

## Processing wood twig waste into biomass pellets using cassava-peel-based natural binders

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### ABSTRACT

Wood branch waste and cassava peel waste are types of organic waste the quantities of which continue to increase, but their utilization remains suboptimal, leading to accumulation, aesthetic degradation, and odor. Wood waste has a high calorific value of approximately 4.300 cal/gram, making it suitable as a fuel source, while cassava peel waste has a high starch content (93.46%), which acts as an adhesive for biomass pellets production. Utilizing these wastes as biomass pellets helps minimize accumulation of biomass in the environment and provide an alternative way to add its economic value. This study analyzed the quality of the optimal biomass pellets produced from wood twig waste with a cassava peel waste binder, in accordance with SNI 8675-2018. The experimental methodology employed a completely randomized design (CRD), which included chopping, mixing, compacting, sun drying, and oven drying at 105 °C. The variations tested were the wood binder mixtures of (95%:5% and 90%:10%) along with oven drying time of 2 hours and 4 hours, each repeated twice. The findings indicated that Sample 4 (90%:10% with 4 hours of drying) was the best pellet, attaining the highest calorific value (4,024 cal/g), bound carbon content (11.83%), density (409 kg/m<sup>3</sup>), water content (8.35%), ash content (4.3%), volatile matter content (75.6%), and combustion rate (0.241 g/minute). Overall, the pellet characteristics met the standards for water and ash content but failed to meet the standards for density, volatile matter, bound carbon, and calorific value.

**Keywords:** cassava peel waste, waste to energy, biomass pellets, wood waste, recycling.

### INTRODUCTION

Waste is an object that has been utilized by people and subsequently discarded without being repurposed. According to Law of the Republic of Indonesia Number 18 of 2008 concerning Waste Management, waste is defined as the solid residue of daily human activities and/or natural processes. Waste is categorized into two types: organic waste and inorganic waste. Organic waste consists of the elements that can be decomposed by microbes or through natural processes, such as food scraps, foliage, fruit peels, wood, and other substances. Inorganic waste refers to the refuse that cannot be decomposed by microorganisms or

through natural processes, such as plastic, glass, metal, and others (Fawwaz et al., 2023). Wooden branches are categorized as organic waste. Wooden branches frequently become scattered and are regarded as waste.

According to the World Bank research published in The Atlas of Sustainable Development Goals 2023, Indonesia is the fifth greatest waste producer globally, following Brazil. In 2023, the total waste generated throughout 239 districts and cities in Indonesia amounts to 28,015,503.01 tonnes annually, with unmanaged waste constituting 9,211,683.56 tonnes per year. In 2024, the waste in Indonesia, derived from data of 227 districts and cities, totaled 19,773,715.37 tonnes

annually, with unmanaged waste accounting for 8,198,830.63 tonnes per year. In Indonesia, waste decreased from 2023 to 2024; however, uncontrolled waste saw just an 11% reduction, equating to 1,012,852.93 units. The waste mix consisted of 40% food waste, 15% paper/cardboard, 15% plastic, 7% metal, 5% wood/branches, 3% cloth, 2% glass, and 10% other materials (SIPSN, Ministry of Environment, 2023). Consequently, technology is essential to tackle the prevailing waste issue.

Biomass pellets have been designed to transform the combustible component of solid waste into fuel. The biomass pellet process repurposes waste, producing substantial thermal energy by dehydrating the source material to diminish its moisture content. The refuse is subsequently pulverized and compacted (Atmika and Suryawan, 2022). Biomass pellets also utilize biomass waste as a source of renewable energy. Biomass waste contributes to substantial quantities of waste and is scattered, negatively impacting aesthetics.

One potential alternative energy source in Indonesia is, since the availability of raw material and the massive use of biomass as an energy source. Biomass is considered as organic materials that come from either plants or animals. Common plant wastes include wood waste and biomass like the branches left behind by downed trees on roadways. The wood-based biomass is abundant and has a high calorific value, making it an excellent candidate for fuel production, especially biopellets (Sari et al., 2023). However, most of the existing studies use wood chips, sawdust, or agricultural residues, with little focus on the unique properties and challenges of wood twig waste, such as the wood branches in biopellet production (Putra, et al., 2024). The use of wood branches and twigs is rarely examined, since the biomass is considered waste. Most of the wood waste is utilized by direct burning, which is not good for human health and the environment.

The utilization of biomass for biopellets is usually achieved by directly mixing the biomass with adhesive, where the investigation of natural-based adhesive, especially using biomaterial-based adhesive, is limited. Furthermore, there has been limited investigation into the potential of starch derived from cassava peel waste as an adhesive for the pellets made from wood waste, since most previous research has concentrated on commercial adhesives or pure starch (Reotutar et

al., 2023). There, the synergy of utilizing wood twig biomass waste and cassava peel binders is interesting to be explored, since the successful utilization of these two potential biowaste-based products could add to the circularity of the product and also enhance the economic value of the biomass-based product.

In light of the foregoing, studies on “Processing Wood Branch Waste into Biomass Pellets Using Cassava Peel as a Natural Binder” are required to ascertain the optimal ratio of various raw materials for making biomass pellets and the optimal composition of cassava peel to use as a binder. The study is important, since the utilization of wood branches and twigs is limited, but the availability of the material is massive in Indonesia. The density, moisture content, ash content, volatile matter content, calorific value, combustion rate, and SNI 8675-2018 for bound carbon content were determined through testing the characteristics of biomass pellets according to Indonesian National Standard (SNI) 8675-2018. The result is expected to provide an insight how to process the biomass-based product to biopellet, which has a high demand in Indonesia as the renewable energy. The study could provide a valuable information for the researchers who focus on the utilization of biomass-based product to functional material which has high value compared to raw material.

## MATERIALS AND METHODS

### Sample preparation

This study employed an experimental methodology utilizing a completely randomized design (CRD) with multifactorial variables, specifically adhesive percentage and drying duration. Four experimental variations and three repetitions were conducted, utilizing wood twig powder from the USU integrated waste facilities combined with cassava peel waste starch adhesive, and varying the drying duration with the following composition ratios: (95%:5%) dried for 2 hours, (95%:5%) dried for 4 hours, (90%:10%) dried for 2 hours, and (90%:10%) dried for 4 hours. Wood twig waste was initially collected from the environment of Universitas Sumatera Utara, alongside cassava peel waste sourced from the warehouse of the cassava processing partner, Singkong Meledak Medan.

The attributes of high-quality biomass pellets conform to the Indonesian National Standard (SNI) 8675-2018, assessed through parameters including density, moisture content, ash content, volatile matter content, calorific value, combustion rate, and bound carbon content as per SNI 8675-2018. First, the preparation of starch powder from cassava peel starch. The obtained cassava peel starch, used as an adhesive, is soaked for 24 hours and blended with distilled water in a ratio of 1:3 (w/w) to form a starch paste. The obtained paste is left for 5 hours and dried in an oven at 100 °C for 3 hours, and air dried under the sunlight for 12 hours. The dried starch is ground into a powder for easy sieving and air-dried for 12 hours.

