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Effect of Variation of Sugarcane Bagasse and Salak Peel Composition on Moisture Content and Combustion Rate of Biomass Briquettes

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Abstract

To the best of our knowledge, the combination of sugarcane bagasse and salak (or snake fruit) peel has never been formulated into biomass briquettes. Our study is the first to map the trade-off between moisture content and combustion rate across five blending ratios of these two materials. We evaluate the effect of varying compositions of sugarcane bagasse and salak peel on the moisture content and combustion rate of biomass briquettes as a means of utilizing agricultural waste for renewable energy. The briquettes were produced through a carbonization process at 400 °C, mixed with tapioca flour as a binder, molded, and dried. Five formulation ratios were tested: 100:0, 75:25, 50:50, 25:75, and 0:100 (bagasse: salak peel). Moisture content was determined based on the mass difference before and after drying, while the combustion rate was calculated from the mass change during the combustion process. The results showed that all briquette variations had a moisture content below 10%, with the lowest value of 7.00% in the 100% salak peel composition and the highest of 8.76% in the 100% sugarcane bagasse composition. The highest combustion rate of 0.27 g/min was obtained for the 100% sugarcane bagasse variant, while the lowest rate of 0.17 g/min was found in the 100% salak peel variant. Blend formulations such as 50:50 and 25:75 demonstrated balanced thermal performance, making them potential candidates for efficient and environmentally friendly solid fuels. These findings indicate that a combination of sugarcane bagasse and salak peel can be utilized as a sustainable raw material for briquettes with good combustion characteristics. As a contribution, the baseline thermal characteristic data for the sugarcane bagasse and salak fruit peel mixture, along with the identified threshold of sugarcane bagasse composition (≥75%) that causes briquettes to exceed the moisture content limit specified in SNI 01-6235-2000, can serve as an initial formulation reference for the development of biomass briquettes based on local agricultural waste.

Keywords:
Biomass briquettes, combustion rate, moisture content, salak peel, sugarcane bagasse

1. Introduction

Energy is one of the key factors supporting sustainable development due to its close relationship with energy consumption patterns and their impact on the environment, particularly carbon emissions (Khan et al., 2020). Energy demand in Indonesia is projected to increase by an average of 2.9% annually from

2019 to 2050 (Dewan Energi Nasional, 2019). This increase poses a major challenge in ensuring the future availability of national energy. The dominant reliance on fossil fuels such as coal, petroleum, and natural gas not only accelerates the depletion of non-renewable resources but also causes environmental pollution and increased greenhouse gas emissions. Therefore, sustainable and environmentally friendly alternative energy solutions are urgently needed. One potential and widely available energy source is the utilization of biomass waste.

Biomass is organic waste derived from living organisms such as plants, animals, and microorganisms. Plants absorb carbon dioxide (CO_2) from the air through photosynthesis and convert it into organic compounds that possess energy value. Biomass waste has been widely developed as a renewable energy source that not only protects the environment but also has potential as an alternative fuel and industrial feedstock (Haberl, 2015). One form of energy utilization from biomass is by converting it into briquettes, a solid fuel that can replace fossil fuels (Dinesha et al., 2019).

Sugarcane bagasse is an agricultural waste product with significant potential as a raw material for briquette production, as its high lignin and cellulose content contribute to the briquettes' calorific value (Pohan et al., 2024). This waste is generated during sugarcane processing and is commonly used as a source of thermal energy, including as fuel in boiler systems (Muriyani et al., 2023). Globally, sugarcane bagasse production is estimated to reach approximately 279 million metric tons per year, making it one of the world's primary biomass sources (Mekonen et al., 2024). The chemical composition of sugarcane bagasse consists of 48–52% water, 3.84% ash, 22.09% lignin, 37.65% cellulose, 27.97% pentosans, 3.01% silica, and 3.3% reducing sugars (Muriyani et al., 2023). In terms of calorific value, the proximate analysis conducted by Daramola and Ayeni (2020) showed a calorific value of 17.36 MJ/kg for sugarcane bagasse, while Sohaib et al. (2017) reported a calorific value of approximately 18.5 MJ/kg. This high calorific value is influenced by the high pentosan content, making sugarcane bagasse an excellent energy source as a raw material for biomass briquettes.

