JOURNAL OF MECHANICAL ENGINEERING, SCIENCE, AND INNOVATION

ITATS

Research Article

Analysis of the Characteristics of Cow Dung Waste Biopellets with Cassava Peel Starch Adhesive as an Alternative Fuel

Journal of Mechanical Engineering, Science, and Innovation
e-ISSN: 2776-3536
2025, Vol. 5, No. 2
DOI: 10.31284/j.jmesi.2025.v5i2.8092
ejurnal.itats.ac.id/jmesi

Indra Kusuma[1], Agus Sulistiawan[1], and Pelangi Eka Yuwita[1]

[1] *University of Nahdlatul Ulama Sunan Giri Bojonegoro, Indonesia*

Corresponding author:
Indra Kusuma
University of Nahdlatul Ulama Sunan Giri Bojonegoro, Indonesia
Email: ikusma9@gmail.Com

Abstract

This study aims to analyze the characteristics of biopellets made from the raw material of dried cow dung waste with cassava peel starch as an adhesive. The research method was carried out experimentally through several stages: raw material preparation, drying of cow dung under sunlight for 14 days, mixing with variations of cassava peel starch adhesive of 10%, 30%, and 50%, molding using a hydraulic press with pressures of 50, 60, and 70 kg, and testing the characteristics of the biopellets. The parameters tested included calorific value, moisture content, combustion rate, and ash content. The results showed that variations in adhesive levels and molding pressure affected the quality of the biopellets. The calorific value obtained ranged from 2,795.4 to 3,595.9 cal/g, moisture content 9.5–12.5%, combustion rate 0.74–1.71 g/min, and ash content 0.90–1.20%. In conclusion, biopellets from cow dung with the addition of cassava peel starch adhesive have characteristics that are feasible to be developed as an environmentally friendly alternative fuel.

Keywords: *Biopellets, Cow Dung, Cassava Peel Starch, Renewable Energy.*

Received: July 29, 2025; Received in revised: August 29, 2025; Accepted: September 1, 2025

Handling Editor: Rizal Mahmud

INTRODUCTION

Global energy needs continue to increase in line with population growth and industrialization, while dependence on fossil fuels such as oil, coal, and natural gas still dominates up to 80% of global energy consumption (IEA, 2022) [1]. This dependence causes environmental problems in the form of increased carbon emissions and climate change. Renewable energy currently contributes only about 13%, while nuclear energy contributes around 7% of global energy consumption [1]. One potential renewable energy source is biomass, including organic waste from livestock.

In the village of Mojomalang, which has a large population of beef cattle, produces quite abundant cow dung. until now, Its use is limited as manure, while the implementation of biogas technology has been hampered by costs and skill limitations. One potential alternative solution is to process cattle manure into biopellets. Biopellets have several advantages, such as high calorific value, good energy density, high combustion efficiency, and lower pollutant emissions compared to fossil fuels [2].

To improve biopellet quality, an adhesive is needed to strengthen the bonds between particles. Cassava peel starch has potential as a natural binder due to its amylose and amylopectin content, which can enhance mechanical strength without compromising combustion efficiency [3]. In addition to reducing waste and increasing farmers' income, biopellet production relies on pellet machines. These machines compress a mixture of cow manure and natural binders into uniform pellets, increasing energy density, mechanical strength, and facilitating storage and transportation. Machine parameters, such as pressure, roller speed, and temperature, greatly influence the final quality of biopellets, making proper selection and operation essential for successful production [4], [5]. However, to date, limited research has been conducted on the adhesive properties of cassava starch in improving biopellet quality, presenting an opportunity for this study to address that gap [6].

A number of studies have examined the use of cow manure as a raw material for biopellet production. Sohail et al. [7] tested biopellets made from cow manure mixed with agricultural waste, which produced higher calorific values, but their mechanical properties were still weak without a binding agent. Other studies [8] also show that cow manure biopellets have the potential to be used as renewable solid fuel, but their quality is highly dependent on the processing method and the presence of binders. Regarding natural binders, Damayanti et al. [9] found that adding tapioca to cocoa husk biopellets can increase density and mechanical strength, although the water content of the product is still relatively high. In addition, there is also research confirming that the use of starch binders affects the calorific value and water content, although the energy efficiency produced is still lower than coal [10].

To date, there has been no research specifically evaluating the use of cassava peel starch as a biopellet binder. This study has proven that flour extracted from cassava peel waste has the potential to be an environmentally friendly and effective biopellet binder. For example, research by Rudiyanto et al. [11] examined the use of cassava peel as a binder in the manufacture of coconut shell briquettes. Therefore, this study aims to fill this gap by examining the use of cassava peel starch as a binder in biopellets made from cow manure waste, as well as analyzing the effect of variations in binder content (10%, 30%, and 50%) and compression pressure (50, 60, and 70 kg) on the properties of the resulting biopellets. This research is expected to support the development of biomass-based renewable energy while providing practical solutions for livestock waste management at the community level [12].

METHODS AND ANALYSIS

Biomass Energy

Biomass is organic material derived from living organisms or biological activity, such as agricultural waste, forestry waste, and livestock waste. The main components of biomass are cellulose, hemicellulose, and lignin, which function as components of plant cell walls [13]. Biomass is classified as renewable energy because it comes from organic materials that can be naturally replenished. Biomass can be utilized directly through combustion or processed into other forms of energy such as briquettes, biopellets, bioethanol, or biogas [14].

