of the composition of the variations of the resulting material did not differ much, but the V1 showed better briquette results than other variations. This is due to the faster rate of combustion, which makes it easier for the briquettes to ignite and burn away without producing a lot of smoke. The V1 shows a more effective and efficient result to be used as an alternative fuel. The results from the one-way ANOVA analysis obtained a P-value <0.05. This indicates that the composition of coconut shell charcoal and cassava peel waste affects the rate of combustion that occurs in briquettes. Based on the results of post hoc Tukey analysis, it is known that the respective variations of V1, V2, and V3 are significantly different from each other, as shown in Table 8.

3.5 Calorific Value

The calorific value is the main parameter in determining the quality of briquettes. The calorific value produced in this study ranged from 6,161 to 6,266 cal/gram. The results of the heat test using the IKA © 2000 Bomb Calorimeter are shown in Figure 6.

Figure 6 shows that the highest calorific value produced by V1 is 6,266 cal/gram, while V3 of 6,161 cal/gram has the lowest calorific value. The higher the calorific value, the better the quality of the briquettes (Haryanti *et al.*, 2020). The calorific value is related to the amount of water and ash in the briquettes. The percentage of adhesive given influences the amount of water and ash produced. The higher the adhesive added, the higher the water and ash produced. Thus, the calorific value created is low and vice versa (Sulistyaningkarti and Utami, 2017). In this case, the results of the one-way ANOVA analysis show the P-value >0.05. It can be seen that the composition of coconut shell charcoal and cassava peel waste does not affect the resulting calorific value. Based on these results, a post hoc Tukey analysis is not required.

The minimum standard calorific value of briquettes, according to SNI 01-6235-2000, is 5,000 cal/gram. However, the calorific value of briquettes in V1, V2, and V3, as shown in Figure 6, they have a value of over 5,000 cal/gram. The highest calorific value was shown by V1 of 6,266 cal/gram with the coconut shell and cassava peel adhesive ratio at 75%:25%. This is influenced by the value of water content and ash content. Moreover, the briquettes produced by V1 offer better quality than other variations.

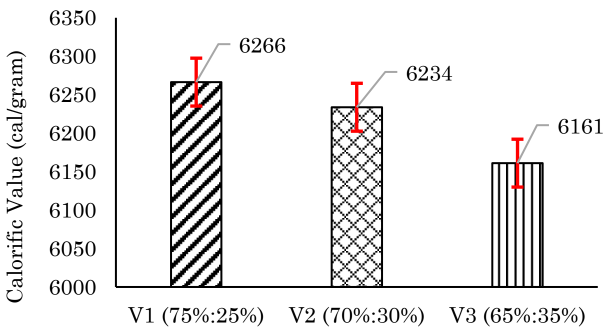

Fig. 6 Calorific value of coconut shell briquettes with cassava peel adhesive

In this study, V1, with a composition of 75% coconut shell and 25% cassava peel adhesive, is the best composition in terms of 4 parameters: density, moisture content, ash content, and calorific value. This is as a result that applying too much adhesive can reduce the briquettes' quality. Therefore the addition of adhesive must be carried out appropriately (Saputra *at. al,* 2021). However, the best result for the combustion rate is sample V2, with a composition of 65%:35%, but this is not very influential because the difference in the combustion rate between V1 and V2 has a slight difference.

4. Conclusion

Based on the research results, it can be seen that the use of coconut shells as raw material for briquettes has an excellent ability to become a renewable energy source in the form of biomass. In this case, the percentage variation of adhesive material such as cassava peel can produce characteristics as fuel for alternative energy sources. It can be seen that the V1 treatment with a ratio of coconut shell with cassava peel adhesive of 75%:25% can produce charcoal briquettes that have better quality than other variations, with a density value of 0.66 gram/cm^3, water content of 5.51%, ash content of 1.50%, combustion rate of 0.026 gram/s and calorific value of 6,266 cal/gram. The one-way ANOVA analysis shows that the composition of coconut shell charcoal and cassava peel waste affects the resulting density, moisture content, ash content, and burning rate. In this case, the heating value is not affected by variations in the composition of the raw materials. However, charcoal briquettes from coconut shell waste and natural adhesives from cassava peel waste are feasible to be used as alternative fuels because of their economic value, easy to obtain, abundantly available, and have complied with SNI 01-6235-2000. Besides, further identification of the starch content in cassava peel, volatile matter content and carbon content in briquettes is required to improve research findings and develop solutions using alternative energy sources with higher quality and more environmentally friendly. This is because the natural adhesive content can reduce the calorific value of briquettes. The addition of adhesive is carried out without a carbonization process, and it is necessary to analyze the value of volatile matter and fixed carbon. Considering their ability to marge, it is important to know the volatile and fixed carbon content. Moreover, if the volatile content is too high and the fixed carbon is too low, it will significantly affect the decrease in the heating value of the briquettes.

Author Contributions: BR; supervision, resources, project administration, IRA; Conceptualization, original draft, ZU; methodology, DAP; formal analysis, MH; writing—review and editing, project administration, BP; supervision, validation, TP: supervision, validation —. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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