Furthermore, the process of producing biomass pellets begins with chopping wood twigs using a wood chipper, followed by powdering with a hammer mill. The obtained biomass powder is sieved through a 40-mesh sieve with varying amounts of twig powder and adhesive (Lela et al., 2016, Arachchige, 2021). Once the material is homogeneous, the pelletization is carried out according to the specified variations. To reduce the moisture content, the finished biomass pellets are oven-dried at 105 °C for 2 hours. This follows the pre-treatment method described by Afrah et al. (2024), which demonstrates that drying at that temperature can effectively lower the moisture content in biomass before processing. The following evaluation and characterization were carried out using the following criteria.

### Density (g/cm<sup>3</sup>)

A range of seven to twelve biomass pellets has been completed through experimentation. Each pellet was measured by weight, then its volume was computed using a vernier caliper. By measuring the pellet length and center, the volume was determined. Pellet density can be determined by referring to Equation 1 provided below:

$$\text{Density} \left( \frac{\text{g}}{\text{cm}^3} \right) = \frac{W}{V} \quad (1)$$

where:  $W$  – sample weight (g),  
 $V$  – sample volume (cm<sup>3</sup>).

### Water content

The biomass pellets were ground, weighed before being dried in an oven, and then reweighed

after drying to a weight of 2 grams. The pellets were placed in a crucible, then weighed as the initial weight. After that, the pellets were placed in an oven at 105 °C for 4 hours. The biomass pellets were cooled in a desiccator and reweighed as the final weight. The moisture content of the pellets can be calculated using Equation 2:

$$\text{Density} \left( \frac{\text{g}}{\text{cm}^3} \right) = \frac{W}{V} \quad (2)$$

where:  $W_1$  – weight before being dried in the oven (g),  $W_2$  – weight after being dried in the oven (g).

### Ash content

A gram of biomass pellets was weighed and considered as the sample weight, then the cup as weight of the empty cup was considered. After that, it was placed in a furnace at a temperature of 800 °C for 2 hours. The biomass pellets were removed and cooled in a desiccator and then weighed. Ash content can be calculated using Equation 3:

$$\begin{aligned} \text{Ash content (\%)} &= \\ &= \frac{W_{\text{total}} - W_c}{W} \times 100\% \end{aligned} \quad (3)$$

where:  $W_c$  – weight of empty cup (g),  
 $W_{\text{total}}$  – weight of cup with sample that has been heated (g),  $W$  – weight of sample (g).

### Volatile matter content

An empty crucible and lid were weighed using an analytical balance. Firstly, 2 grams of biomass pellets were weighed, then placed into the crucible and weighed again. The crucible containing the biomass pellets was placed in a furnace at 950 °C for 10 minutes. Then, the crucible containing the biomass pellet residue was placed in a desiccator. The crucible containing the residue was weighed. The volatile content can be calculated using Equation 4 below:

$$\begin{aligned} \text{Volatile matter content (\%)} &= \\ &= \left[ \frac{W_1 - W_2}{W_1} \times 100\% \right] - M_w \end{aligned} \quad (4)$$

where:  $W_1$  – initial sample weight (g),  
 $W_2$  – sample weight after drying (g),  
 $M_w$  – sample water content (%).

### Carbon content

Bound carbon is the value bound to a substance and is not included in the components of water, ash, and volatile matter. The bound carbon content can be calculated using Equation 5:

$$\begin{aligned} \text{Carbon content (\%)} &= \\ &= 100\% - (M_w + A + VM) \end{aligned} \quad (5)$$

where:  $M_w$  – water content (%),  $A$  – ash content (%),  $VM$  – volatile matter content (%).

### Calorific value

Biomass pellets were weighed 1 gram using an analytical balance. A 10 cm nickel wire was attached to the ignition tank on the bomb cover. The biomass pellets were subsequently inserted into the tube, tightly closed, and supplied with 25 bar of oxygen. The tube was inserted into a bomb calorimeter tube filled with 1250 mL of water. The bomb calorimeter tube was closed, then the electromotor button and the water stirrer were turned on. The water temperature was recorded when it was stable. The igniter was turned on, and after 5 minutes of starting the ignition, the final temperature of the cooling water was recorded. The calorific value can be calculated using Equation 6:

$$\begin{aligned} \text{Volatile matter content (cal/g)} &= \\ &= (\Delta t \times W) / mbb - B \end{aligned} \quad (6)$$

where:  $\Delta t$  – average temperature difference ( $^{\circ}\text{C}$ ),  $W$  – calorimeter water value (cal/ $^{\circ}\text{C}$ ),  $Mbb$  – fuel mass (g),  $B$  – heat correction on iron wire (cal/g).

### Combustion rate

A digital caliper was utilized to ascertain the diameter and height of the biomass pellets. The initial mass of the biomass pellets was measured using a digital scale. The biomass pellets were ignited on the burner. A stopwatch was set to document the precise moment the biomass pellet flame starts. The duration of the biomass pellet flame combustion till extinguishment was recorded. The ultimate mass of the biomass pellets was measured using a digital scale. The combustion rate can be calculated using the following Equation 7:

$$\text{Combustion rate} \left( \frac{\text{gr}}{\text{menit}} \right) = \frac{\Delta m}{t} \quad (7)$$

where:  $\Delta m$  – mass of fuel burned (initial mass of biomass pellets – mass of residual biomass pellets) (g),  $t$  – burning time (s).

## RESULT AND DISCUSSION

### Results

Analysis of the characteristics of biomass pellets derived from wood twig waste with natural adhesive from cassava peel waste (Table 1).

#### Density of biomass pellets

Density refers to the measure of pellet particles that affects the calorific value and the combustion rate of biomass pellets (Widowati, 2023). The density of the pellets influences the calorific value; a higher pellet density allows more mass to be burned, thereby increasing the calorific value (Nuriana et al., 2022). The density analysis of the biomass pellets was conducted in accordance with SNI 8675:2018 at the Bioprocess Engineering Laboratory, Department of Environmental Engineering, Universitas Sumatera Utara (USU). The results of the density analysis for all variations in biomass pellet composition are presented in Figure 1.

Figure 1 shows that the average data of density test results on all biomass pellet samples achieved different results. The highest density value was recorded in sample variation 3 (90%:10%), dried for 2 hours, namely 417 kg/m<sup>3</sup>, while the lowest density was observed in biomass pellet variation Sample 2 (95%:5%), drying for 4 hours, at 347 kg/m<sup>3</sup>. Therefore, it can be concluded that the density of the four produced biomass pellet samples does not conform to the SNI standard.