Biopellets as an Alternative Fuel

Biopellets are biomass-based solid fuels produced through a densification process. They are typically small cylinders measuring 20–30 mm in length and approximately 8–12 mm in diameter [15]. Compared to raw biomass, biopellets offer several advantages, including higher calorific value, uniform size, low moisture content, ease of storage and transportation, and improved combustion efficiency. Additionally, they produce lower greenhouse gas emissions than fossil fuels, making them more environmentally friendly [16]. The biopellet produced is shown in Figure 1.

Cow Dung Waste

Cow dung is a type of solid biomass that is widely available in rural areas, especially in regions with high livestock populations. A cow can produce 8–10 kg of manure per day [17]. The main components of cow manure include organic matter, crude fiber, protein, and minerals, making it a potential feedstock for bioenergy. However, if not managed properly, this waste can cause environmental pollution, unpleasant odors, and increase greenhouse gas emissions such as methane (CH_4) and carbon dioxide (CO_2) [18]. The calorific value of cow dung as a fuel depends on its moisture content and processing. Dried cow dung typically has a calorific value of 15–17 MJ/kg, whereas fresh manure with 50–60% moisture content only has 6–8 MJ/kg. Incorporating cow dung into fuel pellets or blending it with agricultural residues can further increase its calorific value to around 18–19 MJ/kg. Compared to conventional fossil fuels, cow dung-based fuels are renewable, reduce waste, and emit lower levels of greenhouse gases. Utilizing cow dung for bioenergy can reduce reliance on coal, oil, and gas, contributing to a more sustainable and environmentally friendly energy mix, particularly in rural areas with abundant livestock [19].

Cassava Peel Starch as a biopellet adhesive

Cassava peel is an agricultural waste product that is typically underutilized, despite containing starch that can be used as a natural adhesive in biopellet production. Starch has good adhesive properties because it forms a gel when heated with water, thereby increasing the density and strength of biopellet adhesives [20]. The use of cassava peel starch as an adhesive can improve the mechanical strength and density of biopellets without reducing combustion efficiency [21].

Figure 1. Biopellet Form

Biopellet Quality Standards

According to the Indonesian National Standard (SNI 8021-2014) [22], biopellets as solid fuel must meet several quality parameters, including maximum moisture content of 12%, ash content <8%, minimum calorific value of 4,000 cal/g, and density ≥0.8 g/cm^3. This standard aims to ensure the efficiency, safety, and suitability of biopellets as an alternative fuel. Testing of biopellet characteristics generally includes moisture content, ash content, calorific value, bound carbon, and combustion rate [23].

Cow dung-based biopellets, when properly dried and processed, can achieve a calorific value of 15–19 MJ/kg, moisture content below 12%, and ash content under 8%, thereby meeting the SNI 8021-2014 standard. This makes them a viable and environmentally friendly alternative to conventional fossil fuels like coal or wood. Additionally, utilizing cow dung biopellets can reduce greenhouse gas emissions, optimize waste utilization, and support energy sustainability, particularly in rural areas with abundant livestock populations [24].

Biopellet Making Process

The biopellet manufacturing process consists of three main stages: preparation, molding, and testing. In the preparation stage, dried cow dung is collected and sieved to remove coarse impurities. Cassava peel starch is prepared separately through cleaning, refining, filtering, and sedimentation to obtain the starch extract. The biopellet manufacturing process is shown in Figure 2.

The composition of each treatment included varying levels of starch adhesive (10%, 30%, and 50%) and molding pressure (50, 60, and 70 kg/cm^2). After the two ingredients were mixed, they were molded using a hydraulic press. After molding, the biopellets were dried in an oven at 80°C for 1 hour until the moisture content dropped below 12% [25]. A 40-mesh particle size of cow dung (≈0.425 mm) was used because it provides an optimal balance: finer particles increase strength and density but require higher processing energy, while coarser particles reduce pellet quality. Therefore, the 40 mesh size was selected to pro-

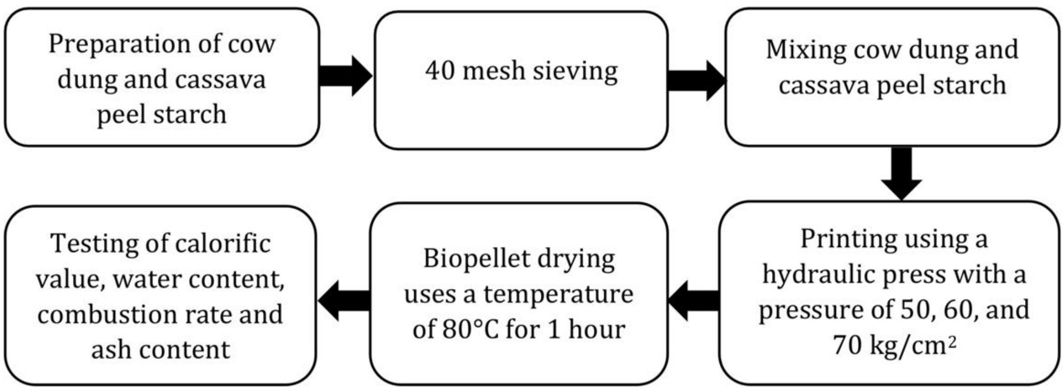

Figure 2. Biopellet Manufacturing and Testing Scheme

Table 1. Composition Of Cow Dung and Adhesive

Sample	Comparison	Cassava Peel Starch (%)	Cassava Peel Starch (Grams)	Cow Dung (%)	Cow Dung (Grams)
Variation 10%	1 : 9	10 %	12.6	90%	113.4
Variation 30%	3 : 7	30 %	37.8	70%	88.2
Variation 50%	1 : 1	50 %	63	50%	63
Total		126 Grams		126 Grams	

duce high-quality biopellets. Therefore, 40 mesh is considered the best particle size for producing high-quality biopellets [26]. The composition between variations is shown in Table 1.

