IPTEK The Journal for Technology and Science, 37(2), 2026 (e/pISSN:2088-2033, 0853-4098)

DOI: 10.12962/j20882033.v37i2.9260 | Received 9 February, 2026; Revised 13 March, 2026; Accepted 13 May, 2026

ORIGINAL RESEARCH

Innovation in the Development of Biobriquette Binder Based on Cassava Peel Waste (Manihot Esculenta Crantz)

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Abstract

Indonesia faces a growing energy crisis due to increasing demand and high reliance on fossil fuels. Biomass briquettes offer a renewable alternative, where the choice of binder critically affects product performance. This study investigates cassava peel, an abundant agricultural waste, as a natural binder for biobriquettes made from carbonized oil palm empty fruit bunches (OPEFB) and fronds (OPF). The binder was prepared via acid hydrolysis of cassava starch into dextrin, combined with casein and triethanolamine, producing a homogeneous adhesive paste. Physicochemical characterization revealed suitable properties for briquette production: viscosity 472 ± 6 cP, adhesion 0.64 ± 0.02 MPa, density 1.20 ± 0.02 g/cm^3, calorific value 18.4 ± 0.1 MJ·kg^{-1}, moisture 8.2 ± 0.2%, ash 3.5 ± 0.1%, and durability 91.6 ± 0.4%. Biobriquettes fabricated with this binder exhibited higher density (0.99–1.01 g/cm^3) and calorific value (6580 ± 45 cal/g) than commercial samples (0.97 g/cm^3, 6450 ± 50 cal/g), indicating improved particle packing, uniform binder distribution, and enhanced energy content. Triplicate measurements confirmed process reproducibility. These findings demonstrate that cassava peel is an effective, low-cost, and environmentally friendly binder capable of producing biobriquettes with superior mechanical integrity and energy performance, supporting sustainable energy production and circular economy initiatives.

KEYWORDS:

Adhesive, Biobriquette, Cassava

1 | INTRODUCTION

Indonesia, the world's fourth most populous country, faces a growing energy crisis due to increasing energy demand and high dependency on non-renewable fossil fuels[1, 2]. Population projections indicate 281.6 million people by 2024, further escalating domestic energy consumption[2]. To achieve long-term energy sustainability, the exploration and development of renewable energy sources are essential. One promising approach is the utilization of biomass waste as an alternative fuel, particularly in the form of biobriquettes[3, 4].

A critical factor in biobriquette production is the choice of binder, which significantly affects fuel quality. Inorganic binders such as cement, clay, calcium oxide, and synthetic polymers provide strong adhesion and thermal stability but generally result in high ash content, lower calorific value, and higher production cost[5]. Composite binders, combining organic and inorganic components, can enhance mechanical strength and water resistance but still face challenges including cost and elevated ash content[6]. In contrast, organic binders offer higher calorific value, widespread availability, cost-effectiveness, and superior mechanical performance, making them more sustainable and environmentally friendly[7].

Previous studies have explored various agricultural wastes as organic binders. Irhamni et al. (2019) used gadung tuber waste, which yielded high ash content (7.7%) and short burn duration (3,300 s) with limited raw material availability[8]. Sari et al. (2018) employed banana peel, resulting in low compressive strength (11.73 g/cm^2)[9]. Saputro et al.[10] reported relatively low calorific value (4860 cal/g) using sugarcane bagasse. These limitations highlight the need for an alternative binder that balances adhesion, combustion efficiency, and material availability.

Cassava peel, an abundant agricultural waste, contains high starch and lignocellulosic fiber, providing natural adhesive properties. Starch contributes to bonding through gelatinization, while lignocellulosic fibers enhance structural integrity[11, 12]. Moreover, cassava peel is biodegradable, environmentally friendly, widely available, and supports the circular economy by reducing dependence on synthetic binders[13–15].

This study aims to evaluate cassava peel as a standalone binder for biomass briquettes. The binder was prepared through washing, drying, and grinding the peels into fine powder, followed by starch extraction and hydrolysis using 1N HCl at 110°C for 10 minutes to produce dextrin. The hydrolyzed dextrin was then combined with casein, cold water, and triethanolamine to form a homogeneous adhesive paste, which was subsequently applied in biobriquette production. The study assesses both mechanical and energy properties, providing comprehensive insight into cassava peel's potential as a sustainable, low-cost binder.

2 | PREVIOUS RESEARCH

Several studies have explored oil palm residues for biobriquette production, often using starch-based binders such as tapioca flour. Gila et al. (2020) investigated OPF and OPEFB blends with cassava peel as an additive; their optimal formulation (80% OPF, 20% OPEFB, 50 g cassava peel, compacted at 90 MPa) achieved a calorific value of 6594.5 cal/g, compressive strength of 2.86 MPa, burning rate of 1.04 g/min, and density of 877.9 kg/m^3. However, the binder function of cassava peel itself was not isolated.

