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# Utilization of Cassava Peel Waste for Biobriquette Production through Coconut Shell Charcoal Addition to Enhance Waste-to-Energy Potential

Gema Fitriyano[1], Yustinah[2,*], Ummul Habibah Hasyim[1], Tri Yuni Hendrawati[2], Irfan Purnawan[1], Norazwina Zainol[3], Rozaimi Abu Samah[3], Aisyah Rachma Hayati[1], Annisa Mutiara Sani[1]

[1] Chemical Engineering Department, Engineering Faculty , Universitas Muhammadiyah Jakarta, 10510, Jakarta, Indonesia

[2] Chemical Engineering Department, Engineering Faculty, Universitas Muhammadiyah Jakarta, 10510, Jakarta, Indonesia

[3] Faculty of Chemical & Process Engineering Technology, Universiti Malaysia Pahang AlSultan Abdullah, Lebuh Persiaran Tun Khalil Yaakob, 26300 Kuantan, Pahang, Malaysia

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**ABSTRACT**

Indonesia's growing demand for renewable energy highlights the need for practical biomass-based solutions to support the national target of achieving a 23% renewable energy share by 2025. Cassava peel waste is an abundant agricultural residue that remains underutilized despite its potential as a solid biofuel precursor. However, limited studies have systematically evaluated cassava peel charcoal as a dominant feedstock component across an extended composition range while assessing compliance with national quality standards. This study investigates the production of biobriquettes from cassava peel charcoal blended with coconut shell charcoal at five composition ratios to evaluate moisture content, ash content, volatile matter, fixed carbon, and calorific value based on Indonesian National Standard (SNI) parameters. A comparative trend analysis between lower and higher cassava peel compositions revealed observable differences in calorific value, moisture content, and ash content, whereas variations in volatile matter and fixed carbon were less pronounced within the tested range. The 50:50 cassava peel charcoal–coconut shell charcoal ratio exhibited the most balanced physicochemical profile, characterized by the highest calorific value among the evaluated formulations within the investigated composition range. These findings demonstrate the technical potential of cassava peel charcoal as a major feedstock component under laboratory-scale conditions and contribute to expanding agricultural residue utilization for renewable energy utilization within a waste-to-energy context.

## 1. Introduction

Indonesia has set a national target to achieve a 23% share of renewable energy in its primary energy mix by 2025. However, as of 2022, the actual contribution of renewables remained below 10%, indicating a substantial gap between policy goals and implementation. Bridging this gap requires practical and applicable research, particularly in the development of alternative renewable

* *Corresponding author.*
*E-mail address: yustinah@umj.ac.id*

energy sources derived from biomass. [1].

One such potential biomass source is cassava peel waste, which has been widely studied at the laboratory and fundamental research level but remains underutilized in real-world energy applications [2]. As the world's fifth-largest cassava producer, Indonesia generates a substantial amount of cassava peel waste that can be converted into solid biofuels such as biobriquettes [3], [4]. However, to meet the Indonesian National Standard SNI requirements for biobriquette quality, particularly in terms of calorific value, moisture content, ash content, and volatile matter, cassava peel charcoal (CP) often requires blending with a higher carbon biomass component to achieve balanced fuel properties [5].

Coconut shell charcoal (CSC), a widely available and well-established biomass resource in Indonesia, offers favorable characteristics that can enhance the fuel properties of cassava peel-based biobriquettes. Therefore, combining CP with CSC presents a promising strategy to improve fuel characteristics while maintaining compliance with SNI quality parameters. This approach also supports broader efforts to increase the contribution of renewable energy resources derived from agricultural residues [6].

Previous studies have demonstrated that CSC can improve the fuel characteristics of mixed biobriquettes [7]. However, in most cases, cassava peel charcoal was treated only as a minor additive rather than being systematically evaluated as a dominant feedstock component [8], [9]. In addition, some studies focused on binder variation, where increasing binder proportion was reported to reduce calorific value and overall briquette quality [10]. Despite these findings, limited research has systematically examined cassava peel charcoal across an extended composition range while assessing its compliance with national quality standards. This limitation indicates a clear research gap regarding the technical feasibility of maximizing CP utilization in mixed biobriquettes.