Characteristic Testing

Moisture Content

Moisture content affects combustion efficiency; the higher the water content, the lower the calorific value produced because energy is used first to evaporate the water [27]. Moisture content testing is carried out using the loss on drying method with a moisture analyzer at 105°C. An initial sample of 2 grams is dried until constant weight, then the moisture content is calculated automatically [28]. The drying time to reach the target moisture content depends on the method, temperature, particle size, and environmental conditions. There is no fixed duration, the key point is to keep the material protected from moisture and monitor it regularly until the moisture content is below 12%. Proper drying ensures optimal combustion efficiency and mechanical quality of the biopellets, making them suitable for storage and use as solid fuel [29] [30], moisture content is calculated using Equation (1):

$$\text{Moisture Content} = \frac{W_{wet-}W_{dry}}{W_{wet}} \times 100\% \tag{1}$$

The parameter W_{wet} refers to the initial weight and W_{dry} represents the final weight.

Calorific Value

The calorific value indicates the energy content of biopellets and is tested using a bomb calorimeter. The sample is weighed, placed in a combustion chamber, filled with pressurized oxygen, and ignited. The calorimeter system records the temperature increase and calculates the calorific value [31]. The formula is given in Equation (2):

$$\text{Calorific Value} = \frac{(E_e \times \Delta T)-e_1-e_2-e_3}{A} \tag{2}$$

The parameter E_e represents the Equivalent Energy (cal/°C), while ΔT denotes the difference between the initial and final temperature (°C). In the calculation, three correction factors are considered: e_1 for acid correction, e_2 for axis correction, and e_3 for sulfur correction. Meanwhile, A indicates the mass of the sample, measured in grams (g).

Burning Rate

The combustion rate is defined as the weight loss per unit time during burning. The initial sample is weighed and burned in a porcelain cup, with the time measured using a stopwatch [32]. The burning rate is calculated using Equation (3):

$$\text{Burning Rate (g/min)} = \frac{m_{1-}m_2}{t} \tag{3}$$

The parameter m_1 represents the initial weight of the sample before combustion (grams), m_2 denotes the difference between the initial and final weights (grams), and t indicates the burning time (minutes).

Ash Content

Ash content is the residue after combustion. A higher ash content reduces the coloric value. The sample is dried in an oven at 105°C for 1–3 hours to reduce water content, then burned in a muffle furnace at 600°C until only inorganic ash remains [33]. The ash content is calculated using Equation (4):

$$\text{Ash Content} = \frac{w_{Ash}}{w_{Dry\ Level}} \times 100\% \tag{4}$$

The parameter w_{Ash} is ash weight after combustion (grams) and $w_{Dry\ Level}$ is sample weight after drying (grams).

Each test (moisture content, calorific value, combustion rate, and ash content) was conducted once for each treatment without repetition. The results presented in this study are single test data. For further research, it is recommended that repetitions and statistical analysis (e.g., three tests with standard deviation) be conducted to improve the accuracy and reliability of the results.

RESULTS AND DISCUSSIONS

Biopellet Characteristics

This study was conducted to analyze the characteristics of biopellets made from dried cow dung waste with the addition of cassava peel starch adhesive. Testing focused on the calorific value, moisture content, combustion rate, and ash content of the biopellets produced with varying cassava peel starch adhesive and molding pressure. The test results are shown in Table 2.

Moisture Content

Moisture content testing was conducted to determine the water content of the biopellets. Moisture content affects the combustion quality of the biopellets. The test was conducted using the loss-on-drying method using a moisture analyzer at a drying temperature of 105°C and an initial weight of 2 grams. The test results are presented in Figure 3.

Based on Figure 3, it shows that the higher the cassava peel starch adhesive content and the higher the molding pressure, the lower the water content of the biopellets, from 12.50% to 8.50%. A low water content indicates that the biopellets are denser and more flammable because less heat energy is wasted on water evaporation. A low water content

Table 2. Biopellet characteristic test results

No	Sample	Sample Code	Calorific Value (cal/grams)	Moisture Content (%)	Burning Rate (gr/minute)	Ash Content (%)
1	Variation 10%	T 1.1	2795.4	12.50 %	1.71	1.20 %
		T 1.2	2811.7	12.30 %	1.54	1.15 %
		T 1.3	2830.3	12.00 %	1.40	1.17 %
2	Variation 30%	T 2.1	3195.3	11.00 %	1.20	1.04 %
		T 2.2	3222.8	10.80 %	1.09	1.02 %
		T 2.3	3245.5	10.50 %	1.00	1.01 %
3	Variation 50%	T 3.1	3552.1	9.50 %	0.88	0.92 %
		T 3.2	3572.4	8.75 %	0.81	0.91 %
		T 3.3	3595.9	8.50 %	0.74	0.90 %