Usmayadi et al. (2018) reported that particle size strongly affects calorific value in palm frond biobriquettes, with the highest 5338 cal/g obtained for particles passing 10 mesh and retained at 20 mesh, while commercial tapioca flour was used. Simanjuntak et al. (2017) found maximum calorific values of 4646 cal/g for OPF (30 mesh) and 4964 cal/g for OPEFB (100 mesh) using tapioca flour. Syukri et al. (2016) tested tapioca adhesive concentrations (6–10%) and particle sizes (30–70 mesh); the best compressive strength (112.2 MPa) and lowest moisture content (0.3%) were obtained with 6% adhesive and 30 mesh. Tampubolon et al. (2015) combined mushroom waste, OPEFB, and OPF using tapioca flour, with the best composition (60:30:10, OPEFB:OPF:adhesive) yielding 5291.2 cal/g calorific value and 0.282 g/min burning rate.

Overall, these studies confirm that starch-based binders can improve briquette performance, but reliance on commercial tapioca limits sustainability. Although cassava peel has been used in some formulations, its potential as a low-cost, waste-derived binder has not been comprehensively evaluated. Therefore, this study addresses this gap by investigating cassava peel specifically as a standalone binder, assessing both mechanical and energy performance in biobriquette applications.

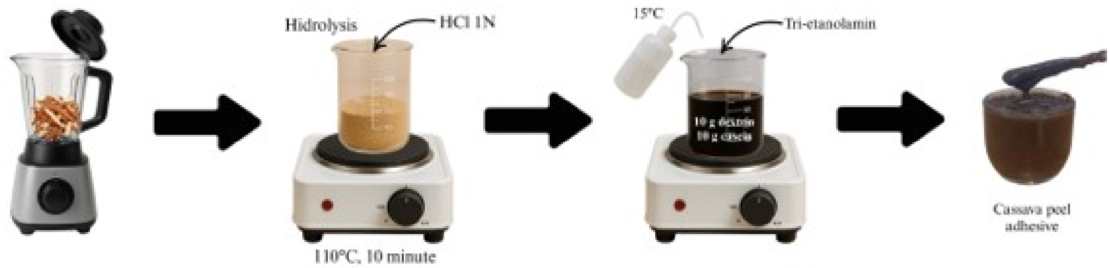

FIGURE 1 The Procedure for Producing Binder from Cassava Peel Waste.

3 | METHODS

3.1 | Raw Material Preparation

Cassava peel waste was collected from traditional markets in Balikpapan, Indonesia, immediately after peeling to minimize degradation. The peels were washed, cut into small pieces, and oven-dried at 60 °C for 24 h. The dried material was ground and sieved through a 60-mesh screen to obtain fine powder suitable for further processing.

3.2 | Dextrin Synthesis

Dextrin was produced via acid hydrolysis of cassava peel starch. A total of 15 mL of 1 N HCl was added to the cassava peel powder and continuously stirred using a magnetic stirrer. The mixture was heated at 110 °C for 10 min to accelerate hydrolysis and cleave glycosidic bonds. The suspension was subsequently cooled to ambient temperature to terminate the reaction.

3.3 | Adhesive Formulation

The hydrolyzed dextrin was blended with casein in a 1:1 ratio (10 g each) under constant stirring until a uniform mixture was obtained. Cold water (15 °C) was gradually introduced to prevent agglomeration and to adjust the consistency. Triethanolamine was added dropwise to stabilize the pH and promote paste formation.

3.4 | Adhesive Conditioning

The resulting paste was diluted with distilled water to reach the target viscosity and reheated at 60 °C under continuous stirring to ensure homogeneity. Heating was terminated once a stable, uniform adhesive paste was achieved, which was subsequently applied in biomass briquette production.

4 | RESULT AND DISCUSSION

4.1 | Mechanism of Binder Formation and Roles of Constituent Materials

Cassava peel can be utilized as a binder material in biobriquette fuel production due to its relatively high starch content, which holds potential as a natural bioadhesive[16, 17]. Starch is a natural polymer that exhibits adhesive properties after undergoing hydrolysis or gelatinization processes[18]. According to Siagian[19], cassava peel contains approximately 20% starch based on its dry weight. This starch can be hydrolyzed into dextrin, which subsequently acts as the primary component of the adhesive. The composition of cassava peel is presented in Table 1 .

Cassava peel samples were hydrolyzed using 1 N HCl to produce dextrin by cleaving the glycosidic bonds. The hydrolysis process aimed to convert starch into dextrin via glycosidic bond cleavage, as illustrated in Figure 2 . The starch present in cassava peel consists of approximately 23.92% amylose and 76.08% amylopectin, containing both α-(1,4) and α-(1,6) glycosidic linkages[21], making it poorly soluble in water.

