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Fabrication of Agricultural Waste-Based Biobriquettes Using Tapioca Starch Adhesive

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Abstract

Background: Energy demand continues to increase along with population growth and human activities, while the availability of fossil energy in Indonesia is becoming increasingly limited. On the other hand, agricultural biomass wastes such as cassava stems, bamboo stems, coconut shells, and corn cobs are abundantly available but have not yet been optimally utilized as alternative energy sources.
Aims: The aim of this research is to to evaluate the effect of combining biomass wastes of cassava stems, bamboo stems, coconut shells, and corn cobs using tapioca starch as a binder on the physical characteristics and energy value of biobriquettes, as well as to assess their conformity with briquette quality standards as an alternative fuel.
Methods: This study produced biobriquettes from cassava stems, bamboo stems, coconut shells, and corn cobs using tapioca starch as a binder with two concentrations (7% and 10%). The biobriquettes were evaluated for physical and energy characteristics, including density, moisture content, compressive strength, shatter resistance index, calorific value, and burning rate, following SNI 01-6235-2000.
Result: Evaluation of biobriquette quality based on SNI 01-6235-2000 shows that all treatments meet the requirements for density, moisture content, and Shatter Resistance Index, indicating good physical quality and mechanical durability. For calorific value, only treatments P2T1, P2T2, P3T1, and P3T2 meet the minimum SNI standard (≥ 5,000 cal/g), while P1T1 and P1T2 do not. Overall, the biobriquettes produced have the potential to comply with SNI 01-6235-2000 as an alternative fuel, although optimization of biomass composition is still needed to improve calorific value.
Conclusion: The combination of cassava stems, bamboo stems, coconut shells, and corn cobs using tapioca starch as a binder was able to produce biobriquettes suitable as an alternative fuel. Treatments P2 and P3, particularly with a 7% binder concentration, met the calorific value requirement of SNI 01-6235-2000, indicating that a lower tapioca binder concentration is more effective and has strong potential for development as a renewable energy source based on biomass waste.

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1. Introduction

Energy demand continues to increase in line with population growth and human activity, while the availability of fossil fuels is increasingly limited (Rezki & Nandyanto, 2022, Sari *et al.,* 2025, Lukma & Yuana, 2025, Haq & Hermana, 2025). In Indonesia, dependence on fuel oil remains relatively high, even though domestic oil production tends to decline year after year. This condition creates a gap between energy production and consumption, which ultimately drives increased imports and increases the burden on the national economy. Based on national energy planning, Indonesia's oil reserves are estimated to be unable to meet long-term needs without the development of more sustainable alternative energy sources (Leni *et al.,* 2018).

Despite these limited fossil fuel resources, the agricultural sector produces another abundant resource: biomass waste. Indonesia, as an agricultural country, has enormous biomass potential. However agricultural waste remains underutilized (Rahmat et al., 2025). Lampung Province is one of the national centers for cassava and corn production. Cassava production reaches 7.37 million tons per year, while corn production reaches 3.18 million tons per year (Lampung Province KPTPH Office, 2023). These activities generate large amounts of waste in the form of cassava stalks and corn cobs, which are generally burned on land or left to degrade naturally. Furthermore, bamboo stalks and coconut shell waste are also commonly found in rural areas and plantations, but their utilization remains limited.

Biomass is an organic material derived from living organisms and is renewable, thus offering potential for development as an alternative energy source to replace fossil fuels (Sinurat, 2011). The carbon and hydrogen content of biomass allows this material to be converted into energy through specific processes. One relatively simple and easy-to-apply form of biomass utilization is biobriquettes (Sidik *et al.,* 2024). Biobriquettes are solid fuels produced through the carbonization and compaction of biomass, resulting in a higher energy density than raw biomass and easier storage and distribution (Asmara *et al.,* 2023).