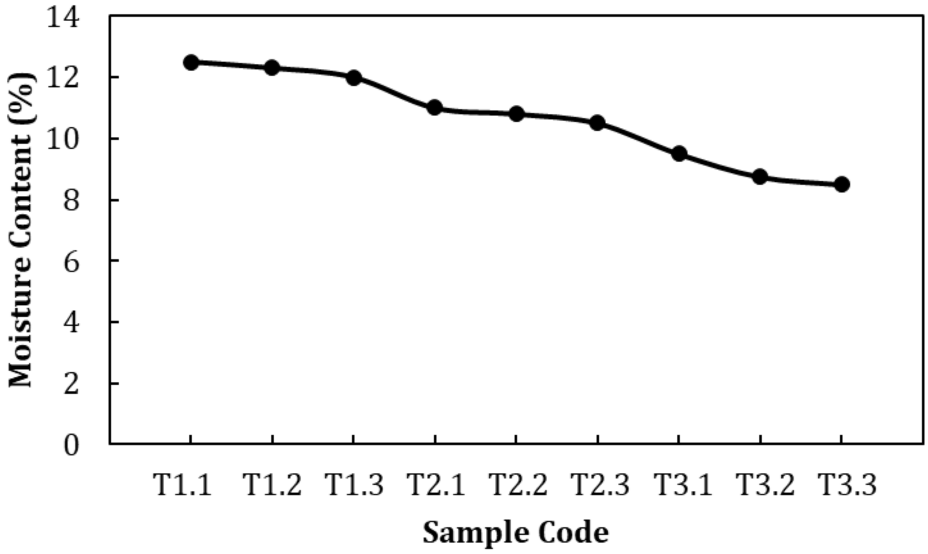

Figure 3. Graph of Moisture Content Testing Results

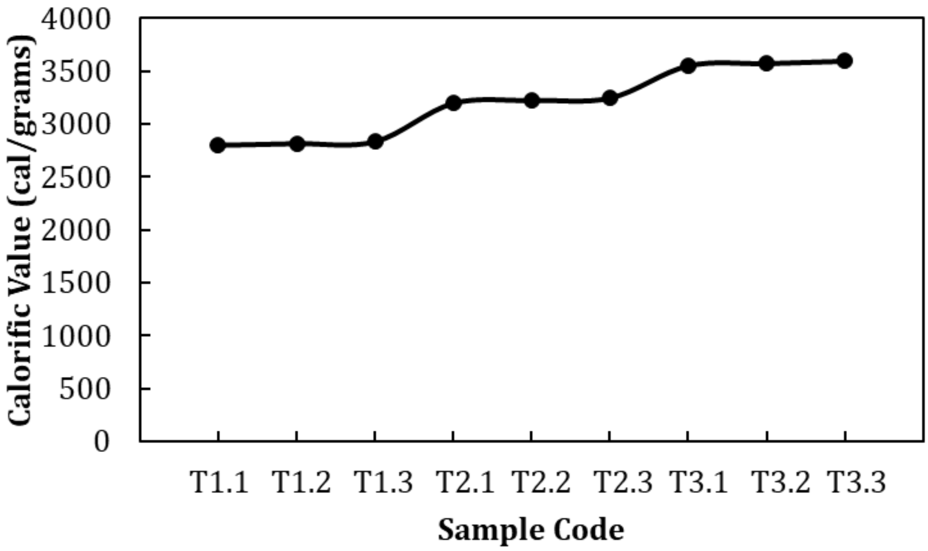

Figure 4. Graph of Calorific Value Test Results

also supports a higher calorific value and a more stable combustion rate. With a lower water content, the biopellets can produce an even flame and better combustion efficiency. These results are consistent with the research of Jasinkas [34], which shows that water content has a negative relationship with the calorific value and thermal efficiency of biopellets.

Calorivic Value

Calorific value is a key indicator of solid fuel quality. The higher the calorific value, the greater the energy produced by the combustion process. Calorific value testing was performed using a bomb calorimeter. The test results are presented in Figure 4.

Figure 4 shows that the calorific value of biopellets ranges from 2,795.5 cal/g to 3,595.9 cal/g. The calorific value increases with increasing cassava peel starch adhesive content and molding pressure. The adhesive not only acts as a binder but also generates heat by burning the starch. Higher pressure makes the biopellets denser, thus reducing their moisture content. Low moisture content promotes more efficient combustion because heat is not wasted on evaporating water, thus reducing the combustion rate.

Increasing the adhesive and pressure affects the quality of the biopellets, resulting in higher density, higher calorific value, lower moisture content, stable combustion rate, and lower ash content. This also aligns with research by Ridjayanti [35], which shows that biopellets with low moisture content and optimal adhesive yield high calorific value.

Burning Rate

The combustion rate is used to determine the speed at which biopellets burn until they are completely burned. The combustion rate value is obtained by dividing the weight before and after combustion by the combustion time. The test results are presented in Figure 5.

Figure 5 shows that the biopellet combustion rate ranges from 0.74 to 1.71 grams/minute. The combustion rate decreases with increasing adhesive content and molding pressure. Biopellets with higher adhesive and pressure become denser, so the flame is more stable and does not burn out quickly. A lower combustion rate also supports combustion efficiency because heat is released slowly and evenly. This is closely related to the low water content and higher calorific value of denser biopellets. The denser the biopellet structure, the smaller the air pores, so combustion is more controlled. These results are consistent with research by Lokesh Kumar Meena [36], which explains that the addition of adhesive affects the combustion speed and flame stability of biopellets.

Ash Content

Ash content indicates the solid residue resulting from biopellet combustion. The ash content value is used to determine the purity of the raw material and the efficiency of biopellet combustion. The test results are presented in Figure 6.

Figure 6 shows that the ash content of the biopellets ranges from 0.90% to 1.20%. A low ash content indicates a nearly complete combustion process with minimal solid residue. Ash content varies depending on the adhesive composition and molding pressure. Higher adhesive and pressure create denser biopellets, resulting in more even combustion and less ash production. Low ash content also contributes to biopellet quality because most of the organic material is burned away into heat energy. Research by Pecenka [37] shows that the addition of organic adhesive significantly affects the moisture content, ash content, and calorific value of biomass briquettes.