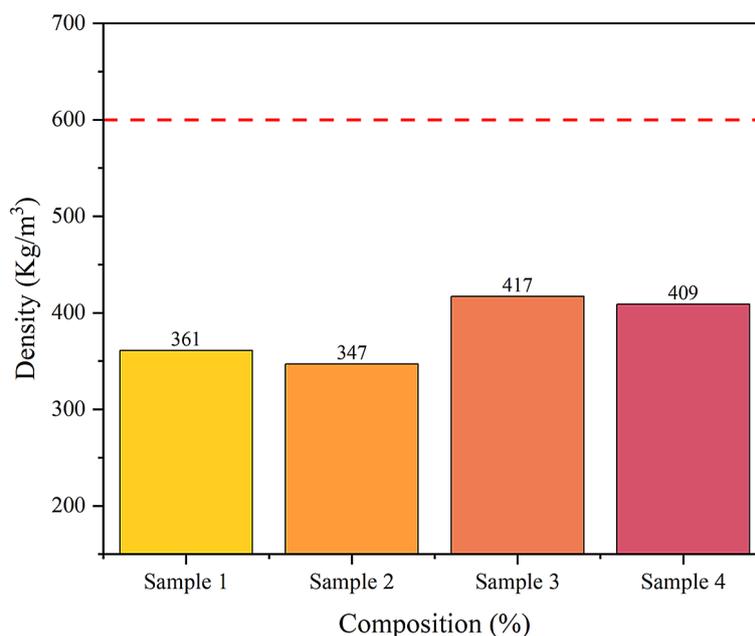
#### Moisture content of biomass pellets

Moisture content is the ratio of the weight of water contained in biomass pellets to the dry weight of the fuel. High moisture content in biomass pellets also affects the calorific value, which will decrease, making biomass pellets difficult to ignite and producing a lot of smoke. As water absorbs heat during evaporation, the energy that would have ignited the pellets is utilized to convert the water into steam (Pradana et al., 2023). Water absorbs heat during combustion due to the energy

**Table 1.** Results of analysis of the characteristics of biomass pellets from wood twig waste with natural adhesive from cassava peel waste

No.	Kode	Sample type		Biomass biopellet testing				
		Sample variation	Repetition	Density (kg/m <sup>3</sup> )	Water content (%)	Ash (%)	Volatile (%)	Carbon (%)
1.	A1	Sample 1 (95%:5%) 2 hour	1	363	8.8	4.4	77.4	9.4
			2	358	8.8	3.79	74.7	12.57
		Average			361	8.8	4.1	76.05
2.	A2	Sample 2 (95%:5%) 4 hour	1	347	8.94	4.29	76	10.86
			2	346	9	3.5	76,7	10.75
		Average			347	8,97	3,9	76.35
3.	B1	Sample 3 (90%:10%) 2 hour	1	415	8.44	4.2	78	9.55
			2	419	8.4	3.7	77,5	10.4
		Average			417	8.42	3.95	77.75
4.	B2	Sample 4 (90%:10%) 4 hour	1	407	8.45	4.6	74.7	12.55
			2	411	8.25	4	76.5	11.1
		Average			409	8.35	4.3	75.6
SNI (Indonesian national standard)				≥ 600	≤ 10	≤ 5	≤ 75	≥ 14

**Note:** Biomass pellets A1 (wood twig waste: cassava peel waste = 95%:5%), drying for 2 hours, Biomass pellets A2 (wood twig waste: cassava peel waste = 95%:5%), drying for 4 hours, Biomass pellets B1 (wood twig waste: cassava peel waste = 90%:10%), drying for 2 hours, Biomass pellets B2 (wood twig waste: cassava peel waste = 90%:10%), drying for 4 hours.

**Figure 1.** Biomass pellet density graph

required for evaporation. Consequently, instead of directly facilitating the combustion process, a larger proportion of the energy derived from biopellet is utilized to dehydrate and evaporate moisture. As a result, combustion efficiency and total energy output are decreased (Wijaya et al., 2023). Biomass pellets with low moisture content can be

stored for long periods because they are not easily attacked by microorganisms and fungi (Kurniawan et al., 2022). Analysis of biomass pellet moisture content testing refers to SNI 8675-2018, which was carried out at the USU Environmental Engineering Bioprocess Engineering Laboratory. The results of the analysis of moisture content

testing for all variations in biomass pellet composition can be seen in Figure 2.

Figure 2 demonstrates that the average data of the water content test results on all biomass pellet samples achieved different results. The lowest water content value was obtained in the variation of biomass pellet Sample 4 (90%:10%) heated for 4 hours, namely 8.35% and the highest water content was in the variation of Sample 2 (95%:5%) heated for 4 hours, namely 8.97%. According to standards, the maximum water content in biomass pellet fuel is 10%, so from the four biomass pellet samples produced, it can be concluded that the water content in the existing biomass pellets has met the SNI standard.

#### *Ash content of biomass pellets*

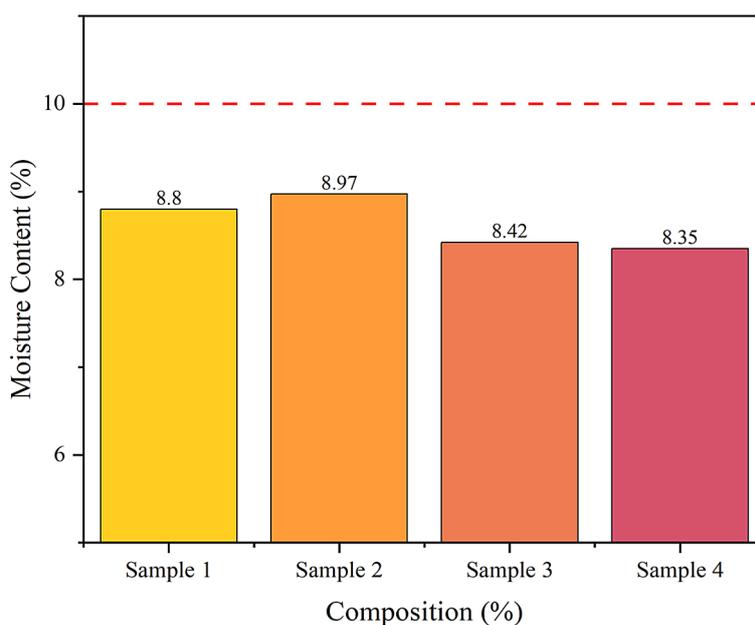
Ash content is the remaining part of the combustion process. High ash content in biomass pellets can reduce fuel quality, because high ash content can reduce the calorific value of biomass pellets, as ash is non-combustible, which hinders heat transfer and also reduces the amount of pellet material that can be converted into energy. Ash content testing aims to identify unburned carbon-depleted biomass pellets (Kurniawan et al., 2022). The lower the ash content, the better, as excessive deposits in the combustion furnace can lead to dirty furnaces and corrosion (Sukarta et al., 2018). The analysis of biomass pellet ash content testing, as per SNI 8675-2018, was conducted at the USU Environmental Engineering Bioprocess

Engineering Laboratory. The results of the ash content analysis for all variations in biomass pellet composition are shown in Figure 3.