The quality of biobriquettes is greatly influenced by the type of raw material and the manufacturing process. Factors such as particle size, carbonization temperature, molding pressure, and the type and amount of adhesive determine the physical and energy characteristics of the resulting biobriquettes (Elfiano *et al.,* 2014; Rahmat *et al.,* 2025). Several studies have shown that the use of a single biomass often results in biobriquettes with certain limitations, such as suboptimal calorific value or unstable combustion properties. Therefore, several studies have begun to combine two types of biomass to obtain better characteristics. Ihsan *et al.* (2019) concluded that the combination of coconut shell and bamboo can produce biobriquettes with a higher calorific value than either material alone. Other studies have shown that corncobs with tapioca adhesive can produce a calorific value approaching national quality standards (Saleh *et al.,* 2013), while cassava stems are known to have a relatively high bound carbon content (Rosdiana, 2022).

However, studies on the simultaneous utilization and combination of several types of local biomass waste are still relatively limited. Each type of waste has distinct characteristics. Cassava stems, with their cellulose and bound carbon content, bamboo with its high lignin content, coconut shells with their high calorific value, and corn cobs with their porous structure, have the potential to complement each other when combined appropriately. However, without planned processing, these wastes remain an environmental problem and do not provide significant added value to the community.

Within the context of national policy, the government has encouraged the use of new and renewable energy through the National Energy General Plan (Rencana Umum Energi Nasional/ RUEN), which targets increasing the contribution of renewable energy to the national energy mix. The development of agricultural waste-based biobriquettes aligns with this policy direction and offers a relatively simple, locally resource-based solution with potential for community implementation..

Based on these conditions, the use of cassava stalks, bamboo stalks, coconut shells, and corncobs as raw materials for biobriquettes is interesting to study. This research aims to examine how combining various biomass wastes, using tapioca starch as a binder, can produce biobriquettes with physical and energy characteristics suitable for use as an alternative fuel.

This study is novel in its integrated use of multiple locally abundant agricultural biomass wastes—cassava stalks, bamboo stalks, coconut shells, and corncobs—combined in a single biobriquette formulation using tapioca starch as a binder, to systematically evaluate their synergistic effects on physical and energy characteristics for sustainable community-based *alternative fuel production*. This approach is expected to not only provide a solution to the problem of agricultural waste but also open up opportunities for utilizing local biomass as a more sustainable energy source.

2. Methods

The tools used in this study include saws and cutting machines, combustion drums (Figure 1), blowers, crusher mills, 40-mesh sieves, analytical scales, briquette screw presses, ovens, desiccators, calipers, stopwatches, thermocouples, and laboratory support equipment. The materials used in this study were cassava stem waste (*Manihot esculenta*), bamboo stem waste (*Bambusoideae*), coconut shell waste (*Cocos nucifera*), and corn cob waste (*Zea mays* L) as raw materials for biobriquettes. The adhesive used was tapioca flour with the addition of water. Coal and diesel briquettes were used as comparison materials and supporting materials for the biobriquette process.