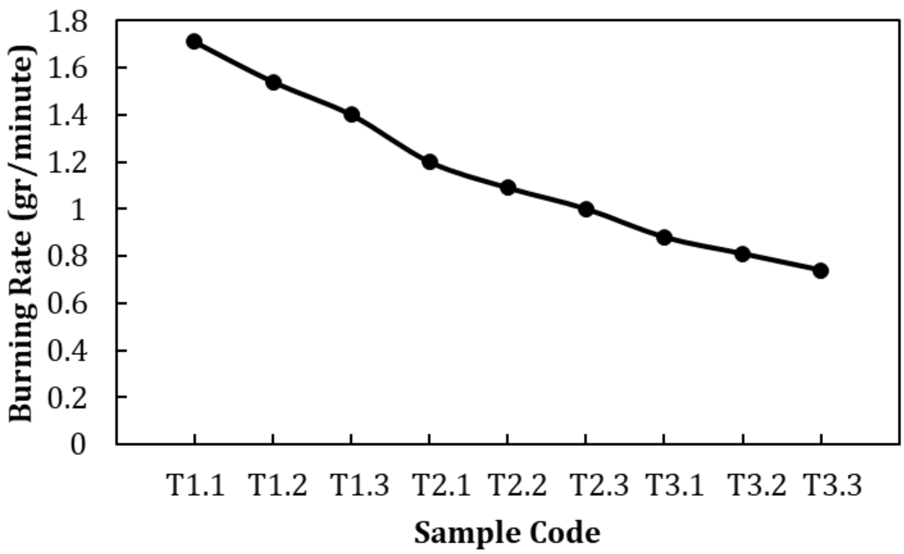

Figure 5. Graph of Burning Rate Test Results

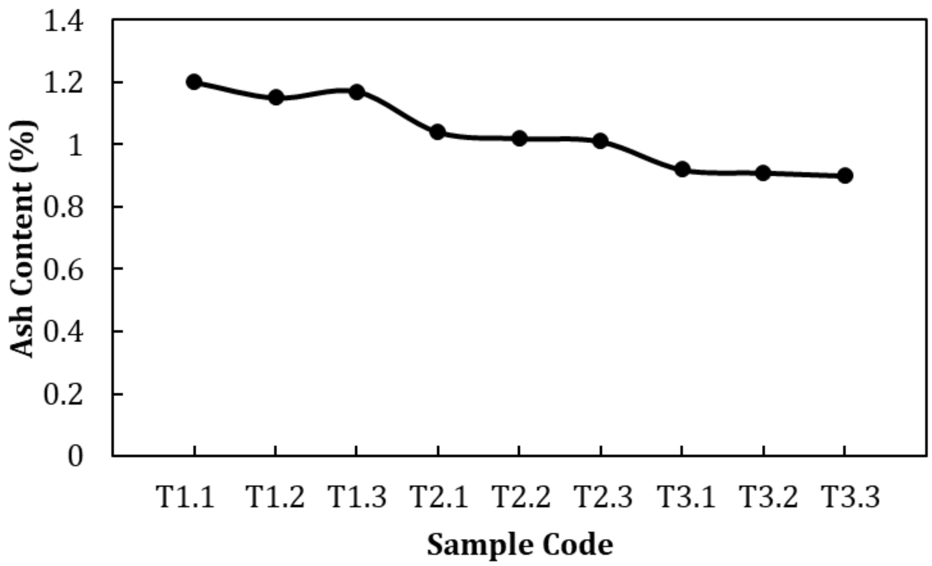

Figure 6. Graph of Ash Content Test Results

Effect of Adhesive Variation and Printing Pressure

Variations in the starch content of cassava peel adhesive and molding pressure have been shown to affect the characteristics of biopellets made from cow dung waste. The addition of adhesive acts as a binder for biomass particles, making the biopellets denser and stronger. Higher molding pressure also increases the density of the biopellets, reducing their water content. The calorific value of the biopellets increases because more solid organic material is burned, plus the starch content in the adhesive also burns, adding heat energy. The combustion rate tends to decrease in denser biopellets due to the limited air supply, making the combustion process more controlled and stable. The ash content of the biopellets is low because most of the organic material is burned to produce heat energy.

Characteristics of the Produced Biopellets

The characteristics of biopellets produced from cow dung waste with the addition of cassava peel starch adhesive indicate good quality. The resulting calorific value ranges from 2,795.4–3,595.9 cal/g, indicating the biopellets are capable of producing sufficient heat energy for alternative fuel. The moisture content is in the range of 8.50–12.50%, meeting biopellet quality standards, which require low moisture content for more efficient combustion.

The resulting combustion rate is in the range of 0.74–1.71 grams/minute, with a stable flame and more even combustion. The low ash content, between 0.90–1.20%, indicates that the raw material is almost completely burned without much solid residue. With these characteristics, cow dung biopellets can be used as an environmentally friendly alternative fuel to replace fossil fuels.

Comparison with Conventional Fuels and Other Biopellet Studies

The calorific values of cow dung–based biopellets in this study (2,795.4–3,595.9 cal/g) are lower than conventional fossil fuels such as coal (5,000–7,000 cal/g) but comparable to other biomass fuels. For example, wood-based biopellets generally reach 4,000–4,500 cal/g, while rice husk biopellets have values ranging from 3,000–3,500 cal/g. Similarly, the ash content obtained (0.90–1.20%) is relatively low and competitive with wood pellets (0.50–1.00%), indicating good fuel quality. These findings demonstrate that cow dung biopellets, although having a slightly lower calorific value, can serve as a viable alternative renewable fuel source, especially when local biomass waste is abundant.