Figure 3 shows that the average data of the ash content test results on all biomass pellet samples achieved different results. The lowest ash content value was obtained in the variation of biomass pellet Sample 2 (95%:5%) heated for 4 hours, namely 3.9% and the highest ash content was in the variation of Sample 4 (90%:10%) heated for 4 hours, namely 4.3%. According to standards, the ash content contained in biomass pellet fuel is a maximum of 5%, so from the four biomass pellet samples produced, it can be concluded that the ash content in the existing biomass pellets has met the SNI standard.

#### *Volatile matter content of biomass pellets*

The burning of biomass pellets releases volatile matter into the air. Because burning the pellets releases carbon from the solid structure as the volatile matter evaporates, a lower-bound carbon content is achieved with a higher volatile matter content. Less solid material burns when volatile matter levels are high. Less smoke from burning biomass pellets means less air pollution, which is why a product with a low volatile matter content is preferable (Windiarti et al., 2022). However, high volatile matter content also has the advantage of making the fuel easier to ignite and burn (Sucahyo et al., 2024). Analysis of volatile matter content testing for biomass



**Figure 2.** Biomass pellet moisture content graph

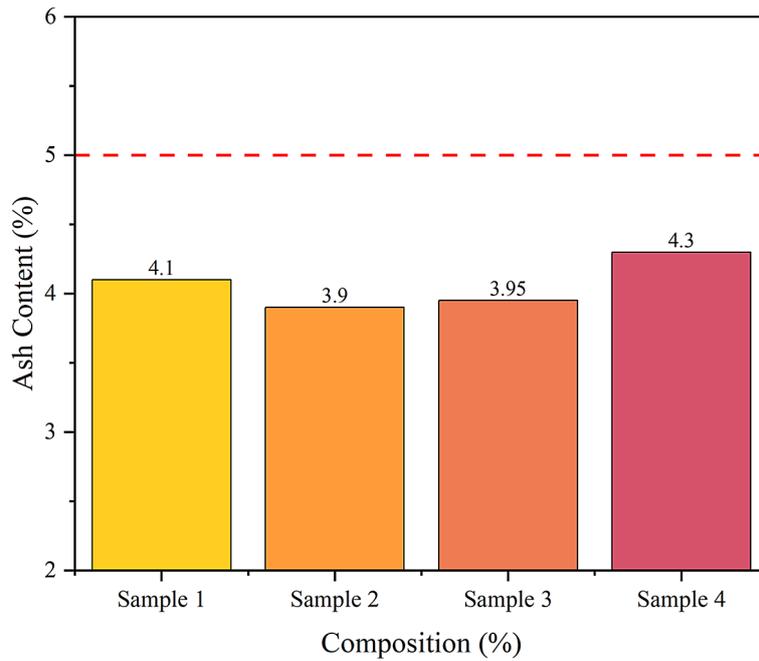


Figure 3. Biomass pellet ash content graph

pellets refers to SNI 8675-2018, which was carried out at the USU Environmental Engineering Bioprocess Engineering Laboratory. The results of the volatile matter content analysis for all variations of biomass pellet composition can be seen in Figure 4.

Figure 4 shows that the average data of volatile matter content test results in all biomass pellet samples achieved different results. The lowest volatile matter content was obtained in the

variation of biomass pellet Sample 4 (90%:10%) heated for 4 hours, namely 75.6% and the highest volatile matter content value was in the variation of Sample 3 (90%:10%) heated for 2 hours, namely 77.75%. On the basis of the results of the four biomass pellet samples, it can be inferred that the current biomass pellets do not meet the SNI standard for volatile matter content, which states that the maximum allowed in biomass pellet fuel is 75%.

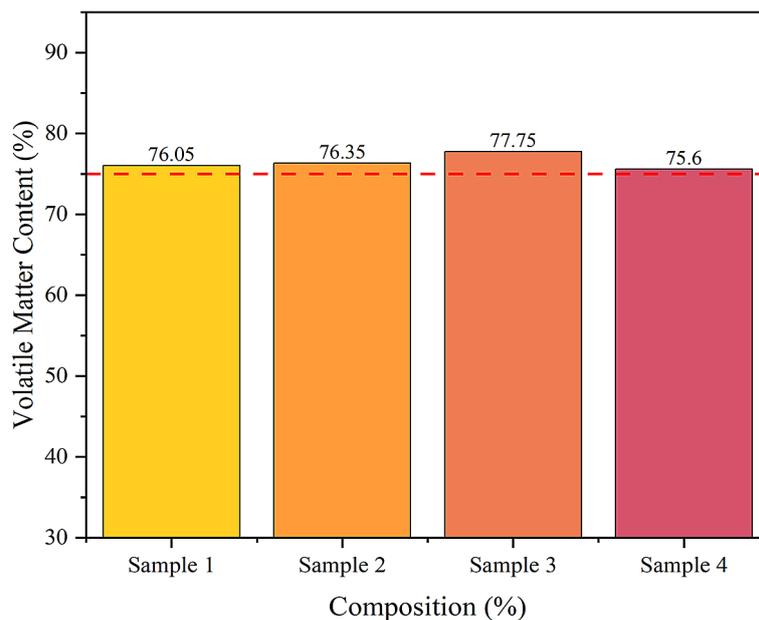


Figure 4. Graph of volatile matter content of biomass pellets

*Biomass pellet-bound carbon content*

In order to determine how much solid material remains after removing volatile components, the bound carbon content is an essential metric for biomass pellet testing. Biomass pellets with high bound carbon values are high-quality fuel. The primary component of pellets, bound carbon, has a high calorific value because its combustion results in the release of calories. As it rises, it becomes more apparent that the combustion of the fuel is accomplished in its entirety (Windiarti et al., 2022). The analysis of the bound carbon content of biomass pellets refers to SNI 8675-2018. The results of the bound carbon content analysis for all variations of biomass pellet compositions are shown in Figure 5.