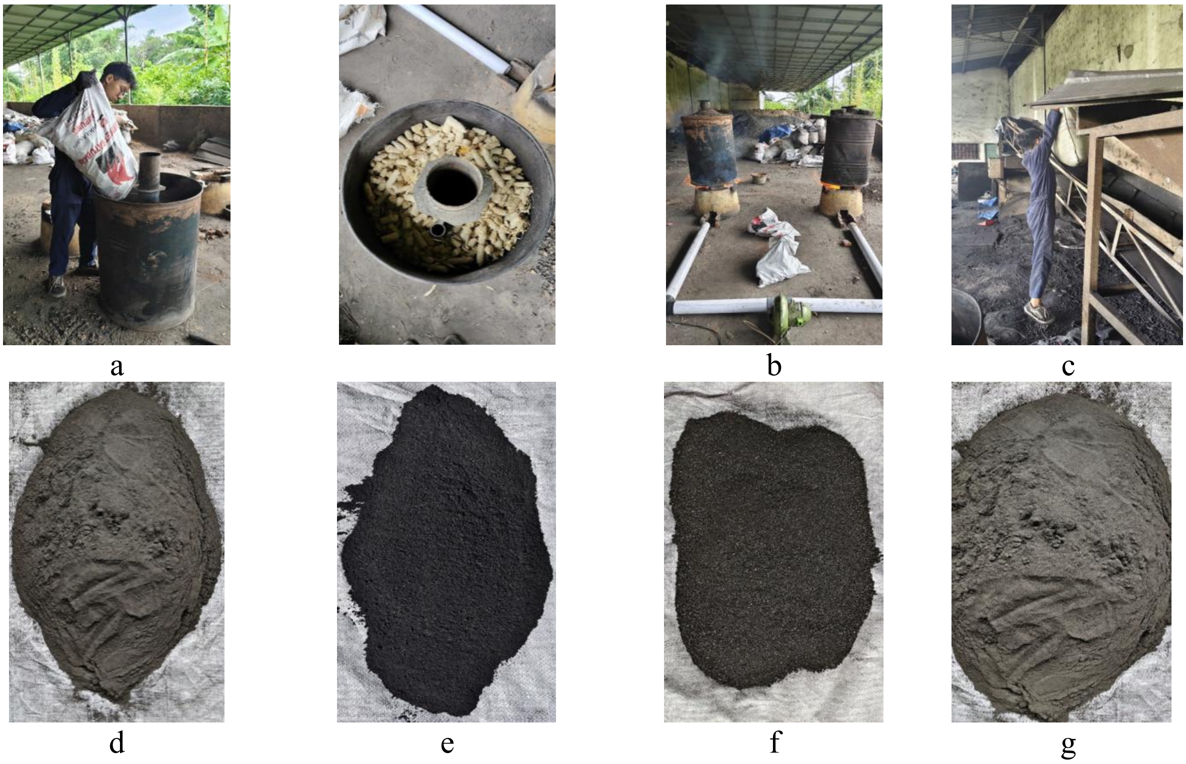

Figure 1. (a) Burning Drum, (b) Material Charcoaling Process, (c) Crusher Mill, and Fine Charcoal from (d) Cassava Stems, (e) Bamboo Stems, (f) Coconut Shells, (g) Corn Cobs

This research was conducted using a laboratory using varying raw material compositions and adhesive concentrations. Treatment variations were designed to evaluate the effect of differences in biomass composition and adhesive content on the characteristics of biobriquettes. The factors studied were biomass raw material composition and tapioca adhesive concentration.

The biomass raw material composition (P) consisted of fine charcoal from cassava stem waste, coconut shells, bamboo stalks, and corn cobs that had been carbonized and sieved using a 40-mesh sieve. The tapioca adhesive concentration (T) was used at two levels. Each treatment combination was replicated three times to obtain more representative data, resulting in a total of 18 experimental samples. The treatment compositions used were:

- P1 = 30% cassava stems: 25% coconut shells: 25% bamboo stems: 20% corn cobs
- P2 = 35% cassava stems: 20% coconut shells: 25% bamboo stems: 20% corn cobs
- P3 = 40% cassava stems: 20% coconut shells: 25% bamboo stems: 15% corn cobs
- T1 = Tapioca adhesive concentration 7%
- T2 = Tapioca adhesive concentration 10%

Biobriquette characteristic testing was conducted to assess the quality of the biobriquettes in accordance with SNI 01-6235-2000 (Kalsum, 2016). The parameters tested included density, water content, compressive strength, shatter resistance index, calorific value, and combustion rate.

1. Density

The density of biobriquettes is determined based on the ratio of mass to volume. The mass of the sample is weighed, while the volume is calculated from the length and diameter of the biobriquettes (Masthura, 2019).

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

Where ρ is the density (g/cm^3), m is the mass (g), and v is the volume calculated using the equation for the volume of a cylinder (cm^3).