The novelty of this research lies in evaluating a broader composition range of CP and CSC mixtures, extending from 50:50 up to 0:100, to identify the formulation that provides a balanced combination of fuel properties while maintaining compliance with Indonesian National Standards (SNI). Unlike previous studies that did not fully explore the dominant utilization of cassava peel charcoal [11], this study systematically analyzes key fuel parameters including calorific value, moisture content, ash content, volatile matter, and fixed carbon to determine the formulation that provides the optimal balance of physicochemical properties within the investigated composition range. [12].

By adopting this approach, the present work aims to systematically evaluate the influence of CP and CSC composition on key fuel characteristics under laboratory scale conditions based on SNI parameters. The findings are expected to strengthen the technical basis for utilizing cassava peel charcoal as a major feedstock component and to support the sustainable development of agricultural waste based bioenergy in Indonesia.

## 2. Methodology

This study adopted an experimental approach to investigate the utilization of cassava peel waste for biobriquette production with the addition of CSC. The experimental work was conducted under laboratory scale conditions. For statistical evaluation, the experimental data were classified into low and high CP groups to assess the effect of material composition on biobriquette performance. The methodological details are presented in the following subsections.

### *2.1 Materials*

The materials used in this study included CSC procured from local market vendors, cassava peels collected as waste from traditional market cassava traders, and commercially available tapioca flour (brand “Pak Tani”). Tap water was used as both the washing agent and solvent.

### *2.2 Experimental Equipment*

The equipment used included a muffle furnace (Nabertherm) for carbonization and ash content analysis, an oven (Memmert) for drying. Laboratory glassware, such as beakers, measuring cylinders, and spatulas, was also utilized. Additional analytical instruments included a bomb calorimeter (LECO AC 600) for calorific value determination.

### *2.3 Bio-briquette production procedure*

The preparation process began with washing the cassava peels thoroughly to remove residual contaminants, followed by sun-drying for approximately one day until the desired moisture content for carbonization was reached. The dried peels were subsequently carbonized in a controlled furnace environment at about 400 °C for one hour [13], [14]. After cooling, the obtained charcoal was milled and sieved to ensure uniform particle size.

To prepare the briquettes, the powdered charcoal was combined with a natural binder made of tapioca starch and hot water. The mixture was stirred thoroughly until a uniform, dough-like consistency was formed [15]–[18]. The resulting blend was manually shaped into cubic briquettes using a hand-operated mold with dimensions of 2.5 cm × 2.5 cm × 2.5 cm [19]. The formed briquettes were then air-dried for 24 hours prior to physicochemical characterization.

In this experiment, the binder composition was maintained as a constant variable, consisting of 9% tapioca starch by mass dissolved in 20 mL of hot water [20], [21]. The independent variable was the blending ratio between CSC and CP, which was varied at proportions of 50:50, 40:60, 30:70, 20:80, 10:90, and 0:100 (w/w).

### *2.4 Characterization and Analytical Methods*

The characterization of the biobriquette samples was conducted in accordance with standardized testing procedures based on the Indonesian National Standard (SNI) guidelines. The evaluated parameters included calorific value, ash content, moisture content, volatile matter, and fixed carbon. The calorific value was determined using a bomb calorimeter following SNI 01-6235-2000. Approximately 1 g of the oven-dried sample was combusted in an oxygen-charged chamber, and the resulting temperature increase was used to calculate the energy content, reported in MJ/kg.

The ash content was measured according to SNI 01-7047-2004 by incinerating the sample in a muffle furnace at 600 ± 25 °C until a constant mass was achieved. The remaining residue was expressed as a percentage of the initial dry mass [22]. The moisture content was determined following SNI 01-6234-2000 by drying the sample in an oven at 105 ± 2 °C for 24 hours or until a constant mass was reached, with the mass loss expressed as a percentage of the initial mass.

