OPEN ACCESS
Jurnal Ilmiah Ilmu Terapan Universitas Jambi
Vol. 10 No. 1. Ferbruary 2026, pp. 201-220 DOI. [10.22437/jiituj.v10i1.48001](https://doi.org/10.22437/jiituj.v10i1.48001)

Research Article

CHARACTERISTICS OF BIOBRIQUETTE FROM ARECA NUT WASTE AND COCONUT WASTE WITH VARIOUS TYPES AND PROPORTION OF BINDERS

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Article Info
Received: Aug 25, 2025
Revised: Jan 09, 2026
Accepted: Feb 16, 2026
OnlineVersion: Feb 19, 2026

Abstract
Biobriquettes derived from agricultural waste such as coconut shells, coconut husks, and areca husks offer potential as renewable energy sources. This study aimed to evaluate the effect of binder type and proportion on the quality of biobriquettes in accordance with the Indonesian National Standard (SNI). The raw materials consisted of 30% coconut shell charcoal, 30% coconut husk charcoal, and 30% areca husk charcoal, combined with three organic binders: tapioca starch, cornstarch, and hibiscus leaf extract. A completely randomized design (CRD) was applied with variations in binder type and proportion. The briquettes were analyzed for moisture content, ash content, volatile matter, burning rate, density, and calorific value. Data were statistically evaluated using one-way ANOVA followed by Duncan's New Multiple Range Test (DNMRT) at 5% and 1% significance levels. The results showed that binder type and proportion significantly affected calorific value, volatile matter content, burning rate, and density, while moisture and ash content were more influenced by raw material characteristics and carbonization process. The findings indicate that binders not only function as mechanical adhesives but also influence combustion behavior and structural properties. Most quality parameters met international standards, although the calorific value did not fully comply with SNI requirements. The novelty of this study lies in the balanced combination of three biomass charcoals and the simultaneous comparative evaluation of three organic binders within one compositional system. These results support the optimization of binder formulation to enhance performance, so that biobriquettes can be developed as a renewable alternative energy source.

Keywords: Areca Husk, Binder, Biobriquettes, Coconut Husk, Coconut Shell.

INTRODUCTION

Biobriquettes are solid fuels produced from organic residues that have undergone a compaction process under specific pressure. They are carbon-rich, possess relatively high calorific values, burn for extended durations, are environmentally friendly, cleanliness, ease of handling, ease of transportation and compact size (Nazrudin et al., 2011; Budi, 2011; Saleh, 2013; Dinesa et al., 2019; Ossei Bremang et al., 2024). Biobriquettes have been widely applied as alternative fuels for household cooking, electricity generation, space heating, and industrial boilers (Kuti & Adegoke, 2008; Chin & Siddiqui, 2000). The raw materials for biobriquettes may be derived from biomass resources in the forestry, plantation, and agricultural sectors. Among plantation-based biomass, areca nut and coconut residues—such as areca husk, coconut husk, and coconut shell—represent promising feedstocks.

Coconut fiber, coconut shell, and areca nut husk biomass have distinct advantages compared to many other biomass sources, as they possess high lignin and energy contents, strong durability, low carbon emissions during utilization, and a wide range of applications beyond energy production, while also being abundant, renewable, and environmentally friendly resources (Iswara et al., 2024; Osarhiemhen, et al., 2021). Previous studies (Yulia et al., 2021) reported that areca husk, coconut husk, and coconut shell charcoals can be converted into biobriquettes. The production process requires the addition of binders to ensure particle cohesion. The type and concentration of binder substantially influence briquette quality parameters, including ash content, calorific value, and volatile matter (Permatasari et al., 2015; Dewi and Kholik, 2020). Binders may be categorized into organic and inorganic types. Organic binders include starch, asphalt, tar, paraffin, and molasses, whereas inorganic binders include clay, cement, glycerol, and sodium silicate (Raslavičius, 2012; Moeksin, 2014; Helwani et al., 2020). The advantages organic binders is high heating value, widely available, low price, and high mechanical strength (Zhang et al., 2018). The type of binder and the proportion used influence the physicochemical characteristics of bio-briquettes (Okot, 2019), as well as their mechanical strength, thermal stability, combustion performance, and production cost (Ige et al., 2018). The selection of a binder from the available types is mainly influenced by several considerations, such as the required binding strength, low emission levels, its impact on briquette combustion performance, environmental friendliness, sustainability, and economic availability (Kumar et al., 2021)

Commonly used binders in biobriquette production include tapioca starch, cornstarch, and hibiscus leaf extract. Shobar et al. (2020) demonstrated that a combination of 5% tapioca and 5% sago binder yielded briquettes with ash content, volatile matter, and fixed carbon meeting the Indonesian National Standard (SNI) for areca husk briquettes. Cholilie and Zuari (2021) further reported that tapioca binder provided the slowest combustion rate (0.116 g/min), compared with cornstarch (0.147 g/min) and sago (0.135 g/min). In addition to these binders, hibiscus leaf extract has also been employed effectively. Dwisaputra (2016) found that 20% hibiscus leaf adhesive was the most suitable composition for briquettes made from coconut and areca midribs, while Efendi (2020) confirmed that the use of hibiscus leaf adhesive at 20–30% for coconut shell briquettes also complied with SNI requirements.

Biobriquette research generally still focuses on one or two combinations of biomass and a single type of binder without a comprehensive comparative assessment and has not fully adopted the Indonesian National Standard (SNI). Meanwhile, areca nut and coconut wastes are abundantly available and can be utilized in an integrated manner as mixed raw materials for biobriquette production. This research gap lies in the limited analysis of the effects of variations in binder types and proportions on the physical and thermal characteristics of biobriquettes derived from the combination of these two wastes. Therefore, the objective of this study is to analyze the effect and evaluate the quality of biobriquettes produced with various types and proportion of binders in accordance with the Indonesian National Standard (SNI). The utilization of areca nut and coconut residues for biobriquette production is expected to enhance both the added value and the economic potential of these plantation by-products and support the development of sustainable and economically viable solid biofuels. The novelty of this research lies in the integrated utilization of multiple plantation by-products and the comparative assessment of binder performance on the physical and thermal properties of biobriquettes.

RESEARCH METHOD

The study will be carried out at the Processing Laboratory, Department of Agricultural Technology, Faculty of Agriculture, Jambi University (Pondok Meja Campus), and at the Integrated Laboratory, Jambi University. The experimental work is scheduled from June to November 2024. The equipment used in this study includes an analytical digital balance, knife, spoon, crucible tongs, rubber gloves, plastic containers, a 60-mesh sieve, a briquette mold, a carbonization furnace, a grinding machine, an oven, baking trays, and instruments for biobriquette quality analysis. The raw materials consist of areca nut husk, coconut husk, and coconut shell, while the binding agents include tapioca starch, cornstarch, and hibiscus leaf extract. Additional materials used are distilled water and ethanol (spiritus).

Considering availability, maturity level, and uniformity, the raw materials (areca nut husk, coconut husk, and coconut shell) were obtained through purposive sampling from Pengabuan District, Tanjung Jabung Barat Regency. This study employed a Completely Randomized Design (CRD) with treatments based on different types and concentrations of binders. Three types of binders were used: tapioca starch, cornstarch, and hibiscus leaf extract. Each treatment was replicated three times, resulting in a total of 36 experimental units.