Cost-Effectiveness Considerations for Future Research

Although this study focused on the physical and thermal properties of biopellets, future work should also address cost-effectiveness. Factors such as raw material availability, processing cost, adhesive preparation, and energy yield per unit cost are crucial for practical application. A cost-benefit analysis comparing cow dung biopellets with conventional fuels (e.g., kerosene, coal, or LPG) will help determine economic feasibility. Incorporating such evaluation will provide a clearer understanding of the sustainability and scalability of biopellet production.

Relationship between Compression Value, Calorific Value, Water Content, Combustion Rate and Ash Content

The compression value of biopellets produced by varying the molding pressure (50, 60, and 70 kg) and cassava peel starch adhesive (10, 30, and 50%) content influences the biopellet characteristics, particularly the moisture content, ash content, calorific value, and combustion rate. The higher the molding pressure and adhesive content, the higher the compression value, as the biopellet structure becomes denser and more compact.

The relationship between compression value, ash content, moisture content, calorific value, and combustion rate is mutually supportive and serves as an indicator of biopellet quality. These results support research by Iskandar [38], which explains that densification pressure and the use of cassava starch adhesive significantly increase the density and calorific value of biopellets, while simultaneously reducing the moisture and ash contents.

CONCLUSIONS

Variations in the cassava peel starch adhesive content and molding pressure have been shown to affect the characteristics of biopellets made from cow dung waste. The addition of adhesive increased the density of the biopellets, resulting in a decrease in moisture content from 12.5% to 9.5%, an increase in the calorific value from 2,795.4 cal/g to 3,595.9 cal/g, a more stable combustion rate in the range of 1.71–0.74 g/min, and a decrease in the ash content from 1.20% to 0.90%.

The resulting biopellets had a calorific value ranging from 2,795.4–3,595.9 cal/g, a moisture content of 12.5–9.5%, a combustion rate of 1.71–0.74 g/min, and an ash content of 1.20–0.90%. These characteristics approach biopellet quality standards and support their use as an environmentally friendly alternative fuel. The relationship between pressure value, moisture content, calorific value, combustion rate, and ash content is interrelated. The denser the biopellets, the less air cavities there are so that the water content decreases from 12.50% to 8.5%, then the calorific value increases from 2,795.4 cal/gr to 3,595.9 cal/gr, the combustion rate is more stable from 1.71 gr/minute to 0.74 gr/minute, and the ash content becomes lower from 1.20% to 0.90%.

Based on the results of this study, it is suggested as follow:

1. Further research could test other variables, such as different types of natural adhesives or varying drying temperatures.
2. Designing a biomass stove specifically for biopellets.
3. Testing the performance of biopellets in a biomass stove.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to their academic supervisors for their valuable guidance and support throughout the research. Appreciation is also extended to all individuals and institutions that contributed to the successful completion of this study.

DECLARATION OF CONFLICTING INTERESTS

The authors declare that they have no potential conflicts of interest regarding the research, authorship, and/or publication of this article.

FUNDING

This research received partial financial support from the second academic supervisor, Pelangi Eka Yuwita. Additional support was provided by private sources. The authors gratefully acknowledge this assistance.

REFERENCES

[1] International Energy Agency (IEA), *Data and Statistics*. [Online]. Available: https://www.iea.org/data-and-statistics

[2] T. A. Pradana, B. Yunianto, and M. Muchammad, "ANALISIS KARAKTERISTIK BIOPELET BERBAHAN DASAR LIMBAH PERTANIAN DAN PERKEBUNAN DENGAN CAMPURAN ZAT PEREKAT ALAMI," JURNAL TEKNIK MESIN, vol. 11, no. 3, pp. 494-499, Jul. 2023.

[3] A. W. Wasistha, M. R. S. Dika, A. S. Aulia, N. M. Samudra, and D. N. Putri, "Physical and Mechanical Characteristics of Edible Film Based on Cassava Peel Starch," *AGRISAINTIFIKA J. Ilmu-Ilmu Pertan.*, vol. 5, no. 2, p. 149, 2021, doi: 10.32585/ags.v5i2.1877.

[4] M. Hassan, M. Anwar, S. Fahad, B. Masud, and W. Ahmad, "Biomass pelletizing : Characterization of cow dung assisted solid recovered bio-fuel from agricultural waste," no. March, 2021, doi: 10.1109/ICECE51984.2021.9406289.

[5] A. M. Kartini, G. P. Sentosa, and E. S. Khoirunnada, "Diseminasi Pengolahan Limbah Kulit Singkong dan Kotoran Sapi Sebagai Bahan Bakar Alternatif di Desa Kemuning Lor Jember Abstrak Jurnal Pengabdian Nasional (JPN) Indonesia," vol. 5, no. 3, pp. 818–827, 2024.

[6] W. A. Wibowo, A. D. Susanti, and P. Paryanto, "Characterization and Combustion Kinetics of Binderless and Bindered Dry Cow Dung Bio-Pellets," *Equilib. J. Chem. Eng.*, vol. 8, no. 1, p. 19, 2024, doi: 10.20961/equilibrium.v8i1.83645.