2. Moisture Content

The purpose of moisture content testing is to determine the hygroscopic properties of biobriquettes (Triono, 2006). The samples were dried in an oven at 105°C for 24 hours until they reached a constant weight.

$$KA = \frac{wa - wb}{wb}\ x\ 100\%$$

Where KA is the moisture content (%), wa is the weight of the sample before the oven (g), and wb is the weight of the sample after being oven-dried (g).

3. Compressive Strength

Compressive strength shows the ability of biobriquettes to withstand loads without experiencing damage (Ridhuan and Suranto, 2016). The test is carried out by applying a load until the sample cracks or breaks.

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

Where P is the pressure force (N/cm^2), F is the maximum force (N), and A is the surface area (cm^2).

4. Shatter Resistance Index (SRI)

The shatter resistance index describes the resistance of biobriquettes to impact. Testing is carried out by dropping samples from a height of 2 m onto a hard surface..

$$SRI = 100 - \left(\left(\frac{ma-mb}{ma}\right) x\ 100\%\right)$$

Where SRI is the Shatter Resistance Index (%), ma is the initial weight of the briquette (g), and mb is the final weight of the briquette (g).

5. Calorific Value

The calorific value indicates the energy content of biobriquettes (Sudiro, 2014). Testing is carried out using a bomb calorimeter by weighing the sample, placing it in a vessel, filling it with oxygen to a pressure of 3,000 kPa, and then burning it until the calorific value is read on the device.

6. Burning Rate

The combustion rate describes the speed at which the biobriquettes burn until they become ash (Almu *et al.,* 2014). The samples were weighed, ignited, and the combustion time was measured using a stopwatch.

$$LP = \frac{m}{t}$$

Where LP is the combustion rate (g/min), m is the mass (g), and t is the time (min).

3. Results and Discussion

3.1 Appearance of Biobriquettes

The resulting biobriquettes were cylindrical with an average length of 4.21 cm, an average diameter of 4.93 cm, and an average weight of 57.77 g (Figure 2). The deep black color of the biobriquettes indicated that the 14-hour carbonization process had proceeded successfully, indicated by a reduction in volatile components and an increase in bound carbon content. This condition contributed to combustion stability and the potential for increasing the calorific value of the biobriquettes.

Figure 2. Physical appearance of biobriquettes.

Tests after the carbonization process showed variations in yield between materials, with the highest values for corn cobs (41.92%), bamboo stalks (34.28%), coconut shells (30.21%), and cassava stalks (26%). These differences are related to the chemical and structural characteristics of each biomass, particularly its lignocellulose and volatile content. These yield variations indicate that each material responds differently to the carbonization process, so combining biomass with complementary characteristics is crucial in producing biobriquettes with more balanced quality.

3.2 Density of Biobriquettes

The density of biobriquettes is influenced by the uniformity of the particle size of their constituents. More homogeneous particles allow for better interparticle bonding, resulting in higher density and compressive strength (Ruslinda *et al.,* 2017). The results of biobriquette density testing are presented in Figure 3. Based on Figure 3, the highest density was obtained in the P1T1 treatment at 0.81 g/cm^3, while the lowest density was found in the P2T2 treatment at 0.61 g/cm^3. The resulting density values are within the range that still meets the requirements of SNI 01-6235-2000, which requires a charcoal briquette density of between 0.5–1.0 g/cm^3.