The treatments were as follows:

Tapioca starch

T1 = 8% tapioca starch
T2 = 10% tapioca starch
T3 = 12% tapioca starch
T4 = 14% tapioca starch

Cornstarch

M5 = 8% cornstarch
M6 = 10% cornstarch
M7 = 12% cornstarch
M8 = 14% cornstarch

Hibiscus leaf extract

D9 = 20% hibiscus leaf extract
D10 = 25% hibiscus leaf extract
D11 = 30% hibiscus leaf extract
D12 = 35% hibiscus leaf extract

Research Procedure

The sample preparation stages in this study were carried out as follows:

Cleaning Process

The raw materials used consisted of areca nut husk, obtained from the processing of dried areca nut seeds with the criterion that the husk had turned yellow, as well as coconut husk and shell derived from mature coconuts. All raw materials were collected from Pengabuan District, Tanjung Jabung Barat Regency. Prior to further processing, the coconut husk and shell were sorted to separate any parts that were still attached to each other.

Drying of Raw Materials

The raw materials were sun-dried for 2–3 days until a moisture content of approximately 15% was achieved, in order to facilitate the subsequent carbonization process.

Carbonization

Carbonization was performed separately for areca nut husk, coconut husk, and coconut shell that had been dried. The process was carried out using a cylindrical carbonization furnace made of steel plate, with a height of 1 m and a diameter of 60 cm. Gas fuel was used as the heat source. The materials were arranged to leave sufficient gaps, ensuring even combustion. The process was considered complete when the smoke emission began to diminish. The resulting charcoal was cooled for 30–60 minutes. The carbonization process lasted for approximately 2–3 hours, depending on the quantity of raw material.

Grinding and Sieving

The carbonized materials were ground separately using a grinding machine. The resulting charcoal powder was then sieved using a 60-mesh sieve.

Binder Mixing

The charcoal powder from areca nut husk, coconut husk, and coconut shell was weighed in a ratio of 30:30:30, with a total mass of 30 g. The 30 g of charcoal powder was then mixed with a binder according to the treatment, based on the total weight of the charcoal powder. For tapioca and cornstarch binders, the starch was mixed with water at a ratio of 1:10, then heated while being stirred to form a paste. For the hibiscus leaf binder, the leaves were prepared according to the treatment, mixed with water equivalent to 10% of their weight, and blended until smooth.

Molding

The mixture of charcoal powder and binder was weighed and placed into a square mold measuring 4 cm × 4 cm × 4 cm. It was compacted using a hydraulic press with 8–10 strokes and left in the mold for approximately 5 minutes to ensure proper adhesion of the particles. After 5 minutes, the briquettes were removed from the mold and allowed to air-dry to solidify the binder.

Drying

The molded briquettes were dried in an oven at 110 °C for 2–3 hours. After drying, the briquettes were stored in an airtight container.

Parameters Observed and Data collection

To evaluate the quality of the produced biobriquettes, several physicochemical parameters were measured, namely moisture content, ash content, volatile matter content, burning rate, density, and calorific value. All tests were conducted in reference to established standards for solid fuel characterization, primarily ASTM methods. Data were collected through direct laboratory measurement using standardized instruments and ASTM procedures.

Moisture Content Test (ASTM D 5142-02)

Moisture content was determined by weighing approximately 1 g of sample into a crucible, followed by heating at 100 °C for 1 h. The crucible was cooled in a desiccator and reweighed. The percentage of moisture was calculated as:

$$B\ (\%) = \frac{(b2)-(b3)}{(b2)-(b1)}\ X\ 100\ \% \qquad \ldots\ldots\ (1)$$

Where:
B = Moisture content (%)
b1 = Weight of empty crucible (g)
b2 = Weight of crucible + sample before heating (g)
b3 = Weight of crucible + sample after heating (g)

Ash Content Test (ASTM D 5142-02)

Approximately 1 g of sample was placed in a crucible and heated in a muffle furnace. The temperature was gradually increased from ambient to 800 °C and maintained for 3 h. The crucible was cooled in a desiccator and reweighed. The percentage of ash content was calculated as:

$$AC\ (\%) = \frac{(m3)-(m1)}{(m2)-(m1)}\ X\ 100\ \% \qquad \ldots\ldots\ (2)$$

Where:
AC = Ash content (%)
m1 = Weight of empty crucible (g)
m2 = Weight of crucible + sample before heating (g)
m3 = Weight of crucible + sample after heating (g)

Volatile Matter Content Test (ASTM D 5142-02)

A 1 g sample was placed in a covered crucible and heated at 950 °C for 7 min. The crucible was cooled in a desiccator and weighed. The percentage of volatile matter was determined as:

$$VM\ (\%) = (\frac{(b2)-(b3)}{(b2)-(b1)}\ X\ 100\ \% \qquad \ldots\ldots\ (3)$$

Where:
VM = Volatile matter content (%)
b1 = Weight of empty crucible (g)
b2 = Weight of crucible + sample before heating (g)
b3 = Weight of crucible + sample after heating (g)

Burning Rate Test

The biobriquette sample was weighed and burned in a furnace. The burning time was recorded from the moment ignition occurred until the briquette was completely consumed (Ajiboye et al., 2017; Aynharan et al.,2020). The burning rate was calculated using the following formula:

$$LP = \frac{A\ (gr)}{B\ (minutes)} \qquad \ldots\ldots\ (4)$$

Where:
LP = Burning rate (g/min)

A = Initial mass of briquette before combustion (g)
B = Burning time (min)

Density Test (ASTM D 5142-02)

This test was conducted to determine the density of the solid fuel (biobriquette). The briquette was weighed, and its length, width, and height were measured using a caliper. The volume and density of the briquette were calculated using the following formulas:

$$biobriket\ (cm^3) = p \times l \times t \qquad \text{........ (5)}$$

$$Kerapatan\ biobriket (g/cm^3) = \frac{m}{V\ total} \qquad \text{........ (6)}$$

Where:
p = Length of briquette (cm)
l = Width of briquette (cm)
t = Height of briquette (cm)
m = Mass of briquette (g)
Vtotal = Briquette volume (cm^3)

Calorific Value (ASTM D 5865-11a)

The calorific value was determined using a Bomb Calorimeter. The calorific value was calculated using the following equation:

$$Nilai\ Kalor = = \frac{(E\ x\ t) - e1 - e2 - e3}{M} \qquad \text{........ (7)}$$

Where:
M = Mass of sample (g)
E = Energy equivalent (Cal/°C)
t = Temperature rise (°C)
e1 = Nitric acid correction
e2 = Fuse wire and cotton thread correction
e3 = Sulfuric acid correction from sulfur determination

Statistical analysis was performed using one-way Analysis of Variance (ANOVA) under a Completely Randomized Design (CRD) to evaluate the effect of binder type and concentration on the physicochemical properties of biobriquettes. Data were expressed as mean ± standard deviation. Prior to ANOVA. When the F-test indicated significant differences at $\alpha = 0.05$, Duncan's New Multiple Range Test (DNMRT) was applied for mean comparison. With a total sample size of 36 experimental units, the statistical power of the study was considered adequate to detect medium to large treatment effects.