[7] H. Sohail, M. Hassan, M. Anwar, S. F. Bin Masuad, and W. Ahmad, "Biomass pelletizing: Characterization of cow dung assisted solid recovered bio-fuel from agricultural waste," *2021 4th Int. Conf. Energy Conserv. Effic. ICECE 2021 - Proc.*, no. March, 2021, doi: 10.1109/ICECE51984.2021.9406289.

[8] A. Szymajda, G. Laskar, and M. Joka, "Assessment of Cow Dung Pellets as a Renewable Solid Fuel in Direct Combustion Technologies," Energies 14, no. 4: 1192, 2021.

[9] R. Damayanti, N. Lusiana, and J. Prasetyo, "Study Effect of Particle Size and Tapioca Starch Addition on Biopelet Characteristic from Cacao Shell (Theobroma cacao L.) as Alternative Renewable Fuel," *J. Teknotan*, vol. 11, no. 1, 2017.

[10] V. Purwandari, M. Harahap, L. I. P. Zai, Dan M. A. Mubarakh, "Pengolahan Limbah Kulit Kakao Dan Kemiri Pada Pembuatan Biopelet Sebagai Bahan Bakar Alternatif," Jurnal Kimia Saintek Dan Pendidikan, Vol. 6, No. 2, Pp. 72–78, 2022. Doi:10.51544/Kimia.V6i2.3492.

[11] B. Rudiyanto, I. Rida, Z. Ulma, D. Ari, Dan M. Hijiriawan, "Utilization Of Cassava Peel (Manihot Utilissima) Waste As An Adhesive In The Manufacture Of Coconut Shell (Cocos Nucifera) Charcoal Briquettes," International Journal Of Renewable Energy Development (Ijred), Vol. 12, No. 2, Pp. 270–276, 2023. [12] D. Kevin and D. A. Sari, "Pemberdayaan Masyarakat melalui Pemanfaatan Kotoran Sapi Menjadi Biogas sebagai Sumber Energi Terbaharukan," *Abdi J. Pengabdi. dan Pemberdaya.*

Masy., vol. 7, no. 1, pp. 119–127, 2025, doi: 10.24036/abdi.v7i1.1043.

[13] Mursalim, Munir, Fitriani, and I. D. Novieta, "Kandungan Selulosa, Hemiselulosa dan Lignin Serbuk Gergaji Kayu Jati (Tectona grandits L.F) dan Daun Murbei (Morus alba) Yang Dikombinasikan Sebagai Pakan Ternak," *Semin. Nas. Sinergitas Multidisiplin Ilmu Pengetah. dan Teknol.*, vol. 2, pp. 323–327, 2019.

[14] N. Adi Sasongko, N. Gunadi Putra, and M. L. Donna Wardani, "Review of types of biomass as a fuel-combustion feedstock and their characteristics," *Adv. Food Sci. Sustain. Agric. Agroindustrial Eng.*, vol. 6, no. 2, pp. 170–184, 2023, doi: 10.21776/ub.afssaae.2023.006.02.8.

[15] Masitoh, Mersi Kurniati, Dan Irzaman, "Analisis Diameter Biopelet Sekam Padi Terhadap Efisiensi Energi Bahan Bakar," Prosiding Seminar Nasional Dan Rapat Tahunan Bidang Mipa (Semirata) — Departemen Fisika Fmipa Ipb, Bogor, 2014.

[16] F. Goembira, D. M. Aristi, D. Nofriadi, and N. T. Putri, "Analisis Konsentrasi PM2,5, CO, dan CO2, serta Laju Konsumsi Bahan Bakar Biopelet Sekam Padi dan Jerami pada Kompor Biomassa," *J. Ilmu Lingkung.*, vol. 19, no. 2, pp. 201–210, 2021, doi: 10.14710/jil.19.2.201-210.

[17] S. Huda and W. Wikanta, "Pemanfaatan Limbah Kotoran Sapi Menjadi Pupuk Organik Sebagai Upaya Mendukung Usaha Peternakan Sapi Potong di Kelompok Tani Ternak Mandiri Jaya Desa Moropelang Kecamatan Babat Kabupaten Lamongan," *Aksiologiya J. Pengabdi. Kpd. Masy.*, vol. 1, no. 1, p. 26, 2016, doi: 10.30651/aks.v1i1.303.

[18] T. M. A. Jr., J. A. O. Vergara, and L. P. Canizares-Gallardo, "Greenhouse gas emissions from livestock manure (cattle) in different feeding formulas, methods and practices," *J. Biodivers. Environ. Sci. | JBES*, vol. 22, no. 1, pp. 7–15, 2023, [Online].

[19] A. Szymajda Dan G. Łaska, "The Effect Of Moisture And Ash On The Calorific Value Of Cow Dung Biomass," Proceedings Of Ismo'19 (Innovations-Sustainability-Modernity-Openness Conference), Bialystok, Poland, 22–23 May 2019; Proceedings, Vol. 16, No. 1, P. 4, 2019. Doi:10.3390/Proceedings2019016004.

[20] F. E. Puri, A. D. Wulandari, And A. R. Setyawati, "Biobriket Limbah Kulit Singkong (Manihot Esculenta), Inovasi Sumber Energi Alternatif Di Wonogiri," Jurnal Jaringan Penelitian Pengembangan Dan Penerapan Inovasi (Jarlitbang), Vol. 1, No. 1, Pp. 60- 66, 2018. [Online]. Available: Https://Jurnal.Wonogirikab.Go.Id/Jarlitbang/Article/View/20

[21] V. A. Surya and D. V. Wijanarko, "Pengaruh Perekat Tapioka terhadap Kualitas Biopelet dari Campuran Tongkol Jagung, Ampas Tebu, dan Ampas Kopi," *J. Tek. Mesin*, vol. 12, no. 02, pp. 39–44, 2024.