The volatile matter was analyzed in accordance with SNI 01-7046-2004 by heating the oven-dried sample in a covered crucible at 950 ± 20 °C for 7 minutes under an inert (air-limited) atmosphere, and calculating the mass loss (excluding moisture) as a percentage. Finally, the fixed carbon content was obtained by difference, subtracting the combined percentages of moisture, volatile matter, and

ash from 100%, as defined by the standard proximate analysis procedure [23].

### *2.5 Statistical Data Analysis*

The experimental data were analyzed using an independent two-sample t-test to compare selected physicochemical properties of biobriquettes across different ranges of CP content. The biobriquettes were prepared with CP proportions ranging from 100 to 50 wt%, corresponding to CSC additions of 0 to 50 wt%.

For statistical evaluation, the six formulations were grouped into two composition intervals representing lower and higher CP content levels. The low-CP group included formulations containing 50, 60, and 70 wt% CP, while the high-CP group comprised 80, 90, and 100 wt% CP. This grouping strategy was applied to examine general differences between broader CP composition ranges rather than to determine statistical differences at each individual formulation level. The classification of formulations used in the statistical comparison is presented in Table 1 to ensure clarity of the grouping structure.

**Table 1**
Grouping of CP:CSC composition ratios for independent two-sample t-test analysis

| No | Statistical Group | CP:CSC Content (wt%) |
|---|---|---|
| 1 | Low CP | 50:50, 60:40, 70:30 |
| 2 | High CP | 80:20, 90:10, 100:0 |

Each formulation was tested once, and the resulting values within each composition interval were used for group-level comparison. The results are presented as mean values and standard deviations calculated across the formulations within each interval. Statistical significance was evaluated at a 95% confidence level ($\alpha = 0.05$) [24]. All analyses were conducted using IBM SPSS Statistics (version 25).

## 3. Results and Discussion

The quality characteristics of biobriquettes are generally evaluated based on a set of technical parameters defined by national standards. In this study, the primary standards used is Indonesia's national standard, SNI 01-6235-2000, for charcoal briquettes. This standard provides benchmark values for critical parameters such as minimum calorific value, maximum moisture content, ash content, and density. Table 2 presents a comparative summary of the threshold values established by this standard, which serve as the basis for evaluating the performance of the biobriquettes produced in this study.

**Table 2**
Biobriquette quality standards based on SNI specifications

| No | Parameter (unit) | Value |
|---|---|---|
| 1 | Calorific value (cal/g) | Min. 5000 |
| 2 | Moisture content (%) | Max. 8 |
| 3 | Volatile matter (%) | Max 15 |
| 4 | Ash content (%) | Max. 8 |
| 5 | Fixed carbon (%) | Min. 65 |

### *3.1 Calorific value*

The calorific value serves as a key indicator of briquette quality. In this study, the obtained calorific values ranged between 5573 and 6240 cal/g. The results of the heat measurement using a LECO AC 600 Bomb Calorimeter are presented in Figure 1.

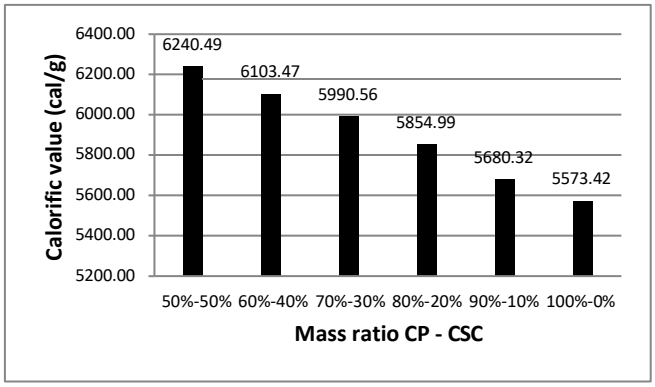



**Fig. 1.** Calorific value of biobriquettes at various mixing ratios of CP and CSC

According to SNI 01-6235-2000, the minimum standard calorific value for briquettes must be met to ensure fuel quality. The highest calorific value, 6240.49 cal/g, was obtained from the briquette with a 50:50 ratio of CSC to CP, representing the highest value among the tested compositions.