RESULTS AND DISCUSSION

Moisture Content

The analysis of variance showed that the use of various type and proportion of binders in the manufacture of biobriquettes from coconut shells, coconut husks and areca nut husk was not significantly affected ($p \leq 0.05$) the average value of the resulting moisture content. The average value of biobriquette moisture content can be seen in Table 1. The average moisture content of the biobriquettes, as influenced by the type of binder, ranged from 4.75% to 8.5%**.** The highest value was recorded in the treatment utilizing a 14% tapioca binder, whereas the lowest value was obtained in the treatment with an 8% cornstarch binder. Treatments employing 14% tapioca and 14% cornstarch binders exhibited moisture contents that exceeded the permissible limit specified by the SNI standard.

Table 1. Average values of moisture content, calorific value, and ash content of biobriquettes based on the type and proportion of binder

Treatments	Parameters		
	Moisture content (%)	Caloric value (kal/gr)	Ash Content (%)
T1 : tapioca 8%	5.25±2.1016	4920.7 ± 59.5977^{kl}	6.61±1.1724
T2 : tapioca 10%	5.74±1.6055	4842.3 ± 67.8350^{ij}	7.12±1.4361
T3 : tapioca 12%	6±2.0412	4812.4 ± 45.8908^{hi}	7.22±1.6147

Treatments	Parameters		
	Moisture content (%)	Caloric value (kal/gr)	Ash Content (%)
T4 : tapioca 14%	8.5±0.7071	4785.5+54.1144[fg]	9.13±5.3934
M1 : corn starch 8%	4.75±1.4434	4912.1±232.0087[jk]	6.04±0.6345
M2 : corn starch 10%	6.25±1.8484	4794.3±168.3340[gh]	6.5±1.0000
M3 : corn starch 12%	7.5±0.7071	4697.7±67.2057[de]	7.47±2.3180
M4 : corn starch 14%	8±2.0412	4592.2±43.6021[bc]	7.5±1.2245
K1 : hisbiscus leaf extract 20%	5.625±2.8395	4714.3±106.0787[ef]	7.73±0.3102
K2 : hisbiscus leaf extract 25%	6.2569±0.8581	4681.7±27.3629[cd]	7.83±0.4763
K3 : hisbiscus leaf extract 30%	6.625±3.0653	4469.7±143.9388[b]	8.09+0.7083
K4 : hisbiscus leaf extract 35%	7.75±2.3629	3963.2±201.0615[a]	8.82±2.2524

*Note: Numbers followed by the same lowercase letters (a,b, c, d and soon) are not significantly different at the 5% level according to the DNMRT test.

Based on Table 1, the type and amount of binder did not have a significant effect on the biobriquettes. However, in Tables 2, 3, and 4, when the binder type was analyzed separately, it showed a significant effect on the moisture content of the resulting biobriquettes. Average values of moisture content, calorific value, and ash content of biobriquettes based tapioca binder can be seen in Table 2. Average values of moisture content, calorific value, and ash content of biobriquettes based corn starch binder can be seen in Table 3. Average values of moisture content, calorific value, and ash content of biobriquettes based hisbiscus leaf extract binder can be seen in Table 4.

Table 2. Average values of moisture content, calorific value, and ash content of biobriquettes based tapioca binder

Treatments	Parameters		
	Moisture content (%)	Caloric value (kal/gr)	Ash Content (%)
T1 : tapioca 8%	5.25±2.1016[a]	4920.7±59.5977[d]	6.61±1.1724[a]
T2 : tapioca 10%	5.74±1.6055[ab]	4842.3±67.8350[bc]	7.12±1.4361[ab]
T3 : tapioca 12%	6±2.0412[bc]	4812.4±45.8908[b]	7.22±1.6147[bc]
T4 : tapioca 14%	8.5±0.7071[d]	4785.5+54.1144[a]	9.13±5.3934[c]

*Note: Numbers followed by the same lowercase letters (a,b, c, d and soon) are not significantly different at the 5% level according to the DNMRT test.

Based on Table 2, proportion of tapioca in the manufacture of biobriquatte significantly affected ($p \leq 0.05$) the average value of the resulting moisture content. The highest moisture content was observed at a tapioca concentration of 14%, while the lowest moisture content occurred at a concentration of 8%. The higher the concentration or amount of tapioca binder used, the higher the moisture content of the resulting biobriquettes. This is consistent with the study conducted by Harmiansyah et al. (2025) and Saragih et al. (2025), which reported that increasing the percentage of tapioca used as a binder leads to an increase in the moisture content of biobriquettes. According to Nuwa and Prihanika (2018), tapioca has a high binding strength.

Table 3. Average values of moisture content, calorific value, and ash content of biobriquettes based corn starch binder

Treatments	Parameters		
	Moisture content (%)	Caloric value (kal/gr)	Ash Content (%)
M1 : corn starch 8%	4.75±1.4434[a]	4912.1±232.0087[ab]	6.04±0.6345[a]
M2 : corn starch 10%	6.25±1.8484[ab]	4794.3±168.3340[bc]	6.5±1.0000[ab]
M3 : corn starch 12%	7.5±0.7071[bc]	4697.7±67.2057[c]	7.47±2.3180[bc]

M4 : corn starch 14%	8±2.0412[c]	4592.2±43.6021[d]	7.5±1.2245[c]

*Note: Numbers followed by the same lowercase letters (a,b, c, d and soon) are not significantly different at the 5% level according to the DNMRT test.

Based on Table 3, proportion of corn starch in the manufacture of biobriquatte significantly affected ($p \leq 0.05$) the average value of the resulting moisture content. The higher the concentration or amount of corn starch binder used, the higher the moisture content of the resulting biobriquettes. This is in accordance with the study conducted by Putri et al. (2025), which stated that the higher the amount of corn starch used, the higher the resulting ash content.

Table 4 Average values of moisture content, calorific value, and ash content of biobriquettes based hisbiscus leaf extract binder

Treatments	Parameters		
	Moisture content (%)	Caloric value (kal/gr)	Ash Content (%)
K1 : hisbiscus leaf extract 20%	5.625±2.8395[a]	4714.3±106.0787[ef]	7.73±0.3102[a]
K2 : hisbiscus leaf extract 25%	6.2569±0.8581[b]	4681.7±27.3629[cd]	7.83±0.4763[ab]
K3 : hisbiscus leaf extract 30%	6.625±3.0653[b]	4469.7±143.9388[b]	8.09+0.7083[bc]
K4 : hisbiscus leaf extract 35%	7.75±2.3629[c]	3963.2±201.0615[a]	8.82±2.2524[c]

*Note: Numbers followed by the same lowercase letters (a,b, c, d and soon) are not significantly different at the 5% level according to the DNMRT test.

Based on Table 4, proportion of hisbiscus leaf extract in the manufacture of biobriquatte significantly affected ($p \leq 0.05$) the average value of the resulting moisture content. The higher the concentration or amount of hisbiscus leaf extract binder used, the higher the moisture content of the resulting biobriquettes.