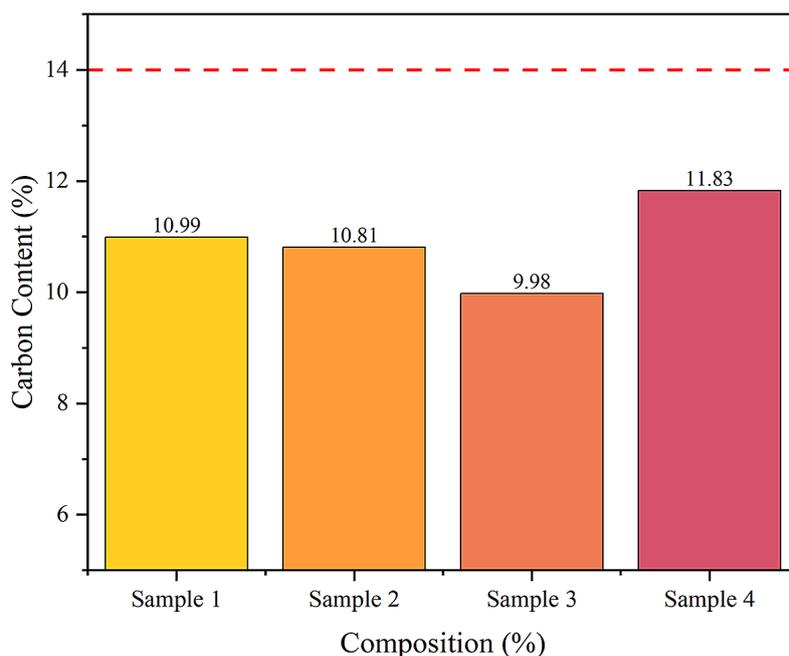
Figure 5 shows that the average data of the bound carbon content test results on all biomass pellet samples achieved different results. The lowest bound carbon content value was obtained in the variation of biomass pellet Sample 3 (90%:10%) heated for 2 hours, namely 9.98% and the highest bound carbon content was in the variation of Sample 4 (90%:10%) heated for 4 hours, namely 11.83%. On the basis of the results of the four biomass pellet samples, it can be inferred that the bound carbon content of the current biomass pellets does not meet the SNI standard, which states that biomass pellet fuel must contain at least 14% carbon.

**DISCUSSIONS**

**The characteristics of biomass pellets from wood twig waste with natural adhesive from cassava peel waste**

*Density of biomass pellets*

Figure 1 displays the research findings that demonstrate a correlation between the percentage of adhesive in biomass pellets and their density. The study also found that drying time impacts density, but that prolonged drying only reduces mass due to water evaporation, which does not alter pellet diameter or height. Consequently, the researchers concluded that drying time has no effect on density. In the study by Li et al. (2022), it was stated that higher heating temperatures and longer heating times would result in lower density due to evaporation and increased porosity of the wood pellets associated with the volatility of the hemicellulose components from the lignocellulosic matrix, as well as a reduction in the moisture content of the pellets without changing their shape or integrity. The study of Paga and Reniana (2024) showed that the higher the percentage of adhesive, the higher the density. There is a difference between the densities of raw materials made before and after sun drying. The density of raw materials is higher before drying than it is after drying. In the study by Suryawan et al. (2022), it was shown that paper waste, garden waste, and



**Figure 5.** Graph of bound carbon content of biomass pellets

food waste have a density 10–15% higher before sun drying compared to after sun drying. This is in line with this study; the highest density was found in Sample 3 with a percentage of adhesive of 10% and the lowest density was found in Sample 1 with a percentage of adhesive of 5%. However, the length of drying time did not affect the high density. This is in line with the research of Harlina et al. (2021), which showed that variations in the length of drying time did not affect the density value.

In this study, the biomass pellets did not meet the density standards set by SNI. This could be because the percentage of adhesive used was very small, ranging from 5% to 10%. As a result, the average density of the pellets was 347–417 kg/m<sup>3</sup>. In contrast, a study conducted by Muziburrahman et al. (2023) found that the pellets made with 10% adhesive and raw materials such as teak sawdust and candlenut shells had an average density of 260–420 kg/m<sup>3</sup>. Thus, if higher density is desired, it is necessary to add more adhesive.

#### *Moisture content of biomass pellets*

On the basis of the research results in Figure 2, it shows that the greater the percentage of adhesive used in biomass pellets and the longer the drying time, the lower the water content in biomass pellets. The research conducted by Indrayanti et al. (2023) supports this idea. They found that when wood pellets contain a higher percentage of adhesive, the water content drops. This is because the particles of tapioca adhesive are smaller than those of sawdust, which means less water gets trapped in the pellet cavity, also known as tared water. Additionally, the adhesive can absorb water from the material, which means the water content can decrease as the pellets dry. Nonetheless, the relationship between water content and drying duration in Samples 3 and 4 aligns with the findings of Irfansyah et al. (2022), which demonstrate that the duration of drying affects the water content of biomass pellets. Specifically, the study found that the biomass pellets dried in 180 minutes at 120 °C had a water content of 10.92%, while the pellets dried in 120 minutes at 120 °C had a higher water content of 19.6%. Sample 2, which was dried for 4 hours, had a higher water content than Sample 1, which was dried for 2 hours; the two samples do not match up in any manner.

If the pellet mold breaks while being molded in a molding machine, the dough is re-inserted into the machine. One reason why the water

content of biomass pellets in Sample 2 with a 5% adhesive percentage and 4 hours of drying is higher than Sample 1 with a 5% adhesive percentage and 2 hours of drying is because, during pressing, the water in the dough comes out of the machine cavity. However, this process is not applied to all pellet variations; only the pellets that are cracked in one mold are molded again until they are perfect without cracks. This is supported by the research of Zawislak et al. (2020), which shows that the moisture content in the raw material before pelleting is higher compared to after pelleting. Hence, when drying biomass pellets with an oven for 2 hours or 4 hours, it is possible for each dried biomass pellet sample not to start with the same water content.

#### *Ash content of biomass pellets*

According to Prasetyo et al., (2022), the type of wood used as a material in making biomass pellets affects the ash content, if the type of wood used is hardwood then the resulting ash content will be lower, and vice versa. According to Muazzinah et al., (2022) high ash content can be caused by the percentage of adhesive used in biomass pellets, the greater the percentage of adhesive used, the higher the ash content produced, this is in line with this study where Samples 3 and 4 with a percentage of adhesive 10% have a higher ash content value than samples with a percentage of adhesive 5%. This can be caused by the inorganic content found in cassava peel starch adhesive, in the study of Cholilie and Zuari (2021) obtained a higher ash content in tapioca flour adhesive of 28.33% compared to cornstarch adhesive of 27.33%. Figure 3 shows that the length of drying time in biomass pellets does not affect the high or low ash content produced. The research by Sukainah and Wijaya (2023) showed that temperature and drying time did not affect ash content. Nevertheless, as stated by Setiawan et al. (2022), an excessively high drying temperature can lead to ashing, which in turn reduces the calorific value of biomass pellets and increases their ash content, so drying for an excessively long period can be detrimental (Setiawan et al., 2022). The chemical composition of the wood determines the amount of ash that is produced; the exact amount of ash depends on the type of wood that is used (Haryanto in Permatasari et al., 2023).

According to Indrayanti and Siska (2021), the higher the silica content in biomass such as wood, the higher the ash during the combustion

process, this occurs because silica is one of the elements that make up ash in biomass; the silica element is not burned during combustion, which causes the ash content to increase. Sengon buto wood, eucalyptus, ketapang wood, trembesi wood, and waru wood are the species present in the grounds of the Universitas Sumatera Utara, permitting their waste to be processed at the USU 3R TPS. In the research conducted by Pari et al. (Awal, 2023), the findings indicated that sengon buto wood possesses the highest ash and silica content among the examined woods, measuring 0.9%. Miranda et al. (2015) indicated that certain barks, particularly non-hardwood varieties, possess a high silica content. This may explain the elevated ash content in the biomass pellets examined in this study. Consequently, it is essential to choose the wood varieties with low silica content to manufacture biomass pellets with reduced ash content, thereby optimizing the quality of the pellets. Ash indicates the mineral composition of a material; therefore, an increase in ash correlates with a higher mineral content and a reduced carbon presence. This illustrates the increasing diversity of the material structure. Lower ash levels enhance the suitability of a material for combustion, as elevated mineral content can impede the process (Wijaya et al., 2023).