[22] Badan Standardisasi Nasional, *SNI 8021:2014 – Pelet kayu*. Jakarta: Badan Standardisasi Nasional, 2014. [Online]. Available: https://www.bsn.go.id

[23] I. Rusnadi, R. Junaidi, S. Hidayat, R. Yuanda, and S. Bayu A, "Biopelet Beraromaterapi Sebagai Alternatif Energi Panas Pengganti Bahan Bakar," *Pros. Semin. Nas. FIRST*, vol. 1, pp. 199–206, 2023.

[24] K. Kusmiyati, D. K. Wijaya, B. J. R. Hartono, G. F. Shidik, and A. Fudholi, "Harnessing the power of cow dung: Exploring the environmental, energy, and economic potential of biogas production in Indonesia," *Results Eng.*, vol. 20, no. July, p. 101431, 2023, doi: 10.1016/j.rineng.2023.101431.

[25] D. M. Kamal *et al.*, "Alat Pengering Biopelet Tipe Rak Dengan Daya 500 Watt," *J. Mech. Eng. Mechatronics*, vol. 8, no. 2, pp. 87–95, 2023.

[26] W. Intagun and N. Tarawadee, "The effect of particle size on the bulk density and durability of pellets: bagasse and eucalyptus bark," *Res. Knowl.*, vol. 2, no. 1, pp. 74–79, 2015, doi: 10.14456/randk.2016.10.

[27] C. Scott, T. M. Desamsetty, and N. Rahmanian, "Unlocking Power: Impact of Physical

and Mechanical Properties of Biomass Wood Pellets on Energy Release and Carbon Emissions in Power Sector," *Waste and Biomass Valorization*, vol. 16, no. 1, pp. 441–458, 2025, doi: 10.1007/s12649-024-02669-z.
[28] L. Fridh, L. Eliasson, and D. Bergström, "Precision and accuracy in moisture content determination of wood fuel chips using a handheld electric capacitance moisture meter," *Silva Fenn.*, vol. 52, no. 5, pp. 1–13, 2018, doi: 10.14214/sf.6993.
[29] P. Murugan, S. Dhanushkodi, K. Sudhakar, and V. H. Wilson, "Industrial and small-scale biomass dryers: An overview," *Energy Eng. J. Assoc. Energy Eng.*, vol. 118, no. 3, pp. 435–446, 2021, doi: 10.32604/EE.2021.013491.
[30] M. I. D. W. Putri *et al.*, "Hybrid Biopellets Characterization of Gamal Wood (Gliricidia sepium) and Robusta Coffee Husk at Various Compositions," *J. Sylva Lestari*, vol. 12, no. 3, pp. 595–609, 2024, doi: 10.23960/jsl.v12i3.913.
[31] O. Nurhilal, "Desain Kalorimeter Bomb Biomassa dengan Metode Oksigen Dinamik," *J. Ilmu dan Inov. Fis.*, vol. 1, no. 2, pp. 21–27, 2017, doi: 10.24198/jiif.v1i02.15355.
[32] A. Fajari, Sudarti, and Yushardi, "Pengujian Laju Pembakaran Briket Biomassa Dari Tempurung Kelapa dan Sekam Padi," *J. Ilm. Wahana Pendidik.*, vol. 2024, no. 23, pp. 1208–1216, 2024.
[33] F. R. Abadi, "Design of a Simple Muffle Furnace for Temperature Optimization in Ash Content Analysis," *J. Neutrino*, vol. 10, no. 2, p. 30, 2018, doi: 10.18860/neu.v10i2.4559.
[34] A. Jasinskas *et al.*, "Assessment of Quality Indicators of Pressed Biofuel Produced from Coarse Herbaceous Plants and Determination of the Influence of Moisture on the Properties of Pellets," *Sustain.*, vol. 14, no. 3, 2022, doi: 10.3390/su14031068.
[35] S. M. Ridjayanti, W. Hidayat, R. A. Bazenet, I. S. Banuwa, and M. Riniarti, "PENGARUH VARIASI KADAR PEREKAT TAPIOKA TERHADAP KARAKTERISTIK BRIKET ARANG LIMBAH KAYU SENGON (Falcataria mollucana)," *ULIN J. Hutan Trop.*, vol. 6, no. 1, p. 38, 2022, doi: 10.32522/ujht.v6i1.5597.
[36] L. Kumar Meena, R. Singh, P. Kalyan, D. Meena, and N. Sharma, "Impact of Binder Materials on the Mechanical and Thermal Properties of Biofuel Briquettes," *Biol. Forum-An Int. J.*, vol. 16, no. 9, p. 178, 2024.
[37] O. F. Obi, R. Pecenka, and M. J. Clifford, "An important component of global renewable energy mix is the use of loose biomass, including agricultural and forestry residues, to produce solid fuels in the form of briquettes. Briquettes play a significant role in bioenergy mix in developing and develo," *Energies*, vol. 15, no. 7, pp. 1–22, 2022.
[38] N. Iskandar, S. Sulardjaka, M. Munadi, S. Nugroho, R. C. Muhamadin, and D. F. Fitriyana, "The effect of water content and binder made from cassava starch and densification pressure on the quality of rice husk bio-pellets," *J. Phys. Conf. Ser.*, vol. 1517, no. 1, 2020, doi: 10.1088/1742-6596/1517/1/012019.