Based on Fig. 1, it can be observed that the higher the concentration of binder used in each treatment, the higher the resulting moisture content of the biobriquettes. Several factors influencing the moisture content of biobriquettes include the type and amount of binder, as well as the raw material used (Yulia et al., 2024; Mardawati et al., 2023; Haliza and Saroso, 2022; Satria et al., 2021; Shobar et al., 2020; Sirun et al., 2016). Increasing the amount of binder tends to raise the moisture content of the biobriquettes. High moisture content also leads to difficulties in ignition and a reduction in combustion temperature (Haliza and Saroso, 2022), while excessive smoke may be generated during burning (Faizal et al., 2014). Conversely, the low moisture content of biobriquettes made from coconut husk and shell with crude palm oil residue as a binder contributes to higher calorific values, thereby improving combustibility (Yulia et al., 2024). According to Arifin et al. (2023), the moisture content of biobriquettes from coconut shell and areca palm fronds decreases with the increasing proportion of coconut shell charcoal, which consequently increases the calorific value. Average moisture content of biobriquettes as affected by binder types and concentrations can be seen in Figure 1.

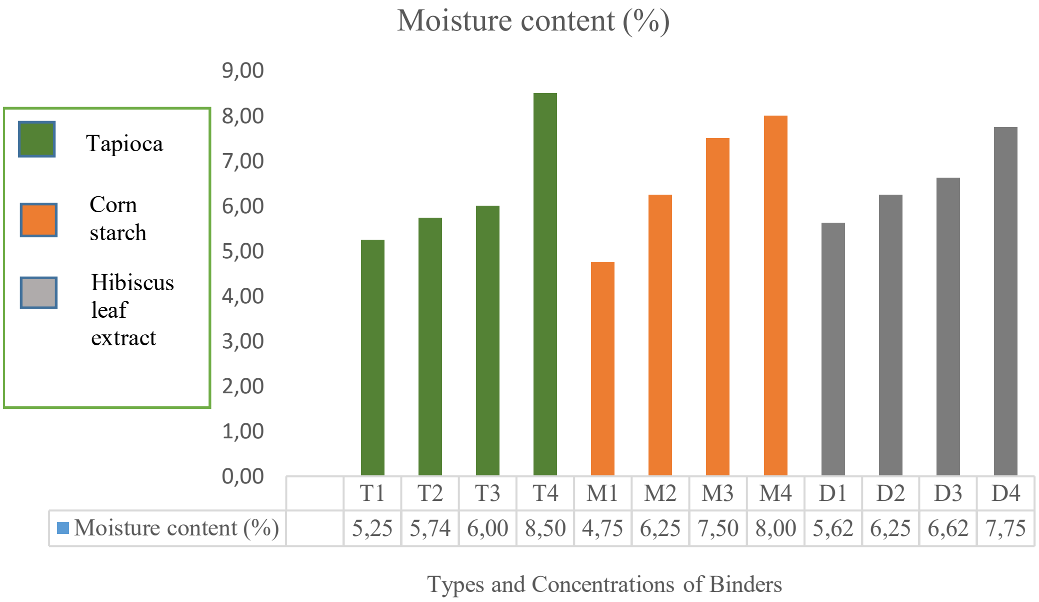

Figure 1. Average moisture content of biobriquettes as affected by binder types and concentrations

The type of binder significantly affects the final moisture content of biobriquettes. This is also related to the proportion of amylose and amylopectin contained in the binder material. According to Indrianti et al. (2013), tapioca starch contains 20–27% amylose and 77–80% amylopectin, while cornstarch contains 25–30% amylose and 70–75% amylopectin (Syukri and Dina, 2022). Cassava starch (tapioca), which is dominated by amylopectin, has high water-binding capacity and swelling power, thereby tending to produce biobriquettes with higher moisture content compared to cornstarch (maize starch), which has a higher amylose proportion. In contrast, hibiscus leaf mucilage, typically applied at lower concentrations, forms efficient interparticle bonding, resulting in relatively lower final moisture content under equivalent drying conditions.

Calorific Value

The analysis of variance showed that the use of various type and proportion of binders in the manufacture of biobriquettes from coconut shells, coconut husks and areca nut husk was significantly affected ($p \leq 0.05$) the average value of the resulting calorific Value. Based on Table 1 the average calorific value of biobriquettes based on binder type ranged from 3,963.28 to 4,920.76 cal/g. The highest calorific value was obtained from briquettes using 8% tapioca binder, while the lowest value was recorded in briquettes with 35% hibiscus binder. The calorific values of the briquettes did not meet the Indonesian National Standard (SNI), which requires a minimum of 5,000 cal/g. However, the calorific values of briquettes with tapioca and cornstarch binders at various concentrations, as well as hibiscus binders at concentrations of 20%, 25%, and 30%, still complied with the ASTM standard, which sets a minimum requirement of 4,000 cal/g.

Table 2 showed that increasing the amount of tapioca binder used results in a decrease in calorific value. This finding is also consistent with the study conducted by Bazenet et al. (2021). According to Chinyere et al. (2014), the greater the amount of cornstarch added, the higher the calorific value of the resulting biobriquettes, and the same result is also shown in Table 3 of this study.

As shown in **Fig. 6**, increasing the binder concentration generally reduced the calorific value of the biobriquettes. According to Lukas et al. (2018), a higher calorific value indicates better briquette quality. The calorific value represents the amount of energy stored within the briquette (Arachchige, 2021). Several factors affect calorific value, including moisture content, volatile matter, ash content, and fixed carbon (Quaicoe et al., 2024; Rudiyanto et al., 2023; Mendoza et al., 2020; Shobar et al., 2020). Elevated levels of moisture, volatile matter, and ash are known to reduce the calorific value of briquettes. Average calorific value of biobriquettes as affected by binder types and concentration can be seen in Figure 2.

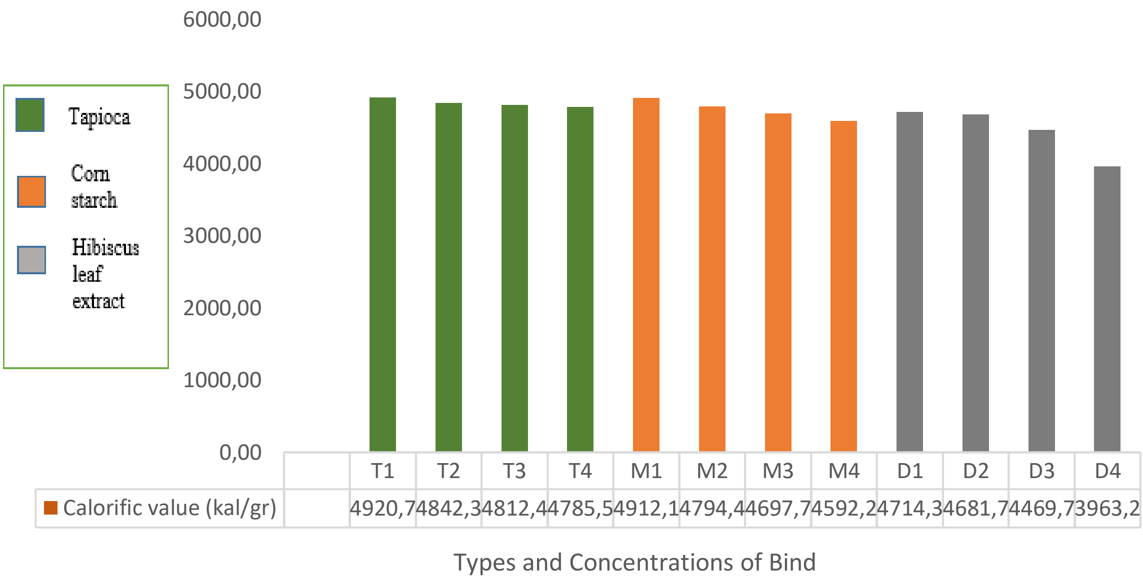

Figure 6. Average calorific value of biobriquettes as affected by binder types and concentration

The calorific value of biobriquettes is strongly influenced by the type of binder used, since each binder contains different chemical constituents, particularly ash content, moisture content, and carbon composition. Starch-based binders such as tapioca and cornstarch generally have low ash content (0.13–0.36%), which contributes to higher calorific values compared to binders with higher ash levels. Ali et al. (2021) reported that the use of tapioca binder at an optimal concentration can increase the calorific value of coconut shell briquettes due to improved density and lower moisture content. Similarly, cornstarch exhibits properties comparable to tapioca; however, several studies have indicated that tapioca-based briquettes often exhibit slightly higher calorific values than those with cornstarch, as tapioca provides stronger binding strength, resulting in denser briquettes and more stable combustion.