TABLE 1 Composition of Cassava Peel [20]

Component	Composition (%)
Moisture	70.25
Starch	21.45
Sugar	5.13
Protein	1.12
Fiber	1.11
Ash	0.54
Fat	0.41

FIGURE 2 Dextrin from Cassava Peel Hydrolyzed with HCl Acid.

When HCl is introduced, the H^+ ions protonate the oxygen atoms in the glycosidic bonds, destabilizing the molecular structure. Consequently, these bonds are broken down into shorter chain fragments known as dextrins. Heating was applied to accelerate the hydrolysis process [21]. Dextrin exhibits better water solubility and enhanced adhesive properties than native starch, making it more suitable as a binding agent. Thus, the use of HCl enables the modification of starch into a more effective form for natural adhesive applications.

In the formulation of the cassava peel adhesive, casein and triethanolamine play critical roles in improving both the adhesive strength and the stability of the final product through specific chemical mechanisms. Casein, introduced into the hydrolyzed dextrin mixture (Figure 3), is a protein rich in carboxyl (-COO^-) and amine (-NH_2) groups that promote hydrogen bonding and electrostatic interactions with starch and dextrin [22, 23]. These interactions enhance adhesion by strengthening molecular bonding within the glue matrix. Additionally, casein undergoes partial denaturation during heating, forming a flexible network structure that improves the viscosity and consistency of the adhesive paste [24].

Triethanolamine functions as an emulsifying and pH-adjusting agent, optimizing the interaction between components. It contains hydroxyl (−OH) and amine (−NH_2) groups, allowing it to act as an emulsifier by forming ionic complexes with water and other constituents in the adhesive mixture [25]. This mechanism helps maintain the homogeneity of the mixture and prevents phase separation. Furthermore, triethanolamine acts as a buffer, stabilizing the pH and preventing starch and dextrin degradation, which could otherwise compromise adhesive performance [26]. These chemical interactions collectively contribute to a more effective, stable, and homogeneous adhesive.

As illustrated in Figure 4 , the produced adhesive thickened during the formulation process. This was attributed to the combined effects of dextrin's increased viscosity, casein's water-binding protein network, and triethanolamine's stabilizing action, resulting

FIGURE 3 Cassava Peel Adhesive Paste after Casein Addition.

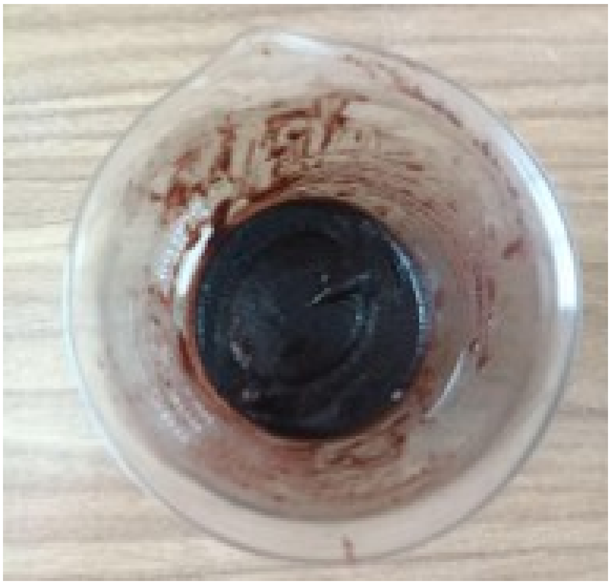

FIGURE 4 Mixture of Dextrin and Casein after Triethanolamine Addition.

in a well-bonding adhesive material, as shown in Figure 5 . The final product is suitable for use as a binder in biobriquette production.

4.2 | Physicochemical and Energy Properties of the Binder

Based on Table 2 , the cassava peel–based binder demonstrated physicochemical and energy characteristics in accordance with biomass briquette standards. Its viscosity (472 ± 6 cP) ensured homogeneous mixing, while adhesive strength (0.64 ± 0.02 MPa) was comparable to starch-based binders, maintaining structural integrity. A density of 1.20 ± 0.02 $g\,cm^{-3}$ satisfied the SNI 01-6235-2000 requirement (> 1.0 $g\,cm^{-3}$), indicating compact briquette formation. The calorific value (18.4 ± 0.1 $MJ\,kg^{-1}$) was equivalent to hardwood and within the standard range (14–20 $MJ\,kg^{-1}$), ensuring efficient combustion. Moisture content (8.2 ± 0.2)% and ash content (3.5 ± 0.1)% complied with SNI and ISO 17225-3:2014 limits, minimizing efficiency loss and fouling potential. High durability (91.6±0.4)% exceeded the international benchmark (> 80%), confirming storage and transport

FIGURE 5 Mixture of Dextrin and Casein after Triethanolamine Addition.