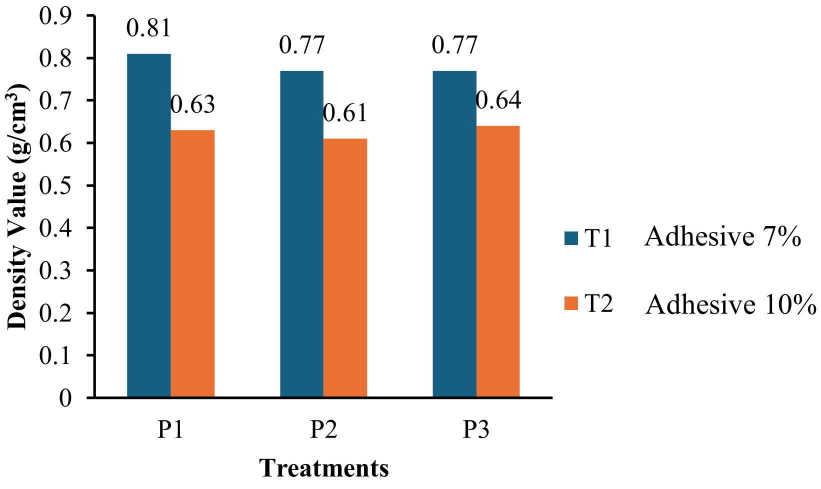

Figure 3. Density of Biobriquettes

The difference in density values is thought to be related to variations in particle size and the briquette molding process. Wahida (2021) stated that less uniform particle size can result in suboptimal interparticle bonding, thus reducing briquette density. Furthermore, the use of a manual molding tool in this study resulted in uneven molding pressure, resulting in the formation of cavities in the briquette structure. Basuki (2020) also reported that larger charcoal powder sizes tend to result in lower densities because the particles are less likely to bond tightly together.

3.3 Moisture Content of Biobriquettes

Moisture content significantly influences the quality of the briquettes produced; the lower the moisture content, the higher the calorific value. A graph of the average moisture content of biobriquettes can be seen in Figure 3. The moisture content of biobriquettes in all treatment combinations shows a relatively low value. This is related to the effective 10-day drying process, allowing the water in the briquettes to evaporate optimally. The lowest moisture content was obtained in the P1T1 treatment combination at 3.37%, while the highest moisture content was found in the P3T1 combination at 4.99%. All of these values are below the maximum moisture content limit stipulated in the Indonesian National Standard SNI 01-6235-2000 concerning Wood Charcoal Briquettes, which is 8%, so the resulting biobriquettes have met the quality requirements in terms of moisture content.

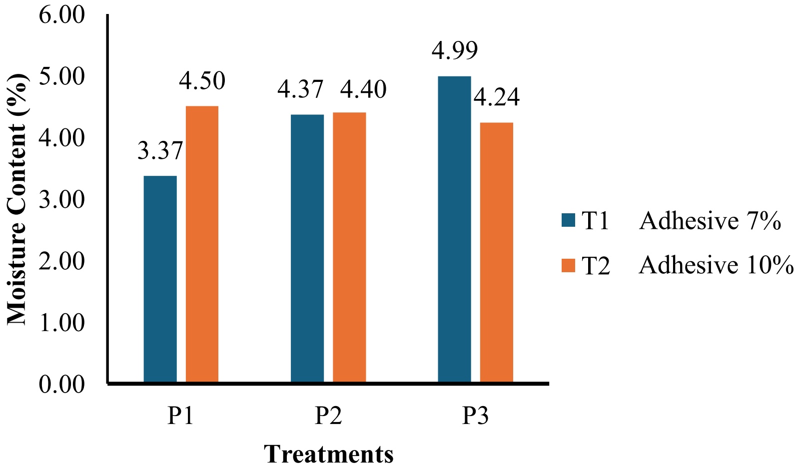

Figure 4. Comparison of water content between treatments

The conformity of the water content to SNI standards indicates that the resulting biobriquettes have good combustion characteristics. According to Rahman (2011) and Hutasoit (2012), a low water content will facilitate the ignition process, increase combustion efficiency, and reduce smoke formation. Feta *et al.* (2018) also stated that a low water content has a positive effect on the combustion rate and calorific value of the briquettes. The water content of the biobriquettes in this study not only meets SNI standards but also supports more optimal and stable combustion quality.