In contrast, natural binders derived from hibiscus (Hibiscus rosa-sinensis) contain a significantly higher ash content (around 11.22%) than starch-based binders, which tends to reduce the calorific value of the briquettes. Consequently, biobriquettes with tapioca binder generally achieve the highest calorific values, followed by those with cornstarch, while hibiscus-based briquettes show the lowest calorific values due to their elevated ash content.

Ash Content

The analysis of variance showed that the use of various type and proportion of binders in the manufacture of biobriquettes from coconut shells, coconut husks and areca nut husk was not significantly affected ($p \leq 0.05$) the average value of the resulting ash content. The average value of biobriquette ash content can be seen in Table 1. The average ash content of the biobriquettes based on the type of binder ranged from 6.05% to 9.13%. The highest ash content was observed in the treatment using 14% tapioca binder, while the lowest was found in the treatment using 8% cornstarch binder. Biobriquettes that did not meet the SNI standard were those produced with 14% tapioca binder, as well as hibiscus leaf binder at concentrations of 30% and 35%. Table 2 shows that increasing the concentration of tapioca added results in a higher ash content. This finding is also consistent with the study conducted by Akbar et al. (2025). In Table 4 indicated that The higher the concentration of hibiscus leaf extract added, the higher the ash content obtained. This finding is consistent with the study conducted by Narbogo et al. (2025).

Based on Fig. 2, it can be seen that the ash content of the biobriquettes increased with higher binder concentrations across all types of binders. Biobriquettes with cornstarch binder exhibited the lowest ash content. This result is related to the intrinsic ash composition of the binders: tapioca contains approximately 0.36% ash (Mahadi & Ulitua Panggabean, 2023), cornstarch contains 0.13–0.35% ash (Ramadan et al., 2023), whereas hibiscus leaves contain about 11.22% ash (Zubairi & Jaies, 2014). Average Ash Content of Biobriquettes as Affected by Binder Types and Concentrations can be seen in Figure 2.

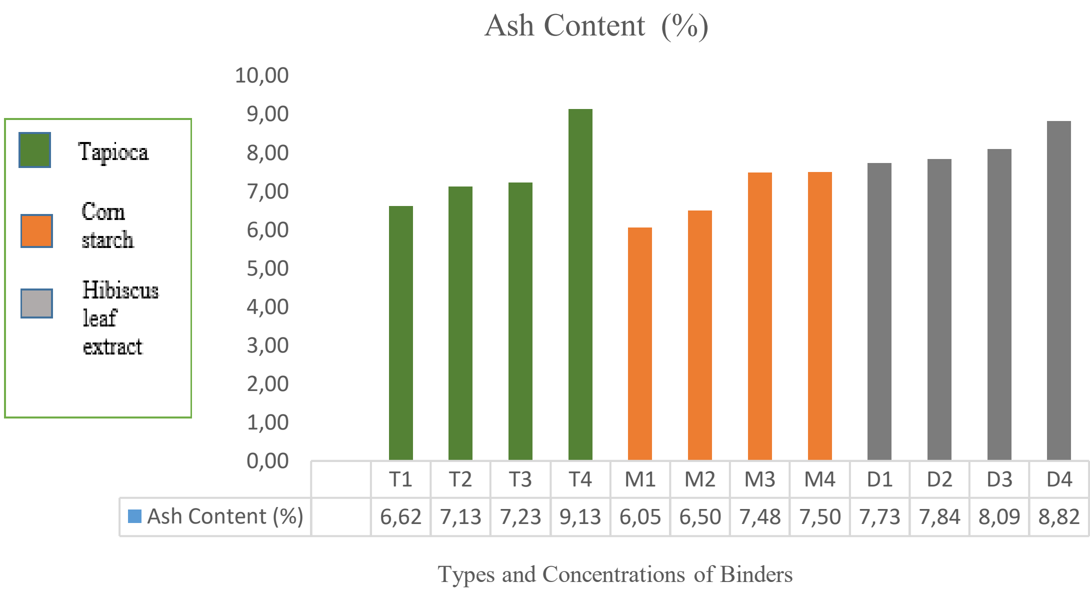

Figure 2. Average ash content of biobriquettes as affected by binder types and concentrations

The type of binder used significantly influences the ash content of biobriquettes. Starch-based binders such as cornstarch and tapioca generally produce lower ash content due to their relatively low mineral composition, with cornstarch tending to yield the lowest values. In contrast, natural hibiscus leaf binder contains higher mineral content, resulting in biobriquettes with relatively greater ash levels. Elevated ash content is associated with a reduction in calorific value and an increase in combustion residues, whereas lower ash levels support higher fuel quality. This finding is consistent with the study by Cholilie and Zuari (2021), which reported that tapioca binder produced higher ash content compared to cornstarch binder.

A study by Anis et al. (2024**)** further demonstrated that the use of different binders such as mocaf, cassava flour, and tapioca in coconut shell-based biobriquettes led to variations in ash content. Similarly, Shobar et al. (2020) reported that both the type and amount of binder significantly affected the ash content of areca nut husk biobriquettes when using tapioca and sago flour as binders. An increase in sago flour concentration was found to raise ash content. Ash content in biobriquettes is closely linked to carbon concentration and calorific value. According to Kawal et al. (2019**)**, high ash levels in biobriquettes made from coconut coir and coconut male flowers reduce calorific value, decrease burning rate, and are considered less desirable as fuels despite producing less smoke. In contrast, Obi et al. (2013**)** reported that low ash content enhances calorific value, while high ash content leads to increased dust emissions, which cause air pollution and negatively affect combustion volume and efficiency.

Volatile Matter

The analysis of variance showed that the use of various type and proportion of binders in the manufacture of biobriquettes from coconut shells, coconut husks and areca nut husk was not significantly affected ($p \leq 0.05$) the average value of the resulting volatile matter. The average value of biobriquette volatile matter can be seen in Table 5. The average volatile matter content of the biobriquettes based on the type of binder ranged from 2.407% to 5.611%**.** The lowest volatile matter content was observed in the treatment using 20% hibiscus leaf binder**,** while the highest was recorded in the treatment with 14% cornstarch binder. The volatile matter content of all treatments complied with the SNI standard, which sets a maximum limit of 15%.