#### *Volatile matter content of biomass pellets*

Muazzinah (2022) states that an increase in the percentage of adhesive in biomass pellets increases the volatile matter content. The results do not align with the study; only Samples 1 and 3 agree. Sample 4 had the lowest volatile matter content after 4 hours of drying with a 10% adhesive percentage, while Sample 3 had the highest after 2 hours of drying. According to the graph, the volatile matter content of biomass pellets is unaffected by the drying time or duration. According to Vegatama et al., (2024) high water content can produce high volatile matter content. In this study, the water content of Sample 2 was higher than the water content of Sample 4. This may be the cause of the higher volatile matter content in Sample 2 with 5% adhesive than in Sample 4, which has 10% adhesive, as well as the lower volatile matter content in 4 hours of drying than volatile matter with 2 hours of drying. In the study of Ghifari and Harsono (2021), it was shown that the higher the adhesive percentage, the higher the volatile matter content. However, in the study, at an adhesive percentage of 20%, the volatile matter content decreased. This

could occur because there is a tendency that the higher the adhesive percentage used, the greater the volatile matter loss at a temperature of 900 °C. Furthermore, the studies conducted by Azis et al. (2025) demonstrated that the volatile matter content of biomass pellets is influenced by drying time and temperature. The volatile matter content decreases as drying time and temperature increase. This is due to the reduction in water content during drying, so that during testing the volatile matter content, less water evaporated. Figure 4 does not show this. This could occur because the size of the biomass pellets is quite large, and drying at only 105 °C cannot penetrate the inside of the biomass pellets, so the volatile matter content is still retained inside the pellets and comes out during testing. However, the high volatile matter content in biomass pellets has advantages and disadvantages for the quality of biomass pellets.

According to Prasetyo et al., (2022) Biomass pellets have a high volatile matter content, which makes them easier to ignite and burn. However, this same high volatile matter content also causes them to have a low bound carbon content and generates more smoke when burned, lowering their quality. According to Sucahyo et al. (2024), even after evaporation, there is still flammable volatile content in wood, which is why it typically has a high volatile matter content.

#### *Biomass pellet bound carbon content*

Muazzinah (2022) stated that low ash and volatile matter content influences high-bound carbon content, meaning that biomass pellets with lower ash and volatile matter content have higher bound carbon content. This is possible because the bound carbon content value is calculated by dividing the total weight (100%) by the contents of water, ash, and volatile matter, and then the remaining value is obtained. In order to make biomass pellets with a high bound carbon content, it is crucial to pay attention to these three parameters with low values when determining the bound carbon content. The study found that the highest bound carbon content was observed in the 10% adhesive with a drying time of 4 hours. Bound carbon in biomass pellets increases as the adhesive percentage rises, according to this study results. This is not in line with the results of Muazzinah's research (2022), which showed that a smaller adhesive percentage will produce a higher bound carbon content. This can happen because Sample 4 with a 10% adhesive percentage has the lowest volatile matter content

of 75.6%, so the bound carbon content is high; in Sample 3 with a 10% adhesive percentage has the highest volatile matter content of 77.75%, so the bound carbon content is low. This study also shows that the longer the drying time on biomass pellets, the higher the bound carbon value in Samples 3 and 4, but not in Samples 1 and 2. Irfansyah et al. (2022) demonstrated that wood pellet drying time correlates with water content decrease; longer drying time at a higher temperature can result in a lower water content. An additional factor that influences the high concentration of bound carbon is a low water content. The higher volatile matter and water content of Sample 2 make it more resistant to drying than Sample 1, which in turn makes it less sensitive to drying time. There is a strong correlation between the low volatile matter content and the high level of bound carbon.

### Determination of the best biomass pellet variation

Despite only the moisture and ash content parameters conforming to SNI 8675-2018, the identification of the optimal biomass pellet composition derived from variations of wood twigs and cassava peel starch adhesive can still be achieved by examining the bound carbon content with the highest value in accordance with the standard. The objective of identifying the optimal biomass pellet composition is to acquire samples for calorific value assessment. The data from the results of testing the characteristics of biomass pellets, including density, moisture content, ash content, volatile matter content, and bound carbon content, can be seen in Table 2.

Table 2 indicates that none of the four biomass pellet samples produced meet the bound carbon content parameter specified in SNI 8675-2018. In

assessing the optimal biomass pellet variation for maximizing calorific value, the variant exhibiting the highest bound carbon content is preferred. Sample 4 demonstrated the highest bound carbon value at 11.83%, composed of 90% Wood Branch Waste and 10% Cassava Peel Waste Starch, subjected to a drying period of 4 hours. In contrast, sample 2, which also underwent 4 hours of drying but contained a lower adhesive ratio of 95% to 5%, yielded a bound carbon content of 10.81%. Utilizing the maximum bound carbon content variation for calorific value assessment, as elevated bound carbon content influences the resultant calorific value; a greater bound carbon content in biomass pellets correlates with an increased calorific value. This aligns with the findings of Elwina et al. (2022), which indicated that elevated levels of bound carbon influence the high calorific value of biomass pellets. An increased bound carbon content correlates with a decreased water content, ash content, and volatile matter content, while simultaneously elevating the calorific value. Sample 2 was selected for the calorific value assessment due to its identical drying treatment, albeit with varying adhesive percentages. This was aimed at evaluating the impact of cassava peel starch adhesive concentration on the quality of biomass pellets, in alignment with the study problem formulation. Consequently, only two types of biomass pellets were selected: one with the highest bound carbon content and another with a differing adhesive percentage, both subjected to identical drying conditions for the calorific value assessment.