In the briquette manufacturing process, biomass feedstocks such as sugarcane bagasse often require a binder to improve the physical and thermal properties of the resulting briquettes, such as moisture content, ash content, combustion rate, and calorific value. Tapioca starch is a commonly used organic binder because it is readily available, inexpensive, and possesses good dry-bonding strength (Smith & Idrus, 2017). However, Afandi et al. (2018) demonstrated that sugarcane bagasse briquettes using sago flour as a binder did not meet the minimum calorific value specified in the Indonesian National Standard (SNI) 01-6235-2000; thus, additional raw materials are needed to improve their thermal performance. Salak peel emerges as a potential alternative for this purpose. Salak peel is an organic waste product that is abundantly available in salak production centers but has not yet been optimally utilized. Research by Alexander et al. (2024) shows that briquettes made from salak peel produce a calorific value of 26–27 MJ/kg, with a carbon content of 42–56%, a moisture content of 8–14%, and an ash content of 9–13%. These values indicate that salak peel has high potential as a solid fuel, both in terms of thermal efficiency and combustion characteristics.

Although these two materials have been studied separately, research on the effects of varying the composition of sugarcane bagasse and salak peel mixtures on the characteristics of biomass briquettes remains very limited. Bot et al. (2023) prepared briquettes from sugarcane bagasse and three other agricultural residues, carbonized at 400 °C followed by starch binding. They found that bagasse alone is poorly suited to large-scale briquette production because of its chemical properties, low initial density, and natural moisture content. They recommended it be blended with a complementary residue to balance these limitations. Meanwhile, salak peel has been examined alongside other fruit-processing residues as a carbonized feedstock with high fixed-carbon content (Perdana et al., 2025). These characterizations, however, treated each fruit waste as a separate sample rather than formulating them into blended briquettes. Similarly, Alexander et al. (2025) demonstrated that carbonized salak peel was bound as a single feedstock rather than as a component of a blend. In contrast, blending salak peel with a second material has been attempted by Rotami et al. (2025), who combined salak peel char with goat manure char, which was livestock waste rather than an agricultural residue. Suluh et al. (2023) reported that salak has been blended with coconut shell at a 40:60 ratio. Taken together, sugarcane bagasse has been shown to require a complementary feedstock, and salak peel has been blended with livestock and plantation wastes. However, to the best of the authors' knowledge, the two have not been co-formulated, and no study has mapped how moisture content and burning rate respond across their blending ratios.

Therefore, this study aims to analyze the effects of varying the composition of sugarcane bagasse and salak peel on the moisture content and combustion rate of biomass briquettes produced through a carbonization process using tapioca flour as a binder. This study is expected to provide a scientific contribution of baseline thermal characterization data for this material pair and identify the bagasse threshold (≥75%) beyond which briquettes exceed the 8% moisture limit set by SNI 01-6235-2000, providing an initial formulation reference for briquette development based on local agricultural residues.

2. Methods and Materials

2.1 Sample Preparation

The briquette production process begins with the natural drying of biomass waste, specifically sugarcane bagasse and salak peel. The dried materials are then chopped to facilitate the carbonization process. Next, the sample is placed in a porcelain cup and carbonized in a furnace at 400 °C for 4 hours. The carbonized samples were then ground using a mortar and pestle. The percentage ratios of sugarcane bagasse to salak peel were 50%:50% (variation 1); 25%:75% (variation 2); 0%:100% (variation 3); 75%:25% (variation 4); and 100%:0% (variation 5). Charcoal powder, weighed according to the specified percentage variations, was then mixed with tapioca as a binding agent. The amount of tapioca flour added to each sample was 3 grams. Water was then added to the sample mixture and stirred until evenly distributed. The sample mixture was then molded using a briquette press machine (Figure 1) to form the briquette shape. The finished briquettes were then oven-dried for 24 hours. The briquette sample formulations are shown in Table 1.