Table 5. The average values of volatile matter, burning rate, and density of biobriquettes based on the type and proportion of binder

Treatments	Parameters		
	Volatile Matter (%)	Burning Rate (gr/minutes)	Density(gr/cm^3)
T1 : tapioca 8%	3.57±0.1074^{c}	0.2321±0.0036^{de}	0.545±0.0308^{a}
T2 : tapioca 10%	3.60±0.5884^{c}	0.2355±0.0046^{ef}	0.5453±0.0247^{ab}
T3 : tapioca 12%	3.73±0.0644^{cd}	0.264±0.0047^{ij}	0.6075±0.0964^{de}
T4 : tapioca 14%	3.81±0.1374^{f}	0.2716±0.0110^{jk}	0.6084±0.0388^{ef}
M1 : corn starch 8%	3.79±0.1327^{de}	0.2018±0.0091^{a}	0.5836±0.0434^{bc}
M2 : corn starch 10%	3.80±0.5677^{ef}	0.2144±0.0122^{ab}	0.592±0.0161^{cd}
M3 : corn starch 12%	4.04±0.4522^{fg}	0.2152±0.0103^{bc}	0.6735±0.0295^{hi}
M4 : corn starch 14%	5.61±1.6067^{gh}	0.2195±0.0063^{cd}	0.739±0.0247^{jk}
K1 : hisbiscus leaf extract 20%	2.40±2.5339^{a}	0.2374±0.0032^{fg}	0.6268±0.0291^{fg}
K2 : hisbiscus leaf extract 25%	3.03±2.6314^{ab}	0.2419±0.0204^{gh}	0.6579±0.0124^{gh}
K3 : hisbiscus leaf extract 30%	3.52±1.1849^{bc}	0.2562±0.0254^{hi}	0.6831±0.0336^{ij}
K4 : hisbiscus leaf extract 35%	4.89±0.2649^{g}	0.2584±0.0030^{ij}	0.8234±0.0826^{l}

*Note: Numbers followed by the same lowercase letters (a,b, c, d and soon) are not significantly different at the 5% level according to the DNMRT test.

Table 6 showed that the average volatile matter content increases with an increase in the concentration of tapioca used. This finding is also consistent with the study conducted by Yuni et al. (2025). Rofiq et al. (2023) reported that increasing the amount of tapioca binder used tends to increase the volatile matter content. Table 7 showed that the higher the concentration of corn starch binder added, the higher the volatile matter content. This finding is consistent with the study conducted by Zanella et al. (2016). The average values of volatile matter, burning rate, and density of biobriquettes based tapioca binder can be seen in Table 6. The average values of volatile matter, burning rate, and density of biobriquettes based corn starch binder can be seen in Table 7. And The average values of volatile matter, burning rate, and density of biobriquettes based hisbiscus leaf extract binder can be seen in Table 8.

Table 6. The average values of volatile matter, burning rate, and density of biobriquettes based tapioca binder

Treatments	Parameters		
	Volatile Matter (%)	Burning Rate (gr/minutes)	Density(gr/cm^3)
T1 : tapioca 8%	3.57±0.1074^{a}	0.2321±0.0036^{a}	0.545±0.0308^{a}
T2 : tapioca 10%	3.60±0.5884^{ab}	0.2355±0.0046^{ab}	0.5453±0.0247^{ab}
T3 : tapioca 12%	3.73±0.0644^{bc}	0.264±0.0047^{c}	0.6075±0.0964^{bc}
T4 : tapioca 14%	3.81±0.1374^{c}	0.2716±0.0110^{c}	0.6084±0.0388^{c}

*Note: Numbers followed by the same lowercase letters (a,b, c, d and soon) are not significantly different at the 5% level according to the DNMRT test.

Table 7. The average values of volatile matter, burning rate, and density of biobriquettes based corn starch binder

Treatments	Parameters		
	Volatile Matter (%)	Burning Rate (gr/minutes)	Density(gr/cm^3)
M1 : corn starch 8%	3.79±0.1327^{a}	0.2018±0.0091^{a}	0.5836±0.0434^{a}
M2 : corn starch 10%	3.80±0.5677^{ab}	0.2144±0.0122^{ab}	0.592±0.0161^{ab}
M3 : corn starch 12%	4.04±0.4522^{bc}	0.2152±0.0103^{bc}	0.6735±0.0295^{bc}
M4 : corn starch 14%	5.61±1.6067^{d}	0.2195±0.0063^{cd}	0.739±0.0247^{d}

*Note: Numbers followed by the same lowercase letters (a,b, c, d and soon) are not significantly different at the 5% level according to the DNMRT test.

Table 8. The average values of volatile matter, burning rate, and density of biobriquettes based hisbiscus leaf extract binder

Treatments	Parameters		
	Volatile Matter (%)	Burning Rate (gr/minutes)	Density(gr/cm^3)
K1 : hisbiscus leaf extract 20%	2.40±2.5339^a	0.2374±0.0032	0.6268±0.0291^a
K2 : hisbiscus leaf extract 25%	3.03±2.6314^{ab}	0.2419±0.0204	0.6579±0.0124^{ab}
K3 : hisbiscus leaf extract 30%	3.52±1.1849^{bc}	0.2562±0.0254	0.6831±0.0336^{bc}
K4 : hisbiscus leaf extract 35%	4.89±0.2649^c	0.2584±0.0030	0.8234±0.0826^d

*Note: Numbers followed by the same lowercase letters (a,b, c, d and soon) are not significantly different at the 5% level according to the DNMRT test.

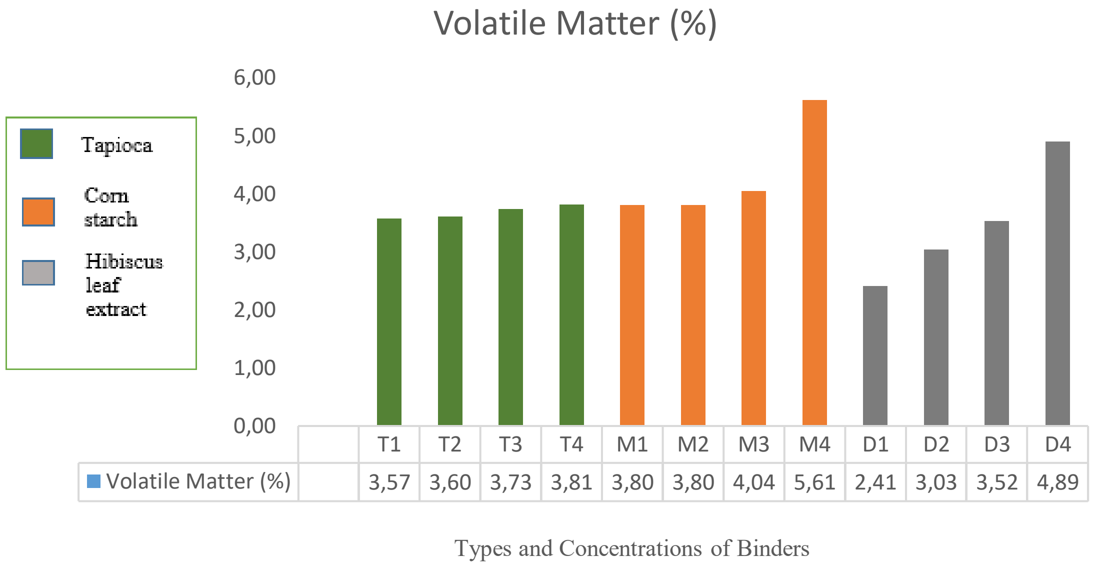

Figure 3. Average volatile matter content of biobriquettes as affected by binder types and concentrations