### Calorific value of biomass pellets

The calorific value is a critical parameter for ensuring the high quality of biomass pellets. The composition of raw materials in biomass

**Table 2.** Results of biomass pellet characteristic tests

No	Characteristics of biomass pellets	Variation of biomass pellet samples				Indonesian National Standard	Results based on SNI
		A1	A2	B1	B2		
1.	Density (kg/m <sup>3</sup> )	361	347	417	409	≥ 600	Unqualified
2.	Water content (%)	8.8	8.97	8.42	8.35	≤ 10	Qualified
3.	Ash (%)	4.1	3.9	3.95	4.3	≤ 5	Qualified
4.	Volatile (%)	76.05	76.35	77.75	75.6	≤ 75	Unqualified
5.	Carbon (%)	10.99	10.81	9.98	11.83	≥ 14	Unqualified

**Note:** Biomass pellets A1 (wood twig waste: cassava peel waste = 95%:5%), drying for 2 hours, Biomass pellets A2 (wood twig waste: cassava peel waste = 95%:5%), drying for 4 hours, Biomass pellets B1 (wood twig waste: cassava peel waste = 90%:10%), drying for 2 hours, Biomass pellets B2 (wood twig waste: cassava peel waste = 90%:10%), drying for 4 hours

pellets significantly influences the calorific value. The calorific value of biomass pellet fuel is significant, as it can reduce the quantity of biomass pellets utilized. A low calorific value in biomass pellets indicates that a greater quantity of fuel is required for combustion compared to biomass pellets with a high calorific value. The calorific value test was conducted without repetition. The analysis results of the calorific value test for the two optimal variations, specifically Sample 2 biomass pellets (95%: 5%) with 4 hours of drying and Sample 4 (90%: 10%) with 4 hours of drying. The assessment of the calorific value of biomass pellets adheres to SNI 8675-2018. The calorific value testing of biomass pellets utilized IKA/Bom Calorimeter - C2000 equipment, conducted at the Nanomaterials for Renewable Energy Laboratory in Medan. The test results can be seen in Figure 6.

Figure 6 illustrates the data derived from the combustion rate test results for the two samples. Figure 6 shows that the combustion rate test results for the two biomass pellet samples yielded disparate outcomes. The minimum calorific value was recorded in biomass pellet Sample 2 (95%: 5%) heated for 4 hours, at 3.985 cal/g, while the maximum calorific value was observed in Sample 4 (90%: 10%) heated for the same duration, at 4.024 cal/g. The calorific value of biomass pellet fuel is required to be a minimum of 4.000 cal/g; therefore, it can be inferred that the calorific value of the two produced biomass pellet samples fails

to meet this standard. The low calorific value of biomass pellets is attributable to the type of wood utilized. Types of wood and their calorific value in the Universitas Sumatera Utara area that can be included in the USU 3R TPS include sengon buto (3.948 cal/g), ketapang (4.223 cal/g), eucalyptus (4.714 cal/g), rain tree (3.926 cal/g), and waru (4.266 cal/g). In the study of Sucahyo et al., (2024) the manufacture of wood pellets using 100% sengon wood produced a calorific value of 4.100 cal/g. According to Hendra in Indrayanti and Siska., (2021) wood pellets with sengon wood raw materials produce a calorific value of 3.556–4.003 cal/g. With the calorific value of biomass pellet wood that does not meet SNI, the results of the calorific value test have the potential to not meet standards. Therefore, from the results of this calorific value test, it can be concluded that biomass pellets with the highest bound carbon content also produce high calorific values. This is in line with research by Asrianti et al. (2024), which showed that the higher the bound carbon content in wood pellets, the higher the calorific value.

Figure 6 shows that the higher the percentage of adhesive in biomass pellets, the higher the calorific value produced. This is in line with the research of Stiawan et al., (2022) which shows that the higher the percentage of adhesive, the higher the calorific value. This condition may arise because Sample 4 biomass pellet possesses a water content of 8.35% and a volatile matter content of

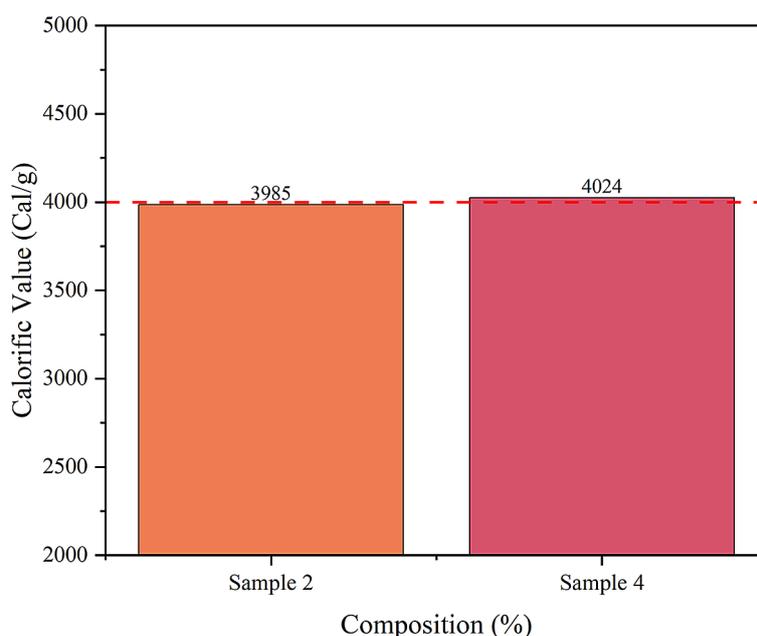


Figure 6. Biomass pellet calorific value graph

75.6%, both of which are inferior to Sample 2, which has a water content of 8.97% and a volatile matter content of 76.35%. The density value and bound carbon content of Sample 4 biomass pellet exceed those of Sample 2 biomass pellet. Asrianti et al. (2024) assert that calorific value is inversely related to water content; as water, ash, and volatile matter content in fuel increase, calorific value diminishes. Conversely, calorific value is directly proportional to bound carbon content; higher bound carbon content correlates with elevated calorific value. Furthermore, in the research of Buhang et al., (2024) the higher the density the higher the calorific value, where in their research the pellet with the lowest density of 1.142 g/cm<sup>3</sup> had the lowest calorific value of 3.549 cal/g, and the highest density of 1.457 g/cm<sup>3</sup> produced the highest calorific value of 3.924 cal/g. In this study, Sample 2 biomass pellet had the lowest density of 347 g/cm<sup>3</sup> with a calorific value of 3.985 cal/g with Sample 4 which had a higher density of 409 g/cm<sup>3</sup> with a calorific value of 4.024 cal/g. This can occur because biomass pellets with high density have denser components so they store a lot of energy, which makes the calorific value high (Mustamu and Pattiruhu, 2018). The composition of the ingredients dictates the calorific value of the pellets. Several variables influence the drying value, regardless of whether it is elevated or diminished. The raw material is the principal factor influencing

the calorific value, which varies according to the properties of the utilized material. The carbonization temperature significantly affects the calorific value; a lower temperature results in a diminished calorific value due to reduced fixed carbon content and increased levels of water, ash, and volatile matter (Sukarta et al., 2023).

Moreover, Bazenet et al. (2021) demonstrated that the calorific value of biomass briquettes containing 10% adhesive was 4.306 cal/g. Although biomass briquettes exhibit a higher calorific value, reaching 4.024 cal/g, the utilization of biomass pellets as a renewable fuel is preferable. This is due to the emissions from biomass briquettes, which include NO<sub>x</sub>, SO<sub>x</sub>, CO, and hydrocarbon (HC) gases, whereas CO<sub>2</sub> emissions from biomass pellets are deemed negligible, as the gases captured during photosynthesis are stored and transformed into energy (Martinez in Febriani et al., 2024).