The calorific value of the bio-briquettes produced from CP and CSC mixtures exhibited a consistent downward trend as the CP proportion increased. The decrease in calorific value suggests that higher CP content reduces the overall fixed carbon content and heating value of the briquettes [25], [26]. This behavior is attributed to the lower carbonization efficiency and higher volatile matter of CP compared to CSC, which consequently diminishes the amount of heat released per unit mass [27].

### *3.2 Moisture content*

Moisture content is a critical parameter influencing the thermal properties and overall quality of bio-briquettes [28]. A lower moisture content generally enhances ignition efficiency, thermal stability, and heat release, while excessive moisture can reduce the calorific value and hinder effective heat transfer during utilization [29], [30]. In this study, the moisture content of bio-briquettes produced from mixtures of CP and CSC was analyzed to evaluate the effect of raw material

composition on water retention capacity. The comparison between different mixing ratios is presented in Figure 2, illustrating the variation in moisture content as the proportion of CP changes.

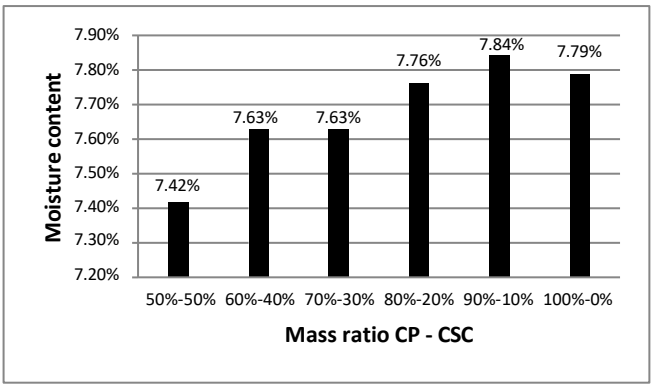



**Fig. 2.** Moisture content of biobriquettes at various mixing ratios of CP and CSC

The moisture content of the bio-briquettes showed a slight increasing trend with the higher proportion of CP in the mixture. The values ranged narrowly between 7.42% and 7.84%. The lowest moisture content was observed at the 50:50 ratio of CSC and CP, while a gradual increase occurred as the CP proportion increased up to 90:10, followed by a slight decrease at 100:0. This trend suggests that CP tends to retain more moisture than CSC due to its higher porosity and hygroscopic nature. Consequently, increasing the CP fraction may slightly elevate the water-holding capacity of the briquettes, which can influence their drying behavior and overall thermal characteristics.

*3.3 Volatile matter*

Volatile matter refers to the portion of gaseous compounds released when bio-briquettes are heated in the absence of oxygen, primarily consisting of light hydrocarbons, carbon monoxide, carbon dioxide, and other organic vapors. This parameter plays a crucial role in determining the thermal decomposition behavior and reactivity during heating of solid fuels. A high volatile matter content can promote rapid release of gaseous compounds during heating, which may influence the overall thermal stability and calorific performance of the material [31]. In this study, the volatile matter content of bio-briquettes produced from different mixing ratios of CP and CSC was analyzed to assess the influence of raw material composition on the release of volatile compounds [32]. The comparison of volatile matter across compositions is presented in Figure 3.