Based on Fig. 3, it can be observed that the volatile matter content of the biobriquettes increased with higher binder concentrations. The type of binder also influenced the volatile matter levels. The highest volatile matter content was obtained from biobriquettes using cornstarch binder, which is consistent with the findings of Cholilie and Zuari (2021), who reported that among the three binders tested—tapioca, cornstarch, and sago flour—the highest volatile matter content (24.99%) was found in cornstarch-based biobriquettes. Similarly, Anis et al. (2024) demonstrated that biobriquettes produced with different binders such as tapioca, cassava flour, and mocaf flour exhibited variations in volatile matter levels. Average volatile matter content of biobriquettes as affected by binder types and concentrations can be seen in Figure 3.

Yirijor and Bere (2024) further highlighted that volatile matter content increases proportionally with the amount of binder added. Moreover, Novitrie et al. (2023) reported that higher tapioca binder concentrations lead to higher volatile matter contents in biobriquettes. Tapioca binders, rich in starch, tend to generate greater volatile matter since starch decomposes readily into volatile gases during combustion. This results in faster ignition but also quicker consumption of the briquettes. Cornstarch, also starch-based, similarly contributes to relatively high volatile matter content. In contrast, hibiscus leaf binder, derived from natural mucilage with lower starch and volatile compounds, produces biobriquettes with the lowest volatile matter. Consequently, these briquettes ignite more slowly but exhibit more stable and longer-lasting combustion.

Burning Rate

The analysis of variance showed that the use of various type and proportion of binders in the manufacture of biobriquettes from coconut shells, coconut husks and areca nut husk was not significantly affected ($p \leq 0.05$) the average value of the resulting burning rate. The average value of biobriquette burning rate can be seen in Table 5. The average burning rate of the biobriquettes, based on binder type, ranged from 0.202% gr/minute to 0.272 gr/minute. The lowest burning rate was observed in biobriquettes using 8% cornstarch binder, while the highest rate occurred in those using 14% tapioca binder. Based on Table 6, it can be seen that the higher the tapioca concentration, the higher the resulting combustion rate. This finding is also consistent with the study conducted by Crisdiantoro et al. (2024). Tables 6 and 7 showed that tapioca and cornstarch binders at various concentrations have a significant effect on the combustion rate of biobriquettes, but in Table 8 showed it indicates that there is no effect.when using hibiscus leaf extract binder.

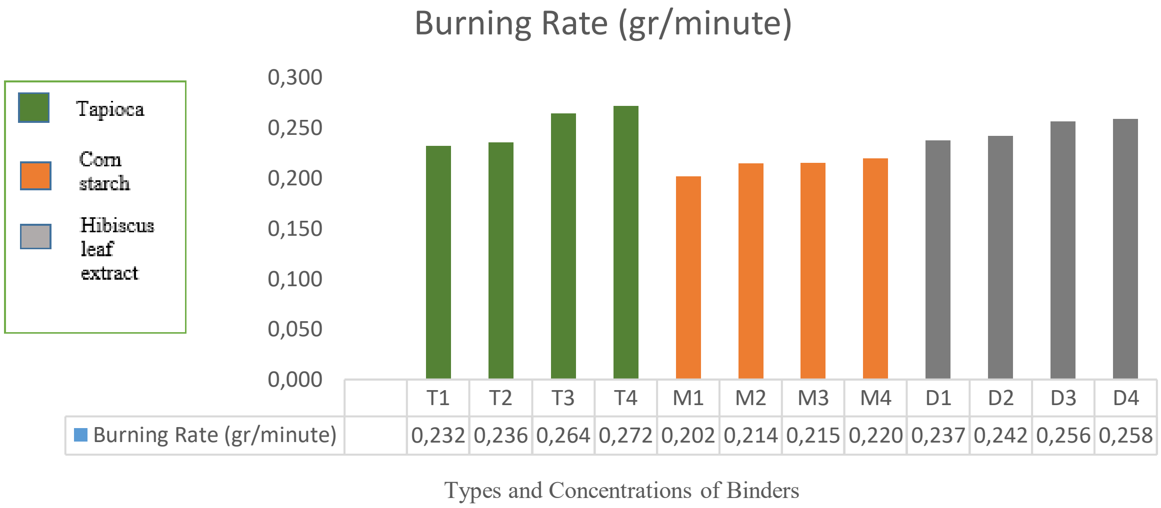

Figure 4. Average burning rate of biobriquettes as affected by binder types and concentrations

As shown in Fig. 4, increasing the concentration of binder resulted in higher burning rates. Different binder types also produced variations in burning rate. These findings are consistent with Jannah et al. (2022) and Ramdani et al. (2020), who explained that higher binder concentrations increase the moisture content of briquettes. This condition requires more water to evaporate during combustion, leading to faster mass loss, which ultimately increases the burning rate and shortens the briquette's combustion duration. Average Burning Rate of Biobriquettes as Affected by Binder Types and Concentrations can be seen in figure 4.

The higher amylopectin content in tapioca compared to cornstarch results in a faster burning rate for tapioca-based briquettes. This is due to the thermal behavior of amylopectin, which is more easily degraded and thus burns more rapidly. In contrast, cornstarch contains a higher proportion of amylose than tapioca. Amylose, being more heat resistant, slows down the burning process. On the other hand, hibiscus leaf binder, which is derived from the mucilage of stems or flowers, contains thick polysaccharide compounds that enhance particle bonding, resulting in denser and more compact briquettes. Furthermore, hibiscus mucilage contains little starch and has relatively low moisture content, making it less hygroscopic compared to tapioca. As a result, hibiscus-based briquettes typically exhibit slower burning rates because their compact structure reduces oxygen penetration, leading to longer and more stable combustion. Several variables influence the burning rate of biobriquettes, including moisture content, calorific value, and density (Nandianto, 2022; Haliza & Saroso, 2022).