Table 1. Percentage composition of raw material mixtures.

Treatment	Charcoal (g)		Tapioca Flour (g)	Water (mL)
	Sugarcane Bagasse	Salak Peel		
Variation 1	3.0	3.0	3.0	15
Variation 2	1.5	4.5	3.0	15
Variation 3	0.0	6.0	3.0	15
Variation 4	4.5	1.5	3.0	15
Variation 5	6.0	0.0	3.0	15

Figure 1. Briquette press machine.

2.2 Observed Parameters

2.2.1 Moisture Content

The briquettes were dried in an oven at 105 °C, and the process was repeated until a constant weight was achieved. Next, the moisture content (%) of the briquettes can be calculated using Eq. 1.

$$Moisture\ Content\ (\%) = \frac{Wo - W}{Wso}\ x100\% \quad (1)$$

where :
wo : weight of the sample and container before drying (g)
w : weight of the sample and container after drying (g)
wso : initial weight of the sample (g)

2.2.2 Combustion Rate

Samples of uniform weight and size are prepared to ensure the consistency and accuracy of test results. This step aims to ensure that all data obtained can be objectively compared. Next, the samples are placed in combustion tubes and burned using a flame to directly observe their combustion behavior. During the process, the burning time is recorded using a stopwatch, and the data obtained is used to calculate the combustion rate using Eq. 2.

$$Lp = \frac{m}{t} \quad (2)$$

where :
Lp : Combustion rate (g/min)
m : Sample weight (g)
t : Burning time (minutes)

3. Results and Discussions

The two main parameters used to assess the quality of biomass briquettes made from a mixture of sugarcane bagasse and salak peel are moisture content and combustion rate. The moisture content of biomass can affect the energy efficiency of briquettes because excessively high moisture content causes most of the energy to be used for evaporating water rather than generating heat, resulting in suboptimal briquette performance (Abdel-Aal et al., 2023). Meanwhile, the combustion rate indicates how quickly the material burns. This can serve as an indicator of combustion stability and the duration of use. Therefore, both tests play a crucial role in assessing briquette quality. These tests can also determine the thermal characteristics of both materials while evaluating the potential of the sugarcane bagasse and salak peel mixture as an efficient and environmentally friendly alternative energy source.

3.1 Moisture Content Testing

The moisture content of biomass is one of the key parameters that can affect the efficiency of the carbonization process and the quality of the energy produced. Biomass with high moisture content tends to require more energy to evaporate the water before the combustion process can proceed effectively, thereby affecting the thermal efficiency of solid fuels such as briquettes (Saidur et al., 2011). In this context, determining moisture content is a crucial initial step in assessing the potential of biomass as an alternative energy feedstock, as shown in Table 2.

Table 2. Biomass moisture content.

Sample	Sample Weight (g)	Charcoal Weight (g)	Water Content (%)
Sugarcane Bagasse	25.8855	3.5624	86.28
Salak peel	27.9891	9.2746	66.86

Based on the test results, sugarcane bagasse had a moisture content of 86.28%, while salak peel had a moisture content of 66.86%. These values were obtained from the difference in mass between the biomass before and after heat treatment in a furnace. The high moisture content in sugarcane bagasse can be attributed to its morphological characteristics, namely fine fibers and high porosity, which allow it to absorb and store large amounts of water. Conversely, salak peel has a denser tissue structure and is naturally water-resistant, so its natural moisture content tends to be lower. This difference in moisture content indicates that each biomass has complementary advantages in briquette formulation. The high moisture content in sugarcane bagasse can increase the porosity of the carbonized charcoal, thereby facilitating the absorption of binding agents and the formation of sturdy briquettes. On the other hand, the lower moisture content in salak peel allows for a more efficient combustion process, as less energy is wasted evaporating water (Demirbas, 2004). The combination of both enables the production of briquettes with optimal thermal characteristics, both in terms of shape stability and combustion efficiency. Briquette production in Indonesia follows the SNI 01-6235-2000 standard, which establishes a number of quality parameters to ensure the efficiency and sustainability of briquettes as an energy source.