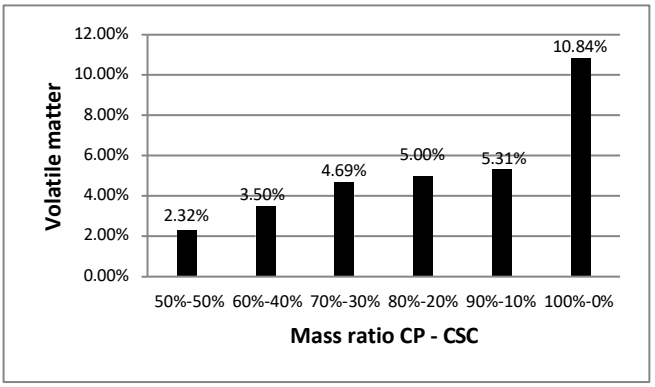



**Fig. 3.** Volatile matter of biobriquettes at various mixing ratios of CP and CSC

The volatile matter content of the bio-briquettes showed a clear increasing trend with higher proportions of CP in the mixture. The values ranged from 2.32% to 10.82%, indicating a progressive rise in volatile compounds as the CP fraction increased. The lowest volatile matter was observed at the 50:50 ratio, while a sharp increase occurred when CP became the dominant component at the 100:0 ratio.

This pattern suggests that CP contains a higher amount of thermally unstable organic compounds compared to CSC. The increase in volatile matter with higher CP content may lead to easier ignition but could also cause more smoke and lower heating value [33]. These findings imply that optimizing the blend ratio is important to achieving balanced physicochemical properties in bio-briquette production.

### *3.4 Ash content*

Ash content represents the inorganic residue remaining after the thermal degradation process under controlled conditions and serves as an important indicator of fuel purity and overall material quality. A lower ash content is generally desirable, as it supports higher calorific value and reduces residual solid fraction after thermal use [34]. Conversely, a higher ash content can lead to operational challenges such as clinker formation and reduced heat transfer efficiency [35]. In this study, the ash content of bio-briquettes made from various mixing ratios of CP and CSC was evaluated to determine the effect of raw material composition on the inorganic fraction of the fuel. The comparison of ash content at different mass ratios is illustrated in Figure 4.

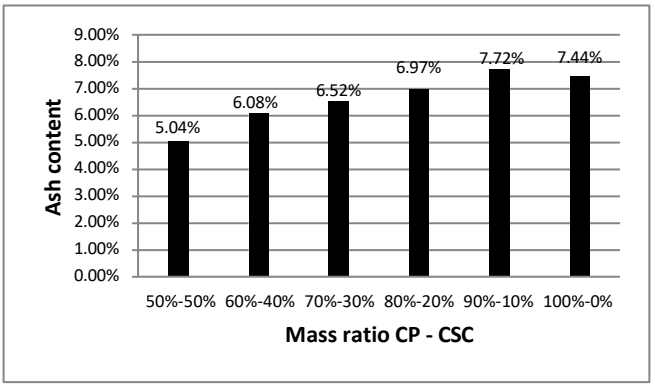



**Fig. 4.** Ash content of biobriquettes at various mixing ratios of CP and CSC

The ash content of the biobriquettes exhibited an increasing trend as the proportion of CP in the mixture increased. The values ranged from 5.04% to 7.72%, indicating a gradual rise in inorganic residue along with higher CP content. The lowest ash content was recorded at the 50:50 ratio, while the highest was observed at the 90:10 composition, followed by a slight decrease at 100:0. This trend suggests that CP contains more mineral and non-volatile components compared to CSC. The higher ash content associated with CP may result from its inorganic compound concentrations. Consequently, increasing the CP fraction may contribute to a higher residual mineral fraction after thermal processing, which should be considered when optimizing raw material composition for balanced physicochemical properties of biobriquettes.

### *3.5 Fixed carbon*

Fixed carbon represents the solid carbonaceous residue remaining after the release of volatile matter during the thermal decomposition process of bio-briquettes. It contributes significantly to the calorific value and reflects the proportion of stable carbon retained in the materia [36]. A higher fixed carbon content is generally associated with increased carbon retention and improved thermal characteristics of the solid fuel [37], [38]. In this study, the fixed carbon content of biobriquettes derived from different mixing ratios of CP and CSC was determined to evaluate the effect of raw material composition on carbon retention. The comparative results of fixed carbon content for each composition are illustrated in Figure 5.