TABLE 2 Mean ± SD (n = 3) of Binder Properties and Characteristics of Cassava Peel-Based Biobriquettes

Parameter	R1	R2	R3	Avg (±SD)
Viscosity (cP)	465	478	472	472 ± 6
Adhesion (MPa)	0.62	0.65	0.64	0.64 ± 0.02
Density (g/cm^3)	1.18	1.21	1.20	1.20 ± 0.02
Calorific Value (MJ/kg)	18.3	18.5	18.4	18.4 ± 0.1
Moisture Content (%)	8.1	8.4	8.2	8.2 ± 0.2
Ash Content (%)	3.4	3.6	3.5	3.5 ± 0.1
Durability (%)	91.2	92.0	91.6	91.6 ± 0.4

stability. These findings highlight cassava peel waste as an environmentally friendly binder capable of producing briquettes with competitive national and international quality standards.

4.3 | Application of the Binder in Biomass Briquettes

Oil palm empty fruit bunches (EFB) and oil palm fronds (OPF) from the KM 30 Oil Palm Plantation, Balikpapan, were used as raw materials. Carbonization of EFB and OPF was conducted at 400 °C for 1 h to reduce volatile matter and increase fixed carbon, producing charcoal with minimal ash [27]. Cylindrical biobriquettes (10 cm × 2.5 cm, 48.9–49.5 g) were prepared from a 50:50 mixture of carbonized EFB and OPF (0.25 mm particle size) using cassava peel as a binder. Visual inspection indicated that commercial biobriquettes appeared darker (Figure 6), likely due to higher adhesive content. Density and calorific value (CV) were measured in triplicate (n = 3). Table 3 summarizes the mean ± SD values for both experimental and commercial biobriquettes.

The experimental biobriquettes exhibited slightly higher density (0.99–1.01 g/cm^3) compared to commercial samples (0.97 g/cm^3), indicating improved particle packing and binder distribution. The calorific value of the cassava peel–based biobriquettes averaged 6580 cal/g, which is higher than that of commercial briquettes (6450 cal/g). This enhancement can be attributed to the effective binding action of cassava peel, which promotes homogeneity in the carbon matrix and minimizes voids, thereby increasing energy content per unit volume. The triplicate measurements confirm the reproducibility of the process, with low standard deviations for both density and calorific value. These results suggest that cassava peel is an effective, low-cost binder

FIGURE 6 (Left) Biobriquette with Cassava Peel Binder, (Right) Commercial Biobriquette.

TABLE 3 Density and Calorific Value (CV) of Cassava Peel-Based and Commercial Biobriquettes (Mean ± SD, $n = 3$)

Sample	Density (g/cm^3)	CV (cal/g)
Experimental biobriquette	0.99 ± 0.01	6580 ± 45
Commercial biobriquette	0.97 ± 0.01	6450 ± 50

for biomass briquettes, capable of producing biobriquettes with superior mechanical integrity and energy performance relative to commercial products.

5 | CONCLUSION

Cassava peel was successfully developed as a natural binder for biomass briquettes, exhibiting suitable physicochemical and energy properties: viscosity (472 ± 6 cP), adhesion (0.64 ± 0.02 MPa), density (1.20 ± 0.02 $g\,cm^{-3}$), calorific value (18.4 ± 0.1 $MJ\,kg^{-1}$), moisture content (8.2 ± 0.2)%, ash content (3.5 ± 0.1)%, and durability (91.6 ± 0.4)%. Application of this binder in biobriquette production using carbonized EFB and OPF produced cylindrical briquettes with density (0.99–1.01 $g\,cm^{-3}$) and calorific value (6580±45 $cal\,g^{-1}$), higher than commercial samples (0.97 $g\,cm^{-3}$, 6450±50 $cal\,g^{-1}$), reflecting improved particle packing, uniform binder distribution, and enhanced energy content per unit volume. Triplicate measurements confirmed the reproducibility and consistency of the fabrication process. Overall, cassava peel serves as a low-cost, environmentally friendly, and efficient binder, capable of producing biobriquettes with superior mechanical integrity, energy performance, and compliance with national and international standards. This study demonstrates the potential of cassava peel valorization to support sustainable energy production and circular economy practices.

CREDIT

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How to cite this article: Yunita T., Yosua A. S., Yurischa D. U., Salsa M., Hana F., Riza H. S., Widi A., Riza H., (2026), Innovation in the Development of Biobriquette Binder Based on Cassava Peel Waste (Manihot Esculenta Crantz), *IPTEK The Journal for Technology and Science*, *37(2):124-132*.

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