The results of the briquette moisture content test in Table 3 show that the five sample variations have moisture content values ranging from 7.00% to 8.76%. Variation 3 (100% salak peel) produced the lowest moisture content of 7.00%, while Variation 5 (100% sugarcane bagasse) produced the highest moisture content of 8.76%. Variation 1 (50:50), Variation 2 (25:75), and Variation 4 (75:25) exhibited moisture contents of 7.39%, 7.59%, and 8.33%, respectively. This aligns with the initial biomass moisture content data in Table 2, where sugarcane bagasse has a significantly higher moisture content (86.28%) compared to salak peel (66.86%), so briquettes with a higher proportion of sugarcane bagasse tend to retain more moisture even after undergoing the drying process.

Table 3. Water content of briquettes.

Sample Variation	Initial Weight (g)	Constant Weight (g)	Moisture Content (%)
Variation 1	8.0628	7.4669	7.39
Variation 2	7.3562	6.7979	7.59
Variation 3	7.8161	7.2690	7.00
Variation 4	8.6748	7.9522	8.33
Variation 5	6.2657	5.7173	8.76

As shown in Figure 2, the trend of increasing moisture content corresponds to the increasing proportion of bagasse charcoal in the briquette formulation. This pattern is closely related to the physical and chemical characteristics of each raw material. Bagasse is a lignocellulosic material composed of cellulose, hemicellulose, and lignin, resulting in charcoal with a relatively more porous structure. This high porosity increases the surface area of the charcoal, thereby enhancing its ability to absorb water vapor from the environment. Conversely, salak peel has a harder and denser texture, with a higher fixed carbon content, resulting in denser charcoal that is less hygroscopic. Therefore, Variation 3, which uses only salak peel charcoal, yields the lowest moisture content, reflecting the material's tendency to absorb less water vapor.

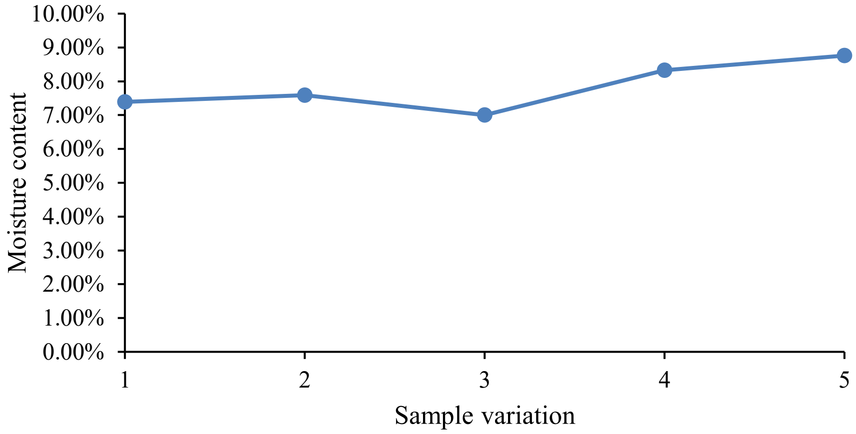

Figure 2. The effect of sample variations on briquette moisture content.

When compared to the SNI 01-6235-2000, which sets the maximum moisture content limit for briquettes at 8%, two variations do not meet this standard: Variation 4 (8.33%) and Variation 5 (8.76%). Moisture content exceeding this limit can hinder combustion efficiency because some energy will be absorbed to evaporate the water before the combustion process proceeds optimally. Thus, the use of sugarcane bagasse as the primary material without additives must be balanced with additional treatments, such as the use of hydrophobic binding agents or more intensive drying processes. Meanwhile, Variations 1 through 3 can be categorized as high-quality briquettes in terms of moisture content, and Variation 3 specifically demonstrates optimal potential in terms of both combustion efficiency and the briquettes' mechanical strength.