Density

The analysis of variance showed that the use of various type and proportion of binders in the manufacture of biobriquettes from coconut shells, coconut husks and areca nut husk was significantly affected ($p \leq 0.05$) the average value of the resulting density. The average value of biobriquette density can be seen in Table 5. The average density of the biobriquettes, based on binder type, ranged from 0.545 to 0.823 g/cm³. The highest density was obtained from biobriquettes using 35% hibiscus leaf binder, while the lowest was found in those using 8% tapioca binder. Based on Table 6, it can be seen that the average density of biobriquettes increases with an increase in the amount of tapioca binder used. The results of this study are consistent with the research conducted by Alayidrus et al. (2025). Based on Table 8, it can be observed that the higher the concentration of hibiscus leaf extract added, the greater the resulting density. This finding is consistent with the study conducted by Efendi (2025), who used hibiscus leaf extract as a binder in biobriquettes made from coconut shell charcoal

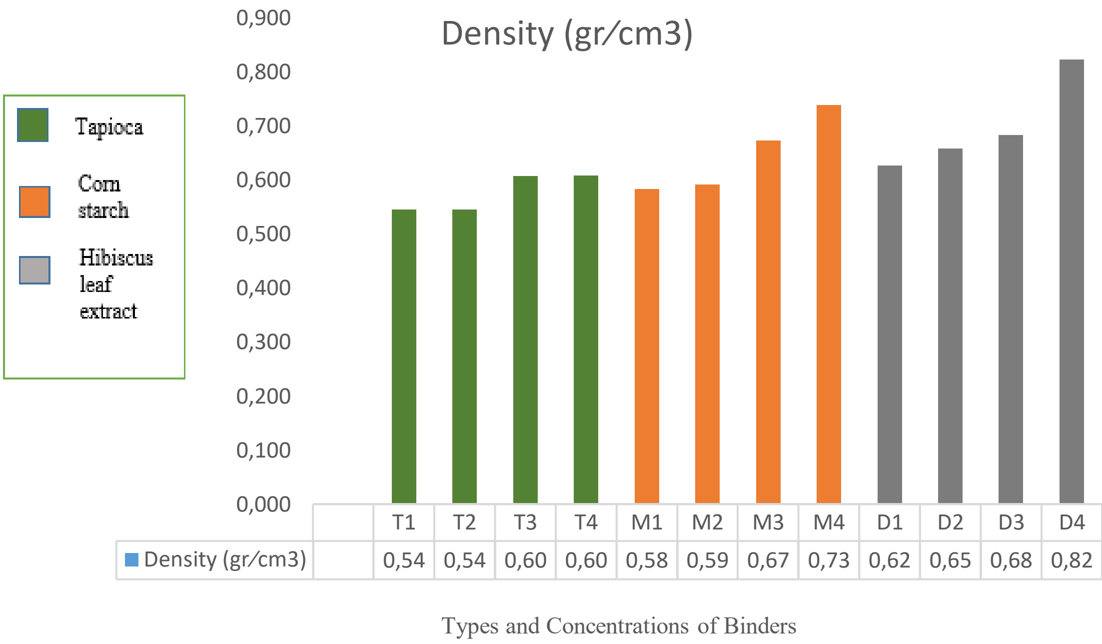

Figure 5. Average Density of Biobriquettes Based on Binder Types and Concentrations

As shown in Fig. 5, increasing the binder concentration enhanced the density of the biobriquettes. Anis et al. (2024) reported that binder type significantly affects the density of coconut shell briquettes. Among the tested binders—tapioca, cassava flour, and mocaf—cassava flour produced the highest density (1.010 g/cm³). The primary function of binder addition is to improve the physical characteristics of the briquettes, where higher binder concentrations result in denser and more compact products that are easier to handle. Average Density of Biobriquettes Based on Binder Types and Concentration can be seen in Figure 5.

Similarly, Ropiudin and Syska (2022) demonstrated that binder concentration and raw material type affect the density of biobriquettes made from coconut shells and cassava peels. Ali et al. (2021) also found that variations in binder type and concentration, such as tapioca and sago starch, influence the density of coconut shell briquettes. High-density briquettes tend to burn more slowly due to reduced pore space, which limits oxygen diffusion, whereas low-density briquettes burn more quickly because their larger pore spaces allow greater oxygen penetration during combustion. However, low-density briquettes are consumed faster due to the presence of excess voids (Fatmawati & Adiwibowo, 2014).

The type of binder significantly influences the density of biobriquettes. Cornstarch, which is rich in amylose, tends to produce tighter interparticle bonding, resulting in relatively higher density and a more compact structure. Conversely, tapioca starch, which is dominated by amylopectin, forms a looser structure, leading to lower density and a more porous briquette. Meanwhile, the natural mucilage from hibiscus acts as a strong adhesive that reinforces interparticle bonding, thereby producing briquettes with the highest density and the most compact structure. These differences in density have direct implications for combustion characteristics: low-density briquettes ignite more easily but burn out faster, whereas high-density briquettes are more difficult to ignite but provide a longer burning duration.

In general, the results of this study indicate that the various type and proportion of binder play a significant role in determining the physical and combustion characteristics of biobriquettes made from a mixture of coconut shell charcoal, coconut husk charcoal, and areca nut shell charcoal, particularly in terms of calorific value, volatile matter content, burning rate and density. In contrast, moisture content and ash content are more strongly influenced by the intrinsic properties of the raw materials and the carbonization process. The findings demonstrate that the binder does not merely function as a mechanical adhesive but also contributes to modifying density and influencing the combustion behavior of the biobriquettes.

The selection of binder type—especially tapioca starch—was found to significantly affect the combustion rate, indicating that binder choice can be optimized according to the targeted energy characteristics of the briquettes, whether in terms of calorific value or combustion performance. This supports the development of agricultural waste-based briquettes as a sustainable alternative fuel. The novelty of this research lies in the use of three types of charcoal biomass combined in a balanced ratio (30:30:30), as well as the comparative evaluation of three different organic binders within the same compositional system, which has rarely been reported simultaneously in experimental studies.

This study still has several limitations, as it was conducted at a laboratory scale and did not optimize the combustion process. In addition, fixed carbon content and combustion gas emissions were not analyzed, nor were techno-economic and environmental feasibility aspects evaluated. Future research is therefore recommended to optimize carbonization temperature and residence time in order to increase calorific value and reduce ash content so that the briquettes can meet the Indonesian National Standard (SNI). Further studies should also include emission testing and mechanical strength analysis, explore alternative binder types, and integrate techno-economic and environmental assessments at the pilot scale to ensure the sustainable industrial potential of the product.

CONCLUSION

The results of this study demonstrate that the composition of coconut shell charcoal powder, coconut husk charcoal powder, and areca nut shell charcoal powder in a ratio of 30 : 30 : 30, combined with 10% binder (maize starch/corn starch, tapioca starch, and hibiscus leaf extract), produced biobriquettes with diverse characteristics. The type and amount of binder significantly affect the calorific value, combustion rate, volatile matter, and density, but do not significantly affect the moisture content and ash content of biobriquettes made from coconut shell, coconut husk, and areca nut husk. When each binder was analyzed individually at the tested concentrations, it showed a significant effect on all biobriquette parameters, except for the combustion rate, which was significantly influenced only by tapioca binder, while cornstarch and hibiscus leaf extract binders showed no significant effect. The biobriquettes exhibited a moisture content ranging from 4.75–8.5%**,** ash content between 6.05–9.13%, and volatile matter content within the range of 2.407–5.611%**.** Furthermore, the combustion rate was recorded at 0.202–0.272%**,** density ranged from 0.545–0.823 g/cm³, and the calorific value varied between 3963.28–4920.763 cal/g**.** Overall, the produced biobriquettes fulfilled most international quality standards, although the calorific values did not reach the minimum threshold required by the Indonesian National Standard (SNI).

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support provided by PNBP DIPA Universitas Jambi under the Fiscal Year 2024 funding scheme.

AUTHOR CONTRIBUTIONS

Author 1 conceptualized and designed the study, conducted the experimental work, analyzed the data, and prepared the original manuscript draft. Author 2 contributed to research methodology development, supervised laboratory analysis, and validated the data. Author 3 assisted in statistical analysis, interpretation of results, and manuscript revision. All authors reviewed and approved the final version of the manuscript.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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