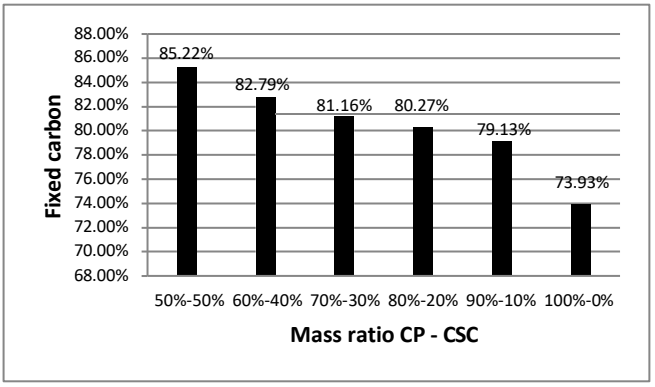



**Fig. 5.** Fixed carbon of biobriquettes at various mixing ratios of CP and CSC

The fixed carbon content of the biobriquettes demonstrated a decreasing trend with increasing proportions of CP in the mixture. The values ranged from 85.22% to 73.93%, indicating a consistent reduction in carbon retention as CP content increased. The highest fixed carbon value was obtained at the 50:50 ratio of CSC and CP, while the lowest was observed at the 100:0 ratio.

This trend reflects the superior carbonization characteristics of CSC, which typically yields higher fixed carbon due to its denser structure and lower volatile matter content [39]. In contrast, CP contains a higher proportion of volatile compounds and inorganic residues, which contributes to a lower fixed carbon content due to the breakdown of organic compounds during the carbonization process [40], [41]. Therefore, increasing the CP fraction tends to lower the fixed carbon and, consequently, the overall energy density of the biobriquettes, emphasizing the need to optimize the raw material composition for better fuel performance.

### *3.6 Statistical analysis*

An evaluation of proximate characteristics and calorific value was conducted for biobriquettes formulated with varying CP contents and corresponding CSC additions. The results, grouped into high and low CP content categories, are summarized in Table 3, with statistical comparisons conducted using an independent two-sample t-test. Overall, the results indicate that variations in CP content significantly influenced several key physicochemical properties, particularly calorific value, moisture content, and ash content.

**Table 3**
Independent two-sample t-test results of biobriquette properties

| No. | Parameter | Group | n | Mean | SD | t-value | p-value |
|---|---|---|---|---|---|---|---|
| 1 | Calorific value (kcal/kg) | High CP | 3 | 5702.91 | 142.13 | -3.74 | 0.020* |
| | | Low CP | 3 | 6111.50 | 125.15 | | |
| 2 | Moisture content (%) | High CP | 3 | 7.79 | 0.04 | 3.21 | 0.03* |
| | | Low CP | 3 | 7.56 | 0.12 | | |
| 3 | Ash content (%) | High CP | 3 | 7.37 | 0.38 | 3.05 | 0.04* |
| | | Low CP | 3 | 5.88 | 0.76 | | |
| 4 | Volatile matter (%) | High CP | 3 | 7.05 | 3.29 | 1.76 | 0.15 |
| | | Low CP | 3 | 3.50 | 1.19 | | |
| 5 | Fixed carbon (%) | High CP | 3 | 77.77 | 3.38 | -2.31 | 0.08 |
| | | Low CP | 3 | 83.06 | 2.04 | | |

Note: *Values are presented as mean ± standard deviation (SD). Independent two-sample t-test (Welch's t-test) was applied. Significant at $p < 0.05$.

Biobriquettes with lower CP proportions, corresponding to higher CSC additions, exhibited significantly higher calorific values, along with lower moisture and ash contents. This trend is consistent with the inherently higher carbon concentration and lower mineral fraction of CSC compared to cassava peel-derived charcoal. In contrast, volatile matter and fixed carbon did not show statistically significant differences between the two CP content groups, suggesting that compositional effects on these parameters were less pronounced within the tested formulation range.