This is supported by Waheed et al. (2022), who state that the optimal moisture content for combustion efficiency is below 10%, as well as Abdel-Aal et al. (2023), who show that briquettes with a moisture content of around 8% have a mechanical strength of up to 96%.

3.2 Combustion Rate Testing

Mirna et al. (2025) state that the combustion rate is a process used to measure how long a briquette can burn and serves as an indicator of its thermal quality. One factor influencing this parameter is the moisture content in the briquette. The higher the moisture content, the greater the resistance during combustion, because the water must be evaporated first before the material can actually burn. Consequently, only a portion of the briquette's mass burns completely, resulting in more ash residue and a longer combustion process.

The combustion rate is an important indicator in assessing the energy performance of biomass briquettes. The test results in Table 4 show that the combustion rates of the five variations ranged from 0.17 to 0.27 g/min. The highest value was obtained for Variation 5 (100% sugarcane bagasse) at 0.27 g/min, while the lowest value of 0.17 g/min was obtained for Variation 3 (100% salak peel). Variation 4 (75:25) also produced a combustion rate of 0.17 g/min, while Variation 1 (50:50) and Variation 2 (25:75) showed values of 0.18 and 0.19 g/min, respectively. The effect of formula variations on the combustion rate of the briquettes can be seen more clearly in Figure 3.

Table 4. Briquette combustion rate.

Sample Variation	Combustion Time (minutes)	Sample Weight (g)	Initial Mass (g)	Final Mass (g)	Combustion rate (g/min)
Variation 1	40	7.2178	7.3812	0.1634	0.18
Variation 2	34	6.4737	6.7063	0.2326	0.19
Variation 3	32	5.5650	5.7111	0.1461	0.17
Variation 4	38	6.7991	7.0073	0.2082	0.17
Variation 5	28	7.7064	7.8934	0.1870	0.27

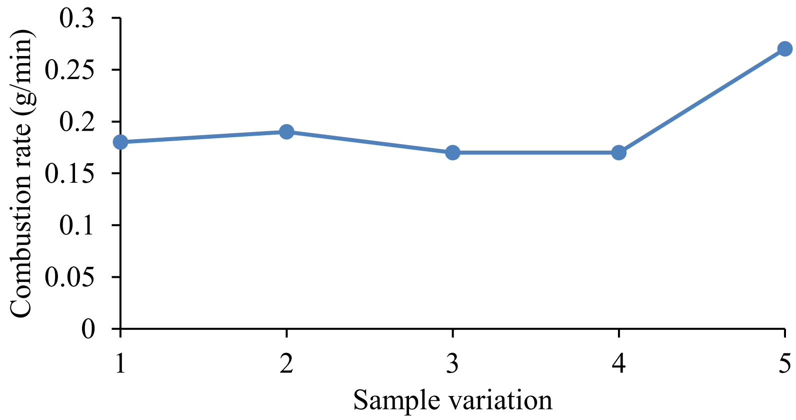

Figure 3. The effect of sample variations on combustion rate.

Based on Figure 3, it can be seen that there is a tendency for the combustion rate to decrease as the proportion of salak peel in the briquette formulation increases. Variation 5, consisting entirely of sugarcane bagasse, exhibited the highest combustion rate, while Variation 3, which used only salak peel, produced the lowest rate. This difference is closely related to the charcoal characteristics of each raw material. Sugarcane bagasse charcoal tends to have a more porous and lightweight structure, facilitating oxygen diffusion during the combustion process and resulting in a higher combustion rate. Conversely, salak peel charcoal has a denser and more homogeneous structure and is believed to contain a higher fixed carbon content, resulting in a slower but more stable combustion rate.

An excessively high combustion rate indicates high thermal reactivity, but this can lead to inefficient combustion and a short flame duration. Conversely, a low combustion rate indicates better flame stability and produces a more stable and long-lasting flame. Therefore, variations with a mixture composition of sugarcane bagasse and salak peel, such as Variation 1 (50:50) and Variation 2 (25:75), which recorded combustion rates of 0.18 and 0.19 g/min, respectively, can be categorized as having balanced thermal characteristics. Briquettes with a moderate combustion rate, such as these, are generally more ideal for household and small-scale industrial use because they can produce good energy efficiency with a sufficiently long burn duration.