#### Biomass pellet burning rate

The combustion rate is a test to determine the speed at which biomass pellets burn to ashes by comparing the mass of the burned biomass pellets with the time it takes for the fire to burn out. The higher the combustion rate, the faster the biomass pellets burn. In order to put biomass pellets to good use, it is necessary to measure their combustion efficiency. The combustion rate is greatly affected by a high calorific value because it affects

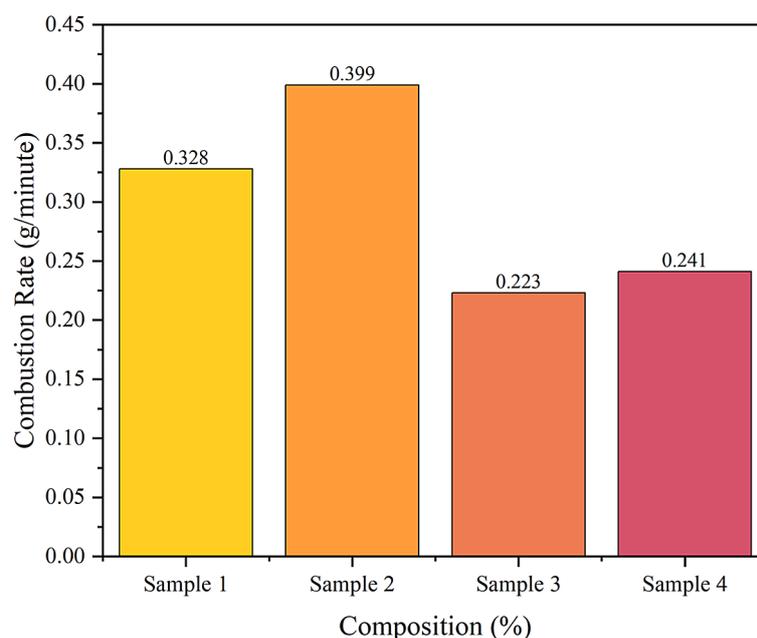


Figure 7. Graph of biomass pellet burning rate

the rate at which the enthalpy of the heat reaction increases (Sucahyo et al., 2024). Biomass pellets with a high density will slow the combustion rate, and a larger mass of biomass pellets will require a longer time to turn to ashes (Hadijah et al., 2022). The results of the combustion rate test analysis for all variations of biomass pellet composition can be seen in Figure 7.

Figure 7 illustrates that the combustion rate test data for the four biomass pellet variations yielded disparate results. The lowest combustion rate value was obtained in Sample 3 biomass pellets (90%:10%) drying for 2 hours, namely 0.223 g/minute and the highest combustion rate value was in the sample variation 2 (95%:5%) drying for 4 hours, namely 0.399 g/minute. The outcomes of the biomass pellet combustion rate test align with the previously conducted density parameter results, indicating that Samples 3 and 4 exhibit a higher density, specifically Sample 3 has a density of 417 kg/m<sup>3</sup> and Sample 4 with a density of 409 kg/m<sup>3</sup>, while Sample 2 has the lowest density, namely 347 kg/m<sup>3</sup> and Sample 1 with a density of 361 kg/m<sup>3</sup>.

Furthermore, Biomass pellets with a higher density produce a lower combustion rate. This is because the denser the biomass pellets, the more difficult it is for oxygen to enter, resulting in slower combustion due to their lower speed (Lukmanto and Banowati, 2024). This is in line with research by Paga and Reniana (2024) which showed that the higher the adhesive concentration in the pellets, the lower the combustion rate. This is because the organic material contained in the adhesive fills the voids in the pellets and strengthens the attractive forces on the powder, making them denser and more compact.

According to Stiawan et al. (2022), high-quality biomass pellets are those that burn slowly and sustainably. A higher combustion rate is achieved when the mass is reduced or converted to ash more rapidly (Paga and Reniana, 2024). Therefore, although no standard regulates the combustion rate of biomass pellets, good biomass pellets are those that have long durability in the combustion process. This study shows that Sample 4 with a low combustion rate but has a higher calorific value of 4.024 cal/g compared to Sample 2 with a higher combustion rate has a lower calorific value of 3.985 cal/g. This shows that the higher the calorific value, the lower the resulting combustion rate. However, in the research of Sommad and Praswanto (2022) showed that the lowest calorific

value in Sample 4 (10 g coffee grounds: 20 g sawdust) and the highest in Sample 1 (30 g coffee grounds: 0 g sawdust) is directly proportional to the combustion rate, with the lowest combustion rate of Sample 4 and the highest combustion rate of Sample 1. In addition, Jannah et al. (2022) showed that combustion rates are negatively correlated with calorific values. Thus, it is clear that density is the only variable that correlates with biomass pellet combustion rate, rather than high or low calorific value.

## CONCLUSIONS

On the basis of the research outcomes, the following conclusions can be drawn. Sample A1 (95% wood twigs, 5% adhesive, and 2 h of drying), resulting in a moderate density of 361 kg/m<sup>3</sup>, along with an acceptable level of ash at 4.1% and moisture at 8.8%. Its relatively short drying duration resulted in higher volatile matter and moderate combustion rate (0.328 g/min). Sample A2 (95%:5%, 4 h of drying) had the lowest density (347 kg/m<sup>3</sup>) while attaining the highest combustion rate (0.399 g/min). The extended drying duration probably facilitated the release of volatile matter and augmented burnability, although its calorific value (3.985 cal/g) remained slightly below the SNI threshold. Sample B1 (90%:10%, 2 h of drying) reached the highest density (417 kg/m<sup>3</sup>) due to greater adhesive content but showed the lowest combustion rate (0.223 g/min). An increased adhesive proportion enhanced pellet density, diminishing oxygen diffusion during combustion and consequently decelerating the burning process.

Sample B2 (90%:10%, 4 h of drying) demonstrated improved calorific value (4.024 cal/g) and the highest energy performance. Extended drying reduced moisture (8.35%) and stabilized carbon content (11.83%), supporting higher thermal efficiency. Nonetheless, its combustion rate (0.241 g/min) was still lower than that of A2, confirming that higher adhesive content favors energy retention rather than combustion speed. In conclusion, drying time and adhesive content exerted contrasting influences: extended drying times led to reduced density but enhanced combustion behavior, whereas increased adhesive content elevated density and calorific value while diminishing combustion rate. Only Sample B2 met the calorific value criterion (>4.000 cal/g); however,

other samples complied with SNI for moisture (<10%) and ash (<5%). Consequently, B2 is more appropriate for energy-efficient fuel consumption, whereas A2 is optimal for the applications that rapidly combust fuel.

## Acknowledgement

The authors acknowledge Universitas Sumatera Utara for providing the research facilities. This research is fully funded by Penelitian Talenta of Universitas Sumatera Utara under the specific scheme Penelitian Kajian Strategi/Tematik 2024, with a Contract Number 2588/UN5.1.R/SK/PPM/2024

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