### *3.7 Integrated Discussion, Study Limitations, and Practical Implications*

Taken together, the results demonstrate that controlled substitution between cassava peel (CP) charcoal and coconut shell charcoal (CSC) significantly influences the proximate characteristics and calorific value of the resulting biobriquettes. Variations in ash content, fixed carbon, moisture content, and calorific value collectively indicate that material composition plays a critical role in determining the physicochemical profile of the product. Within the tested formulation range, the 50:50 CP–CSC ratio exhibited a balanced combination of relatively low ash content, high fixed carbon, and favorable calorific value. It should be noted that this selection applies specifically to the investigated composition range and carbonization conditions employed in this study.

These findings support the concept that the incorporation of CSC can enhance selected physicochemical characteristics of cassava peel–based biobriquettes, thereby strengthening the potential utilization of agricultural waste resources within a waste-to-energy framework. Rather than replacing cassava peel entirely, partial substitution enables value addition while maintaining material sustainability considerations.

However, several limitations should be acknowledged. The experimental evaluation was conducted under controlled laboratory-scale conditions with a limited number of formulation levels and without replication at each composition level. The grouping of compositions into high and low CP categories simplifies the compositional gradient and may not fully capture nonlinear interactions between the raw materials. Furthermore, this study focused on physicochemical characterization and calorific evaluation, without including long-term durability testing, large-scale production assessment, or extended operational performance analysis.

From an implementation perspective, the proposed CP–CSC substitution approach presents a potential material formulation strategy for enhancing the material quality of cassava peel–derived biobriquettes. Nevertheless, factors such as raw material logistics, preprocessing requirements, production scalability, and techno-economic feasibility were beyond the scope of this work and require further investigation. Future studies incorporating pilot-scale trials and techno-economic analysis would provide a more comprehensive evaluation of real-world applicability.

## 4. Conclusions

The present study demonstrates that variations in cassava peel (CP) and coconut shell charcoal (CSC) composition significantly influence the proximate characteristics and calorific value of the resulting biobriquettes. Differences were primarily observed in calorific value, moisture content, and ash content across the tested formulation ranges, while variations in volatile matter and fixed carbon were comparatively less pronounced.

Within the investigated composition range and experimental conditions, the biobriquette produced at a 50:50 CP–CSC mass ratio exhibited the most balanced physicochemical profile, with a calorific value of 6240.49 cal/g, moisture content of 7.42%, ash content of 5.04%, and fixed carbon of 85.22%. These values represent the highest calorific value and fixed carbon, alongside the lowest ash content, among the tested formulations, supporting its selection as a representative formulation based on proximate analysis and compliance with SNI quality parameters.

This study contributes to the existing literature by systematically evaluating cassava peel charcoal as a dominant feedstock component across an extended composition range, rather than limiting its role to a minor additive. The findings highlight that controlled CP–CSC substitution can improve key physicochemical characteristics, thereby supporting the technical potential of cassava peel utilization within a waste-to-energy framework under laboratory-scale conditions.

Further investigation is required to assess mechanical durability, emission characteristics, binder optimization, and techno-economic feasibility in order to provide a more comprehensive evaluation of large-scale implementation potential.

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**Conflicts of Interest Statement**
The authors declare that there is no conflict of interest regarding the publication of this paper. No financial support, grants, or other forms of compensation were received that could have influenced the outcomes of this work. The research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Author Contributions Statement

All authors contributed to manuscript revision, read, and approved the final version.

## Data Availability Statement

All data generated or analyzed during this study are included in this published article. Additional datasets are available from the corresponding author upon reasonable request. Where applicable, publicly available datasets used in the study are cited in the references.

## Ethics Statement

This study was conducted in accordance with the ethical standards of the institutional and/or national research committee. Ethical approval was obtained where required, and informed consent was obtained from all participants involved in the research.

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