3.4 Shatter Resistance Index (SRI)

Based on the test results shown in Figure 5, the Shatter Resistance Index (SRI) values for the biobriquettes in all treatments were above 99%. This value is considered very high and has exceeded the minimum limit of biobriquette quality standards according to SNI 01-6235-2000, which is 98%. The uniformity of the SRI values across all treatments indicates that the resulting biobriquettes have a compact structure and good physical quality, making them relatively resistant to impact.

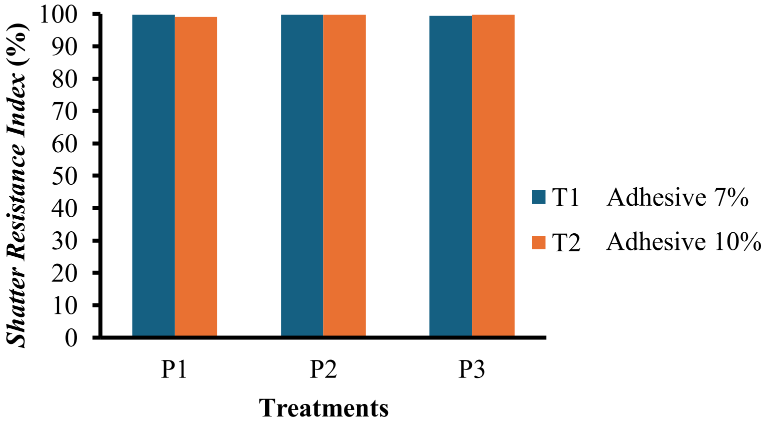

Figure 5. Shatter Resistance Index Value.

Kaliyan and Morey (2009) stated that the water content in the adhesive can act as a lubricant, reducing the coefficient of friction between raw material particles, as well as between the particles and the walls of the molding chamber (screw housing) and the walls of the molding shell (die). This condition can affect the pressure and temperature during the briquette molding process. Tanko et al. (2022) reported that increasing the amount of adhesive tends to produce stronger briquettes and is more resistant to mechanical damage. The briquettes' resistance to impact is reflected in the Shatter Resistance Index value, which according to recommended standards should not be less than 90%. Given the loads and impacts during transportation, distribution, and storage, mechanical durability is an important aspect of solid fuel quality. Based on the SRI value obtained in this study, the resulting biobriquettes are considered to have good durability, making them safe for storage and transportation.

3.5 Compressive Strength of Biobriquette

The compressive strength of briquettes is tested using a pressure tester, gradually applying pressure until the briquettes crack or break, thus determining the maximum load they can withstand. The higher the compressive strength, the better the durability and compactness of the briquettes (Sulaiman *et al.,* 2020). The results of the briquette strength test are shown in Figure 6.

Based on the test results shown in Figure 6, the compressive strength values of the biobriquettes varied with each treatment combination. The lowest value was obtained in the P1T2 treatment at 14.48 kg/cm², while the highest value was found in the P3T1 treatment at 19.60 kg/cm². This difference in compressive strength values indicates that each briquette experienced damage under different loads, as indicated by the appearance of cracks during testing. Lower adhesive concentrations tended to produce higher compressive strength values.