The moisture contents in our study (7.00–8.76%) fall within the 5–10% band recommended for good-quality briquettes from agricultural waste and are consistent with the threshold of about 8% identified by Abdel-Aal et al. (2023) and Waheed et al. (2022) as favorable for combustion efficiency. Meanwhile, our result of the 8.76% recorded for the 100% bagasse variant is higher than the 5.97% reported by Bot et al. (2023) for bagasse briquettes produced under a comparable route. For the 100% salak peel variant, our moisture content of 7.00% exceeds the 4.63–5.62% obtained by Alexander et al. (2025) for starch-bound salak peel briquettes. Both gaps are plausibly attributable to differences in post-molding drying: 24 hours of oven drying in our study versus three days of sun drying in Bot et al. (2023). It indicates that the drying stage is the most promising target for further reduction.

4. Conclusions

Our study aims to analyze the effect of varying proportions of sugarcane bagasse and salak fruit peel on the moisture content and combustion rate of biomass briquettes. The novelty of this study lies in the co-formulation of sugarcane bagasse and salak peel, a material pair not previously reported in briquette research, and in mapping the trade-off between moisture content and burning rate across five blending ratios. Five mixing ratios (100:0, 75:25, 50:50, 25:75, and 0:100) were carbonized at 400 °C for 4 hours, mixed with 3 grams of tapioca flour as a binder, compressed into briquettes, and then dried for 24 hours. Its contribution is twofold. First, it provides baseline thermal characterization data for this pair. Second, it identifies the bagasse threshold (≥75%) at which briquettes exceed the 8% moisture limit of SNI 01-6235-2000. Together, these serve as an initial formulation reference for briquette development from local agricultural residues, particularly for household and small-scale industrial applications.

Moisture content was determined from the difference in mass before and after drying, whereas the combustion rate was calculated from the change in mass over the combustion period. The results showed that moisture content ranged from 7.00% to 8.76% and the combustion rate ranged from 0.17 to 0.27 g/min, with a tendency for moisture content to increase and the combustion rate to decrease as the proportion of snake fruit peel increased. Based on the test results, all briquette variations showed a moisture content below 10%, meaning they meet the optimal limit for solid fuel. The 100% salak peel composition (Variation 3) yielded the lowest moisture content of 7.00%, while the 100% sugarcane bagasse composition (Variation 5) yielded the highest moisture content of 8.76%. However, Variation 4 (75% sugarcane bagasse) and Variation 5 did not meet the maximum moisture content limit of 8% set by SNI 01-6235-2000, thus requiring additional treatment such as more intensive drying or the use of hydrophobic binding agents. Meanwhile, Variations 1, 2, and 3 can be categorized as high-quality briquettes in terms of moisture content.

In terms of combustion rate, variations in raw material composition have a significant effect on the thermal characteristics of the briquettes. Briquettes with a 100% sugarcane bagasse composition exhibited the highest combustion rate (0.27 g/min), reflecting high thermal reactivity but with a shorter burn duration. Conversely, the 100% salak peel briquette produced the lowest combustion rate (0.17 g/min), indicating slower but more stable combustion. The mixed formulations, particularly Variation 1 (50:50) and Variation 2 (25:75), exhibit balanced thermal characteristics, making them more ideal for household and small-scale industrial needs. Overall, the combination of sugarcane bagasse and salak peel has proven to have high potential as a raw material for sustainable biomass briquettes based on local agricultural waste.

Further research is recommended to include testing of calorific value, briquette compressive strength, and exhaust gas emissions to obtain a more comprehensive picture of energy performance. Additionally, thermogravimetric analysis (TGA) is also necessary to analyze the degradation characteristics of the raw materials with respect to temperature in greater depth.

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