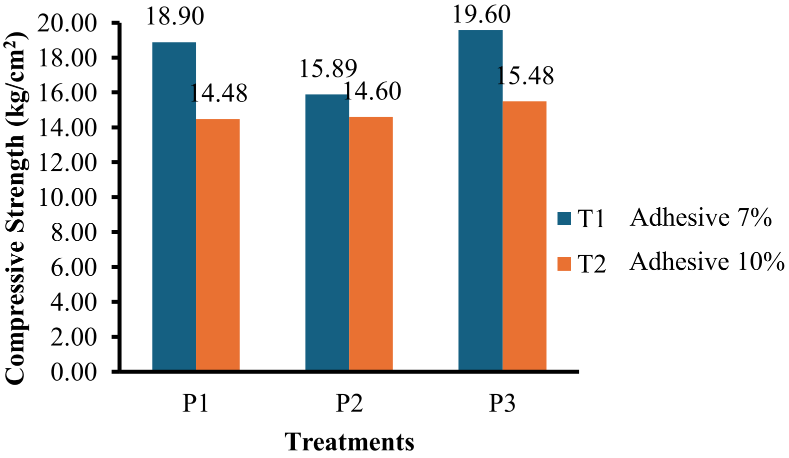

Figure 6. Compressive Strength Value of Biobriquettes

This condition is related to the increased density of the briquettes, so that the bonds between the raw material particles become stronger and more compact. Good bonds between particles play an important role in improving the physical and mechanical properties of briquettes, especially compressive strength (Mani *et al.,* 2004). However, excessively high pressing pressure and density also need to be controlled, because briquettes that are too dense have the potential to be difficult to burn, while briquettes with low density tend to easily decompose during combustion even though they have a fast combustion rate (Sudrajat, 1984).

3.6 Biobriquette Combustion Rate

The burning rate describes how long the briquette's weight decreases per minute during the burning process. The longer the briquette's weight decreases, the lower the burning rate. Conversely, the faster the briquette's weight decreases, the higher the burning rate.

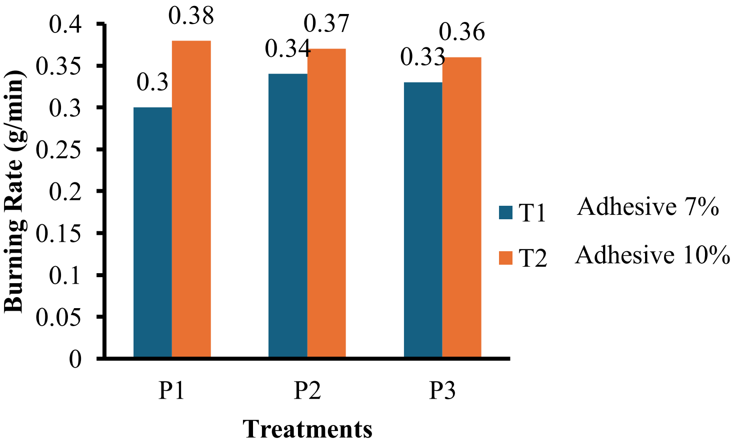

Figure 7. Biobriquette Burning Rate

The test results in Figure 7 show that the briquette combustion rate in this study ranged from 0.30 to 0.38 g/minute. The highest combustion rate was found in the P1T2 treatment combination at ±0.38 g/minute, while the lowest combustion rate was found in the P1T1 treatment at ±0.30 g/minute. Furthermore, the composition of the raw materials also influenced combustion characteristics, with the P3 treatment containing more cassava stem waste showing a higher combustion rate than treatments P1 and P2.

In general, combustion rates tended to increase in briquettes with lower adhesive concentrations. The use of a smaller amount of adhesive decreases the briquette's density, resulting in a more porous structure. This allows oxygen to more easily penetrate the briquette and accelerates the combustion process. Consequently, low-density briquettes burn faster than higher-density briquettes (Desgira, 2020).

3.7 Calorific Value of Biobriquettes

Calorific value is a measure of the amount of heat contained in a fuel and is a primary indicator of its quality. Calorific value significantly determines the quality of briquette charcoal. The higher the calorific value, the better the quality of the resulting briquette charcoal. As a quality parameter, calorific value is a crucial factor in assessing briquettes as a fuel. Therefore, testing the calorific value in briquette production is necessary to determine the amount of heat generated during the combustion process.

The test results, presented in Table 1, show that the calorific value of biobriquettes varies between treatment combinations. The highest calorific value was obtained in the P2T2 treatment at 6,283.59 cal/g, followed by P3T1 at 6,254.20 cal/g. Meanwhile, the lowest calorific value was found in the P1T2 treatment at 4,343.46 cal/g. In general, biobriquettes with a tapioca adhesive concentration of 7% (T1) tend to produce higher calorific value compared to a 10% adhesive concentration (T2) in various variations of raw material composition.

Table 1. Calorific Value of Biobriquettes

Treatment	Calorific Value (cal/g)
P1T1	4591.82
P1T2	4343.46
P2T1	6266.18
P2T2	6283.59
P3T1	6254.20
P3T2	6143.03

According to Tirono and Sabit (2011), the carbonization process, which takes place at a temperature of 300-500 °C, can produce charcoal with a high carbon content. At this temperature, volatile compounds are released in the form of smoke, while the remaining solid residue is predominantly carbon. Because carbon does not combust in the absence of oxygen, increasing the carbonization temperature generally increases the bound carbon content, which in turn contributes to an increase in the calorific value of the biobriquettes. Furthermore, differences in calorific value can also be influenced by the uneven distribution of heat in the carbonization drum, resulting in each raw material receiving different amounts of heat during the carbonization process.

Based on the quality standards for charcoal briquettes according to SNI 01-6235-2000, the minimum required calorific value is $\geq$ 5,000 cal/g. Referring to the results of this study, biobriquettes in treatments P1T1 and P1T2 did not meet these requirements, while other treatments met the specified calorific value standards. This indicates that the composition of raw materials and the concentration of adhesive play an important role in determining the quality of energy produced by biobriquettes.

3.8 Comparison of Research Results with SNI 01-6235-2000

The biobriquette quality evaluation in this study refers to SNI 01-6235-2000 concerning Wood Charcoal Briquettes, which includes parameters such as density, moisture content, impact resistance (Shatter Resistance Index), and calorific value. The comparison results indicate that most of the physical and mechanical characteristics of the biobriquettes meet the requirements of SNI 01-6235-2000 (Table 2).

Table 2. Comparison of Biobriquettes with SNI 01-6235-2000

Parameter	SNI 01-6235-2000	Biobriquettes Research Results	Kesesuaian
Density (g/cm^3)	0.5-1	0.61-0.81	matching
Moisture content (%)	Max. 8	3.37-4.99	matching
Shatter Resistance Index (%)	Min.98	>99	matching
compressive strength (kg/cm^2)	-	14.48-19.60	-
Calorific value (cal/g)	Min. 5000	4343-6284	matching (P2T1,P2T2,P3T1,P3T2)

The density of the biobriquettes ranged from 0.61 to 0.81 g/cm^3, ensuring that all treatments met the Indonesian National Standard (SNI) requirements (0.5 to 1.0 g/cm^3). The moisture content of the biobriquettes ranged from 3.37 to 4.99%, well below the SNI maximum limit of 8%, indicating good ignition potential and more stable combustion. Furthermore, the Shatter Resistance Index (SRI) values for all treatments were above 99%, exceeding the SNI minimum limit of 98%, indicating that the biobriquettes had excellent mechanical resistance during handling and distribution.

In terms of calorific value, variations were still found between treatments. Treatments P2T1, P2T2, P3T1, and P3T2 produced calorific values above 5,000 cal/g, thus meeting SNI standards, while treatments P1T1 and P1T2 did not meet these requirements. This indicates that the composition of raw materials and the concentration of adhesive significantly influence the energy quality of biobriquettes. In general, the resulting biobriquettes have the potential to meet SNI 01-6235-2000 standards, with the caveat that optimization of the material composition is necessary to ensure all products meet the calorific value standard.

4. Conclusion

Based on the research results, the combination of biomass waste in the form of cassava stems, bamboo stems, coconut shells, and corn cobs with tapioca starch adhesive is able to produce biobriquettes with energy characteristics that are suitable as an alternative fuel. Treatment with the composition of P2 and P3 materials, especially at a glue concentration of 7%, shows a calorific value that meets the SNI 01-6235-2000 standard (≥ 5,000 cal/g), while increasing the glue concentration to 10% tends to decrease the calorific value. Thus, the use of tapioca adhesive at low concentrations is more effective in producing biobriquettes that comply with national quality standards and have the potential to be developed as a renewable energy source based on biomass waste.

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